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Monday, 9th September 2019

Session 1

NUTRIENTS RECOVERY AND REUSE
Water Reclamation and Nutrients Recovery Facilities in the Chinese Framework

X. Huang
State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China
Email: xhuang@tsinghua.edu.cn

Abstract: Water and nutrients shortage is increasing worldwide. For relieving the problem, water reclamation and phosphorous recovery were carried out in China. For water reclamation, the average wastewater reuse rate in China is still lower, only about 10%. Meanwhile, the water reclamation situation in all regions of China is not quite balanced. Wastewater reuse in the water-scarce areas or clean water-lacking areas has been developing rapidly.

Keywords: Wastewater treatment plant (WWTP); water reclamation; phosphorous recovery

Nowadays with the worldwide developing of economic and population, the demand for water and valuable resources such as phosphorus is increasing. The shortage is constantly growing, and China faces the similar problem.

For relieving the lack of water resource, Chinese government had set a series of standards to promote water reclamation from wastewater treatment plants (WWTPs). At present, the number of WWTPs in China is roughly more than 5,600. In WWTPs, AAO, oxidation ditch and other processes are mainly used. But the current average wastewater reuse rate in China is still lower, only about 10%. Meanwhile, the water reclamation situation in all regions of China is not quite balanced. Wastewater reuse in the water-scarce areas or clean water-lacking areas has been developing rapidly.

In water reclamation, physicochemical advanced treatment methods are mainly applied. Among them, membrane technology, such as membrane bioreactor (MBR), is gaining great attention, which can ensure one-step treatment to achieve high quality and stability effluent. The total capacity of large-scale MBRs (capacity ≥ 10,000 m³/d) for municipal wastewater treatment and reuse has reached 10 million m³/d, accounting for more than 5% of China’s overall municipal wastewater capacity.

Speaking of the phosphorus recovery, at present only some attempts were tried in China. For example, some well-equipped WWTPs achieved phosphorus recovery by struvite crystallization method in anaerobic digestion process, such as Tianjin Jinnan Wastewater Treatment Plant. However, the released phosphorus concentration is low due to chemically bound phosphorus, which causes low phosphorus recovery rate. Additionally, the recovery cost is higher than commercial cost of phosphorus product. There are still some challenges to promote the practical application.
Building an Operational Framework for Nitrogen Recovery via Electrochemical Stripping

M. J. Liu*, B.S. Neo*, W.A. Tarpeh*

*Dept. of Chemical Engineering, Stanford University, Stanford CA 94305 USA  wtarpeh@stanford.edu

Abstract: Electrochemical stripping has recently been demonstrated to selectively recover over 90% of ammonia nitrogen from varying wastewater influents. To accelerate this process toward implementation, we combined modelling and experiments to identify impacts of rate-limiting steps. Ammonia volatilisation in the cathode was determined to play a central role in limiting nitrogen recovery; we explored effects of catholyte temperature, influent concentration, and gas permeable membrane choice on nitrogen recovery, removal, operation times. We constructed and validated a mass transfer model to predict energy requirements for varying operating parameters to help prioritize strategies that accelerate rates of nitrogen recovery from wastewater.

Keywords: Ammonia; fertilizer; electrodialysis

BACKGROUND Humans have altered the global nitrogen cycle more than any other biogeochemical cycle, asymmetrically doubling its throughput due to industrial fertilizer production via the Haber-Bosch process (Galloway et al., 2008). While nitrogen undergirds modern agriculture, in environmental waters it induces algal blooms that damage aquatic ecosystems and threaten human health (algal cyanotoxins, methemoglobinemia in infants)(Dodds et al., 2009; Nyenje et al., 2010). In response to this urgent need to feed a growing population while preserving the environment, the U.S. National Academy of Engineering identified managing the nitrogen cycle as the only element-specific 21st century grand challenge (NAE Grand Challenges for Engineering, 2008).

In previous work we described electrochemical stripping, a novel nitrogen recovery process that selectively extracts nitrogen as ammonium sulfate from wastewaters (Tarpeh et al., 2018). Thus far, electrochemical stripping has been successfully applied to urine (Tarpeh et al., 2018) and hydrothermal liquefaction effluent (Li et al., 2018). The process exhibits two major benefits over conventional ammonia stripping: pH increase without base addition and energy-efficient membrane stripping without a stripping tower. A cation exchange membrane and gas permeable hydrophobic membrane are used to separate nitrogen based on its charge and volatility; nitrogen is captured as ammonium sulfate in a sulfuric acid trap. We established proof-of-concept for electrochemical stripping, observing >90% recovery of influent ammonium at lower energy than conventional ammonia stripping. To enhance fundamental understanding of the process and identify influential operating parameters, we combine modeling and experiments to probe relative kinetics of each transport and reaction step for nitrogen during electrochemical stripping.
MATERIAL AND METHODS We first constructed a descriptive model in MATLAB that incorporated ammonia speciation, electrochemical reactions (cathodic hydrogen evolution and anodic oxygen evolution), and transport through both membranes. After fitting to experimental data, we enhanced the model to predict recovery efficiencies and rates for different influents. Predicted parameters were confirmed with experiments in electrochemical devices fabricated using Perspex frames bolted together to form chambers separated by membranes, and a Gamry potentiostat was used to control current density in batch and continuous experiments. Dual ion chromatographs (Dionex, ThermoScientific) were used to analyse concentrations of inorganic ions. Total ammonia nitrogen was measured by ion chromatography by acidifying samples to pH <3 so that all TAN was present as NH₄⁺; pH was also measured regularly to determine nitrogen speciation.

RESULTS AND CONCLUSIONS Based on governing ordinary differential equations describing nitrogen transport and reactions, lumped parameters were determined based on fits to experimental data (Figure 1.1). Ammonia volatilisation was identified as a major factor affecting fit of the descriptive model to experimental data. Given the high pH reached in the cathode (>12), adjusting ammonia speciation and subsequently the Henry’s constant for ammonia drastically increased the model fit (Figure 1.2). Thus, ammonia volatilisation contributes non-trivial losses to electrochemical stripping, and depends on pH and thus electrolysis time. Experimental flux measurements confirmed the influential role of cathodic processes on nitrogen recovery during electrochemical stripping. For all influents, flux from the cathode to trap was lower than flux from anode to cathode, indicating a rate limiting step in the cathode chamber.

![Figure 1.1](image1.png) Nitrogen fluxes for ammonium sulphate, synthetic, and real urine for each membrane.

![Figure 1.2](image2.png) Simplified descriptive model and effects of operating parameters on electrochemical stripping.

While changing operating parameters did affect performance, electrochemical stripping exhibited robust performance over a range of realistic ambient temperatures, three gas permeable membranes, and three orders of magnitude of influent concentrations. Practically, these results demonstrate that electrochemical stripping is viable across a range of waste streams and resilient to fluctuations in temperature and nitrogen concentration; they also establish operational trade-offs between residence time and energy consumption. As a result of this work, electrochemical stripping continues to mature from concept to practice and provides lessons for developing other resource recovery technologies.
REFERENCES


Nutrient Recovery from Wastewaters Using Novel, Nano-Enhanced Adsorptive Media

M. Ownby*, E Weinberg**, C. Vaneeckhaute*

*BioEngine, Université Laval, 1065 ave. de la Médecine, Québec, QC, Canada, G1V0A6
celine.vaneeckhaute@ghc.ulaval.ca, miles.ownby.1@ulaval.ca
** ESSRE Consulting, Inc., 20 Rucker Rd., Richboro, PA, US, 18954, edweinberg_essre@verizon.net

Abstract: Current nutrient recovery practices for phosphorus (P) from wastewaters result in low-grade, slow-release, land applied fertilizer. Residual dissolved nutrients not captured are harmful in the environment and act as biocatalysts contributing to the ever-increasing frequency of harmful algae blooms. RD&D efforts demonstrate that commercially available nano-enhanced media, a new class of adsorbents, offer immediate relief to pollutant nutrient overloads in impaired watersheds. One such media, hybrid ion exchange resin (HIX-Nano) has been used to remove naturally occurring arsenic from drinking water, and can remove soluble reactive P from agricultural wastewaters. The nano-enhanced media are regenerable, and customized regeneration chemistry can result in liquid N-P-K fertilizer and non-fertilizer products with greater market value compared to recycled P products such as struvite.

Keywords: Ion-exchange; nano-enhanced adsorptive media; phosphorus recovery; wastewater treatment.

INTRODUCTION Current nutrient recovery practices for phosphorus (P) from wastewaters carryout precipitation of total P to make struvite/brushite, or carryout aggressive liquid/solids separation that focuses on the solids bound P. Either approach results in low-grade, slow-release, land applied fertilizer. A review of operating costs of each of these nutrient recovery technologies used on multiple continents at water resource recovery facilities (WRRFs) indicates that the value of such recovered products cannot compete with commodity synthetic fertilizer and the cost to recover P on a pound basis is greater than its value as P in the market place. Unless there are other redeeming benefits, such as operations and maintenance cost savings by preventing struvite precipitation or enhanced biosolids management, these precipitation approaches are favourable at only the largest scale WRRFs. Moreover, the unreacted dissolved P is instantly bioavailable and significantly contributes to the production of harmful algae blooms in fresh water bodies.

This research aims to develop a new, disruptive approach to nutrient recovery, which focuses on the residual soluble reactive nutrients (nitrogen, N and P), using adsorptive nano-scale materials that carry out more than removal/recovery/partial reuse of these pollutants. One such nano-enhanced material is a hybrid ion exchange (HIX) resin that serves as a “carrier” for dispersed and immobilized nano metal oxide particles. The high surface area nanoparticles are the workhorse for superfast
adsorptive kinetics and cost-effective soluble reactive P removal. In total, this alternative approach using commercial available nano-enhanced adsorptive media, which are nanocomposites, provides “6Rs” of sustainable treatment of soluble reactive pollutant nutrients, i.e. Removal, Recovery, Reconcentration, Reuse, Recycle and Redistribution. Because effluent soluble reactive nutrients are captured and ultimately reused, the approach is supplementary and complementary to the existing nutrient recovery precipitation processes.

MATERIALS AND METHODS HIX nanotechnology has been developed and commercialized to remove trace levels of arsenic (10-500 ppb) from drinking water in the US and several countries. HIX nanomaterials are conventional anion exchange resin beads dispersed with bound nanoscale iron, Fe(III), or more recently with zirconium, Zr(IV), or lanthanum, La(III), oxide based particles. This nanocomposite is a regenerable media and the robust resin material can withstand the rigors of multiple regenerations, where multiple reuse of “refreshed” media lowers the overall production cost and is the key to nutrient recovery. In this research, the use of HIX-Nano for 6Rs-treatment of a variety of agricultural effluents has been tested at laboratory and pilot scale. Microcolumns have been constructed for rapid, scalable testing of the nano-enhanced media. Both the HIX-Nano capture efficiencies and recoveries (desorption) were researched and evaluated. The technology has been selected as one of the Ten Finalists of the international George Barley Water Prize competition that aims to achieve a low-cost treatment for P removal/recovery from P impaired fresh water.

RESULTS AND CONCLUSIONS HIX-nanomaterials were found to be extremely effective in capturing phosphate and nitrate by adsorptive mechanisms because dissolved nitrate/phosphate chemistry in the aqueous phase is very similar to that of arsenic. This strong selectivity makes dissolved nutrient pollutant removal from wastewater or freshwater at low or high effluent concentrations easy to implement. No noticeable drop in sorption capacity has been recorded after prolonged use. The key to nutrient recovery using HIX-Nano is regeneration of the spent media. The conventional practice is to use a weak alkaline solution of caustic soda (NaOH). A representative elution curve (Figure 1) shows the Na2PO4 concentration profile (as P) vs. bed volumes alkaline rinse (NaOH) for regenerate P solution desorbed from HIX(Zr)-Nano. Similar results are generated using HIX(Fe)-Nano.

If ammonium hydroxide or potassium hydroxide or both are used as the alkaline rinses, the resultant liquid fertilizer solution (N-P-K) can be customized to produce specific N-P-K formulations for hydroponic and greenhouse growers. These niche
formulations have a higher market value compared to struvite or brushite land applied fertilizers to promote a circular economy driven by soluble P removal and recovery. The reuse/recycle of removed soluble pollutant P from each of the sources/pathways to fresh waters establishes a new redistribution cycle for P that avoids the perpetuation of land applied fertilizer losses from runoff, erosion or drainage.

Current research looks at the recovery of non-fertilizer products as another P redistribution cycle that avoids land application of fertilizer and one that creates higher market value for recovered nutrients using the nano-enhanced media. Leading candidates based on high-purity ammonium phosphate solutions made from recycled pollutant nutrient phosphate are fluidized catalytic cracking catalyst (phosphate supported synthetic zeolite) used in oil refineries and lithium-ion battery cathode material, lithium-ferri-phosphate (LiFePO_4).

REFERENCES

Enhanced Ammonia Recovery from Wastewater by Nafion Membrane with Highly Porous Honeycomb Nanostructure and its Mechanism in Membrane Distillation


*School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, China, jxguo4-c@my.cityu.edu.hk
**Thermal & Fluid System R&D Group, Korea Institute of Industrial Technology, 89 Yangdaegiro-gil, Ipjang-myeon, Seobuk-gu, Cheonan, 331-822, Republic of Korea, jglee@kitech.re.kr
***King Abdullah University of Science and Technology (KAUST), Water Desalination and Reuse Center (WDRC), Biological and Environmental Science &Engineering (BSE), Thuwal 23955-6900, Saudi Arabia, noreddine.ghaffour@kaust.edu.sa
****,*School of Energy and Environment, City University of Hong Kong, Tat Chee Avenue, Kowloon, Hong Kong, China, alicia.kjian@cityu.edu.hk

Abstract: Nitrogen removal in wastewater by conventional treatment methods requires substantial energy, only to release it back to the atmosphere as gaseous nitrogen. Herein, we investigated the applicability of membrane distillation (MD) in treating sludge digestate to recover resource by controlling the volatility and pressure of the vapor transport across the membrane to concentrate ammonia in the permeate stream. A mixture of Nafion ionomer and Multiwall Carbon Nanotubes (MWCNTs) was incorporated into a Poly(vinylidene fluoride-co-hexafluoropropene; PVDF-HFP) nanofiber matrix to fabricate a honeycomb-nanoporous Nafion membrane that has high recovery and increased mechanical strength. This study demonstrated an innovative and realistically applicable MD treatment process that allows for resource recovery with low-grade heat integration and has scaling-up potential for wastewater treatment plants.

Keywords: Nafion membrane; ammonia recovery; membrane Distillation; modelling

Over the recent decade, membrane distillation (MD) has recently been gaining attention as an emerging separation method for ammonia from water stream or the subsequent treatment of anaerobically-digested effluents (Ding et al., 2006; EL-Bourawi et al., 2007; Qu et al., 2013; Wu et al., 2015; Xie et al., 2009; Zarebska et al., 2014). MD allows the passages of volatile NH₃ gaseous across a microporous hydrophobic membrane to concentrate ammonia in the permeate stream under acidic conditions. Previous studies have commonly noted the pH level and temperature of ammonia-containing feed wastewater as major factors that affect the mass transfer coefficient and solubility of ammonia. In other words, increasing the pH and temperature of the feed wastewater favors the dissociation of ammonia from the aqueous to produce volatile ammonia molecules, which can be removed by MD.

Specifically, we fabricate a nano-porous Nafion membrane for MD for enhancing ammonia recovery. Nafion, a copolymer of perfluorosulfonic acid (PFSA) and tetrafluoroethylene (Teflon®) has notable advantages in removing volatile compounds due to its thermal/mechanical/chemical stability and has a high selectivity for ammonia in particular (He and Cussler, 1992; Kuntke et al., 2012; Park et al., 2015). However, a major issue of a Nafion polymer membrane is that it is prone to
deterioration from mechanical stress (Baker et al., 2014). Therefore, the present study aimed to achieve the following three objectives. First, we aimed to improve the mechanical stability of Nafion by incorporating MWCNT nanoparticles as reinforcement and thereby fabricate a suitable and innovative nanofiber Nafion membrane for MD operation. Secondly, we set out to quantify the efficiency of Nafion membranes in ammonia removal and recovery by investigating the ammonia gas permeability of Nafion membranes containing various Nafion concentrations (0-8%) in a DCMD system. In this process, we minimized the water vapor flux generated by the transmembrane temperature difference to enable accurate measurement of ammonia gas permeability, which is primarily driven by diffusion based on the concentration difference. Lastly, we propose to explain the enhanced ammonia recovery under different Nafion concentrations, pH levels, and temperatures by revealing the ammonia mass transfer resistance across boundary layers adjacent to the Nafion membrane using a theoretical modeling approach.

![Figure 1.1](image)

**Figure 1.1** FE-SEM images of (a) the Nafion 0% membranes, (b) the Nafion 6% membrane, and (c) the Nafion 8% membrane.

**REFERENCES**


H. Cruz*, J.S. Guest****, A. Oehmen**, W. Verstraete***, B. Laycock**, I. Pikaar*

* School of Civil Engineering, The University of Queensland, QLD 4072, Australia
** School of Chemical Engineering, The University of Queensland, QLD 4072, Australia
*** Center for Microbial Ecology and Technology (CMET), Ghent University, Coupure Links 653, 9000 Gent, Belgium
**** Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Illinois 61801, United States

Abstract: A key challenge for urban water management is how to re-envision its role within the circular economy will be to develop technologies that enable mainstream ammonium recovery. In this paper, a new pathway is proposed that allows for mainstream ammonium recovery based on physico-chemical sorption using polymer hydrogels. Our results show that this adsorption-based approach holds potential for high-rate mainstream continuous adsorption coupled with side-stream recovery of ammonium with minimal chemical requirements. Modified polymer hydrogels achieved final effluent concentrations of 10.1 ± 0.12 to 18.3 ± 0.53 mg/L NH$_4$-N in real sewage at a contact time of ~10 minutes. At this effluent concentrations, simulation results show that allowable discharge concentrations (<10 mg/L) can be achieved after biological assimilation of the residual nitrogen from the mainstream sorption process.

Keywords: Mainstream ammonium recovery, next generation adsorbents, circular economy

Throughout the 20th century, the prevailing approach towards nitrogen management in municipal wastewater treatment was to remove reactive nitrogen by transforming it into nitrogen gas using dissipative processes such as the activated sludge process. While this has been a very successful strategy for safeguarding human health and protecting the environment, the dissipation of reactive nitrogen into its elemental form is incompatible with the developing circular economy of the 21st century (Cruz et al., 2019). Considering the world’s average energy usage for the Haber Bosch process of 12.1 kWh per kg NH$_3$ and using the median ammonium and COD excretion loads of (8.2 – 13.81 g N person-day$^{-1}$ and 588 – 761 kJ person-day$^{-1}$) of 15 representative countries, we assessed that the average energy embedded in ammonium accounts for as much as 58% - 76% of the total energy recoverable in sewage. Furthermore, the current routes for dissipating reactive nitrogen also produce N$_2$O, a very strong greenhouse gas with externalized damage costs that can amount to the order of $2.2 – $120 per kg N$_2$O-N (Pikaar et al., 2017).

In general, the recovery of reactive nitrogen from wastewater streams is not new with e.g. struvite precipitation and ammonia stripping implemented by the water industry for several years. The key technological challenge for the successful implementation of ammonium recovery from domestic wastewater is the up-concentration of the recovered ammonium to more than 1 g/L NH$_4$-N, at which point existing technologies for ammonium recovery (i.e. stripping) can become cost-effective (Cruz et al., 2018). Among physico-chemical techniques, adsorption has some potential to address this challenge since it is (i) a relatively simple process, (ii) some adsorbents are known to have high affinity and selectivity for ammonium, (iii)
high up-concentration factors can be achieved (i.e., it can potentially up-concentrate ammonia from a very large volume of influent, into a very small volume during regeneration), and (iv) it is a temperature-independent process.

In this study, poly(acrylic acid)-based hydrogels, polymers designed to absorb water, were designed and modified specifically ammonium sorption. The performance of the optimized hydrogels were evaluated in synthetic and real sewage as seen in Figure 1.1. Depending on the initial hydrogel loading, effluent concentrations of 10.1 ± 0.12 to 18.3 ± 0.53 mg/L NH$_4$-N in real sewage at a contact time of < 10 minutes were achieved. The fast sorption achieved using polymer hydrogels enables the sorption step to be placed in the mainstream prior to biological treatment step as illustrated in Figure 1.2. Simulation results performed using ASM1 show that allowable discharge concentrations (below 10 mg/L) can be achieved after biological assimilation of the residual nitrogen from the mainstream sorption process. At an incoming TKN concentration of 10 mg/L, the final discharge concentration after subsequent biological treatment would be ~1.89 mg/L NH$_4$-L which is below the maximum allowable discharge concentrations in most countries. Further studies are needed to investigate both their sorption and regeneration performance of the hydrogels, nevertheless, the findings in this study have clearly demonstrated the potential of polymer hydrogels as ammonium sorbents for WWTP applications.

![Figure 1.1](image1.png)  
**Figure 1.1** a) Ammonium sorption performance of PAA hydrogels in NH$_4$Cl solution and real sewage at different hydrogel loadings. b) Projected final effluent concentrations using ASM1. X-axis refers to the incoming effluent after sorption process and Y-axis refers to the effluent after assimilation of residual nitrogen.

![Figure 1.2](image2.png)  
**Figure 1.2** Schematic diagram for mainstream continuous ammonium adsorption followed by side-stream regeneration using polymer hydrogels.

**REFERENCES**


Nitrogen Recovery from Process Water of Digested Sludge Dewatering with Membrane Contactors

L. Richter*, M. Wichern**, M. Grömping***, U. Robecke****, J. Haberkamp*

* Münster University of Applied Sciences, IWARU, Corrensstr. 25, D-48149 Münster (Germany), richter.l@fh-muenster.de (corresponding author)
** Ruhr-Universität Bochum, Chair of Urban Water Management and Environmental Engineering, Universitätsstr. 150, D-44780 Bochum (Germany)
*** Aachen University of Applied Sciences, Institute Nowum Energy, Bayernallee 9, D-52066 Aachen (Germany)
**** City of Münster, Department of Public Works, Zum Heidehof 72, D-48157 Münster (Germany)

Abstract: Membrane contactors are expected to be an attractive alternative to other physicochemical and biological sidestream treatment processes for removing and recovering nitrogen from process water deriving from digested sludge dewatering. Münster wastewater treatment plant (WWTP) is the first German WWTP to implement a full-scale membrane contactor treatment with the objective to improve the nitrogen elimination and recovery efficiency. Within the scope of this investigation, influences on the operation and membrane performance are studied. First results confirm a high nitrogen removal efficiency of > 95 % and the production of marketable ammonium sulphate solution.

Keywords: Nitrogen recovery; membrane contactors; municipal process water

Process water from digested sludge dewatering is characterized by high ammonium concentrations, therefore causing additional nitrogen loads if returned to the biological wastewater treatment process. Apart from improving the WWTP’s overall nitrogen elimination rate by sidestream treatment, nitrogen can be recovered from process water by physicochemical treatment. Hydrophobic membrane contactors have already been used in industrial applications for extraction, stripping and absorption processes (Melin and Rautenbach, 2007); however, with regard to municipal WWTPs, they represent an innovative technology for the physicochemical nitrogen removal and recovery from process water. The general applicability for the treatment of process water from municipal WWTPs has been demonstrated by few operational experiences from pilot plants and bench-scale experiments (Darestani et al., 2017). However, only limited data of extended operation and experiences with recovered nitrogen from municipal wastewater as a fertilizer are available.

The objective of the application at Münster WWTP is to accomplish stable long-lasting operation, efficient recovery of ammonium sulphate solution and the reduction of the overall energy consumption. Within the scope of this study, online monitoring and chemical analyses investigate influences of varying operating parameter (e.g., pH of process water and absorbent, flow rates, temperature) on membrane performance. Appropriate membrane cleaning strategies are tested with different backwash/cleaning cycles and chemicals (e.g., alkaline and acid solutions).
In 2018, a full-scale membrane contactor facility has been installed at Münster WWTP to reduce the high ammonium concentration of process water (ca. 800 mg/l NH₄-N; cf. Table 1) by more than 90 %. Nitrogen is recovered from the process water as ammonium sulphate solution by using sulphuric acid as absorbent within the membrane contactor process. The ammonium sulphate solution will be marketed as agricultural fertilizer. The three-step membrane contactor system includes a total of 16 Liqui-Cel® hollow-fibre membrane modules (polypropylene, 0.02-0.1 µm pore size) with 3520 m² membrane surface area and 30 m³/h maximum treatment capacity (3M Company, 2015). The pH value is adjusted from pH = 7.6 to pH ≥ 10 by addition of caustic soda. A lamella clarifier and three subsequent filtration steps are installed prior to the membrane stage to remove particulate matter from the process water. Typically, the treatment is backwashed every six hours.

Further investigations concerning operation and chemical cleaning of membrane contactors are carried out by means of a bench-scale facility with one smaller Liqui-Cel® membrane module. The applied module has 1.4 m² membrane surface area and 0.02 m³/h treatment capacity. The bench-scale investigations are conducted using filtered process water from Münster WWTP as well as synthetic process water.

After the successful commissioning of the full-scale membrane contactor facility at Münster WWTP, a process water treatment capacity of 14.25 ± 4 m³/h has been achieved. Sidestream effluent concentrations of approx. 29 ± 24 mg/l NH₄-N, corresponding to 96.4 ± 3 % nitrogen elimination efficiency, are accomplished. The sulphuric acid is recirculated in two different cycles until the maximum pH value or saturation concentration of the ammonium sulphate solution is reached. Analyses of the absorbent revealed ammonium sulphate concentrations of about 4.1 %. Because of varying particle concentrations in the process water, the process stability was temporarily affected. A depth filtration stage has been included in addition to the previously installed microsieves, resulting in the stable operation of the membrane contactors. Based on the experience from the first operation phase, membrane contactors appear to be a promising and efficient technology for process water treatment and nitrogen recovery at municipal WWTPs.

Table 1.1 Process data and results of the first operation phase.

<table>
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<th>Value</th>
<th>Unit</th>
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<td>Flow rate of process water</td>
<td>14.25 ± 4</td>
<td>m³/h</td>
</tr>
<tr>
<td>Influent ammonium concentration</td>
<td>816 ± 45</td>
<td>mg/l NH₄-N</td>
</tr>
<tr>
<td>pH value before NaOH addition</td>
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<tr>
<td>NaOH addition</td>
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<tr>
<td>pH value inlet after NaOH addition</td>
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<td>-</td>
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<tr>
<td>Effluent ammonium concentration</td>
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<td>Removal efficiency</td>
<td>96.4 ± 3</td>
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<td>NH₄-N concentration in (NH₄)₂SO₄ produced</td>
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REFERENCES
3M Company 2015 14 x 28 Extra-Flow Product Data Sheet, Liqui-Cel® Membrane Contactors.
 Nitrogen Recovery Using a Membrane Contactor: Modelling Nitrogen and pH Evolution


*CALAGUA – Unidad Mixta UV-UPV, Institut Universitari d’Investigació d’Enginyeria de l’Aigua i Medi Ambient – IIAMA, Universitat Politècnica de Valencia, Camí de Vera s/n, 46022 Valencia, Spain. guinohe@cam.upv.es; jserralt@hma.upv.es; jferrer@hma.upv.es.

**CALAGUA, Unidad Mixta UV-UPV, Departament d’Enginyeria Química, Universitat de València, Avinguda de la Universitat s/n, 46100 Burjassot, València, Spain. luis.borras-falomir@uv.es; aurora.seco@uv.es.

Abstract: Membrane contactor has been applied for nitrogen recovery from anaerobic digestion supernatant. The results obtained show that the recovery efficiency depends on the pH of the nitrogen-rich stream. Complete nitrogen recovery was achieved at pH values over 9 but at pH values below 8.6, the process is stopped. A mathematical model was developed in order to represent the evolution of pH and nitrogen concentration during the recovery process. The model developed shows a good accuracy for describing the evolution of pH and nitrogen concentration in the different experiments carried out.

Keywords: Modelling; nitrogen; recovery

INTRODUCTION

The aim of this research is to evaluate the performance of a membrane contactor for nitrogen recovery using an anaerobic digestion (AD) supernatant and to develop a mathematical model to predict the evolution of pH and ammonium concentration during the process.

MATERIAL AND METHODS

The membrane contactor module of gas-permeable membrane used was a X50 2.5x8 Liqui-Cel® Extra-flow (polypropylene) with a surface of 1.4m². Figure 1.1 shows the experimental set-up. The acid stream circulates in the lumen side while the AD supernatant is fed in the shell side. Both streams are recirculated and fed counter-currently. The pH of AD supernatant was adjusted with NaOH.

Different temperatures (25-36°C), flow rates (0.2-3.5 L/min), total ammonia nitrogen (TAN) concentrations (250-1000 ppm N-NH₄) and pH (9-11) were applied.

![Figure 1.1 Experimental set-up.](image-url)
MODEL DEVELOPMENT Table 1.1 shows the stoichiometry coefficients, the kinetic equation and the conversion factors of the model. To model the pH, the same structure as BNRM2 (Barat et al., 2013) was applied. Proton (\( S_H \)) is included as a component of the model so a conservation equation is applied to calculate the variation of total proton concentration of the process.

Table 1.1 Stoichiometry coefficients (a) and conversion factors (b) of the model.

<table>
<thead>
<tr>
<th>Components</th>
<th>a)</th>
<th>Process</th>
<th>S_{NH4}</th>
<th>S_{H}</th>
<th>Kinetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stripping</td>
<td></td>
<td>-1</td>
<td>0</td>
<td></td>
<td>( r = k \cdot (C_{NH3 _aq} \cdot C_{NH3 _ac}) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Components</th>
<th>b)</th>
<th>Species</th>
<th>S_{NH4}</th>
<th>S_{H}</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( H^+ (\text{kmol/m}^3) )</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( N (\text{kg N/m}^3) )</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

RESULTS AND CONCLUSIONS For process simulation, membrane volume was divided into 10 subunits as a plug flow reactor. As an example, Figure 1.2 shows the evolution of pH and TAN concentration in the feed tank with a continuous pH adjustment (exp. 1) and without it (exp. 2) jointly with the model predictions. The flow rate applied was 0.6 L/min at an initial pH of 9. In experiment 1 TAN was completely recovered because of pH was maintained. However, the decrease of pH below 8.6 during the experiment 2 stopped the recovery process (Figure 2b) due to the low free ammonia concentration at this pH. Because of that, the recovery efficiency was 45%. In both experiments the model developed in this research was able to reproduce accurately the pH and nitrogen evolution. The value obtained for the process rate was \( k=0.5 \text{ min}^{-1} \) in both cases.

**Figure 1.2** TAN and pH evolution in: (a) exp 1 (with pH control) (b) exp 2 (and without pH control).

It can be concluded that the membrane contactor is a promising technology for nitrogen recovery working at pH higher than 9 reaching a 100% of recovery rate. Furthermore, the developed model accurately reproduced the experimental results.

REFERENCES
Nitrogen up-concentration from mainline and sidestream effluent in WWTPs for fertilizer valorization


* CETAqua Carretera d'Esplugues, 75 08940 Cornellà de Llobregat. amayor@cetaqua.com; silivia.lopez@cetaqua.com; irene.mozo@cetaqua.com; gabriel.lopez.ext@cetaqua.com
** Aquambiente Av de la zona Franca, 48, 08038, Barcelona; lprietod@aquambiente.es
*** EMUASA Plaza Circular, 9, 30008 Murcia; agadea@emuasa.es
**** Chemical Engineering Department, Universitat Politècnica de Catalunya-Barcelona TECH, Barcelona, cesar.alberto.valderrama@upc.edu; jose.luis.cortina@upc.edu

Abstract: Nowadays, nitrogen (N) is removed through nitrification-denitrification (N/DN) process in conventional Waste Water Treatment Plants (WWTPs). Energy demand for air supply and the associated emissions of CO₂ (direct and indirect) and N₂O (direct) could be reduced by implementing alternative technologies for N concentration i.e. zeolites and valorising the ammonium recovered as fertilizer. It has been estimated that a medium size conventional WWTP (130,050 PE) presents a carbon footprint of 0.14 kg CO₂/m³ at a cost of 1€/kg N removed. The same WWTP with a zeolites based system for N recovery would have a carbon footprint of -0.06 kg CO₂/m³ and up to now at a relatively higher cost, 1-4 €/kg N recovered. More research is needed to ensure both sustainability and viability of such a solution. This study assess the technical and economic viability of activated clinoptilolite (natural zeolites) applied to three different streams in a WWTP: mainline effluent (50 mg NH₄⁺-N/L), centrate sidestream (1000 mg NH₄⁺-N/L) and a tertiary effluent (5 mg NH₄⁺-N/L). More research is needed to ensure both sustainability and viability of such a solution. This study assess the technical and economic viability of activated clinoptilolite (natural zeolites) applied to three different streams in a WWTP: mainline effluent (50 mg NH₄⁺-N/L), centrate sidestream (1000 mg NH₄⁺-N/L) and a tertiary effluent (5 mg NH₄⁺-N/L).

Keywords: Zeolites; Nitrogen recovery, Technical and economic assessment.

INTRODUCTION

Nutrient removal is a priority for conventional WWTPs in which more restrictive discharge limits entails an increase in both energy requirements and chemical consumption. On the other hand, the agricultural sector consumes large amounts of nitrogen as fertilizers. The production of nitrogen (NH₃) through the Haber-Bosch process is associated with a negative environmental impact due to its high energy demand [1]. There is, clearly, a potential unexploited connexion between upstream nitrogen recovery and fertilizer production for sustainable agriculture. Closing the loop linking the two fields is a key contribution towards circular economy. In this way, zeolites could act as the connector between both worlds allowing to concentrate nitrogen to be further transformed into fertilizers (ammonium salts) in a final step involving membrane contactors. Alternative fertilizers need to become competitive in the inorganic fertilizer market (0.3 - 1 €/kg N). In a conventional WWTP, the main line transports the 80-85% of the total N at the influent (50-80 mg NH₄⁺-N/L), while the 15-20% remaining may be found in the anaerobic digestion centrates (800-1000 mg NH₄⁺-N/L). Working with zeolites in the main line allows to potentially recover the majority of the incoming N while in the sidestream the recoverable amount of N is lower but the performance is enhanced at higher ammonium concentrations. Besides, application of zeolites as polishing treatment could enable to meet restrictive discharges limits i.e. <1 mg NH₄⁺-N/L.
MATERIALS & METHODS

The experimental N recovery chain in the main line was carried out at pilot scale (1 m³/h) in Vilanova WWTP as part of a European funded project (LIFE NECOVERY; 2015-2017) [2] while the sidestream was first studied at lab scale (1-3 ml/min) as well as complementary tests with secondary effluent. An alternative N recovery chain is being tested in the sidestream at pilot scale in Vilanova WWTP in a Catalan funded project (DIGESTAKE 2018-2019) and in Murcia Este WWTP in the frame of a European funded project (LIFE ENRICH 2019-2021) [3]. Finally the tertiary effluent is being studied at lab scale (influent at 5 mg NH₄⁺-N /L). The zeolite employed was provided by Zeozem with a mean particle diameter of 0.5-1 mm. This zeolite has been previously activated to its Na⁺ form with a solution of NaOH 1M for 24h. The zeolites were then loaded into a column (60 g of zeolite at lab-scale and 100 kg at pilot scale). The operation consisted in feeding the columns with the corresponding water and measuring the ammonium at the effluent till the breakthrough (C_{influent}/C_{effluent}=0.2)

RESULTS & CONCLUSIONS

Results from the finished R&D projects are displayed in Table 1 as well as forthcoming results corresponding to on-going trials. In the case of N concentration in the main line, pilot scale experiments were developed during two years proving technical viability since stable high effluent quality (<1 mg NH₄⁺-N /L) was achieved. Based in the assessed zeolite capacity (10 mg NH₄⁺-N/L) and regeneration requirements (90% NH₄⁺ recovered), data was extrapolated to design a full-scale system with zeolites resulting in a CAPEX of 1.8 M€ for a 130,050 PE plant.

<table>
<thead>
<tr>
<th>Influent concentration (mg N-NH₄⁺/L)</th>
<th>Zeolite capacity (mg N-NH₄/g zeolite)</th>
<th>Effluent concentration (mg N-NH₄/L)</th>
<th>Cost of process (€/kg N recovered)</th>
<th>Carbon footprint (Kg CO₂ eq/ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>25</td>
<td>50</td>
<td>0.8</td>
<td>-</td>
</tr>
<tr>
<td>50</td>
<td>10</td>
<td>&lt;1</td>
<td>2</td>
<td>-0.06</td>
</tr>
<tr>
<td>&lt;5</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Conventional N removal (50 mg N-NH₄/L)

TBD: to be determined

The advantage of using zeolites in the main line stream resides providing excellent effluent quality while replacing or lowering the volume of the existing biological reactor and reducing the energy required for the aeration as well as mitigating the environmental impact. It is clear that the higher the N concentration, the higher the capacity of the zeolites to capture ammonium leading to CAPEX and OPEX reduction when zeolites are placed in the sidestream for N-recovery. It is concluded that N concentration with zeolites allowing further valorisation as fertilizers is a promising technology. Although, up to now, recovery costs are in the same-higher range as removal, future regulation changes as well as new business models bringing alternative fertilizers to the market will favour the deployment of recovery technologies rather than removal. While this happens, it is important to direct the efforts towards the optimization of these technologies.

REFERENCES

Sustainable Ammonia Recovery from Source-Separated Urine Using Isothermal Membrane Distillation

N.Y. Yip*,**, S. McCartney*, C. Boo*, N. Williams*

*Department of Earth and Environmental Engineering, Columbia University, New York, New York 10027-6623, United States
**Columbia Water Center, Columbia University, New York, New York 10027-6623, United States

Abstract: The current once-through approach of nutrients utilization is unsustainable; a new paradigm is urgently needed to enable the transformation to a more sustainable circular economy model with fully realized nutrient reuse. Urine is rich in nutrients, but is immediately diluted over 100 times by flushing and subsequent mixing with other wastewater streams. A more rational and forward-looking approach would be to take advantage of the favorable high concentrations by carrying out source-separation for decentralized resource recovery. This study demonstrates the sustainable recovery of ammoniacal nitrogen from simulated aqueous waste streams driven by low-grade heat with a novel technology termed isothermal membrane distillation. Using a moderate temperature of 40 °C, high ammonia vapor flux of 13.9 molm⁻²h⁻¹ is obtained. Critically, exceptional ammonia to water vapor flux selectivity of 92.8 mol-NH₃/kg-H₂O is achieved, representing a concentration factor of 185 relative to the initial feed solution. In comparison, conventional direct contact membrane distillation exhibited drastically lower selectivity of 1.6 mol-NH₃/kg-H₂O. The thermal energy required to drive the process can be supplied by low-grade heat sources from locally-available waste flows or on-site low-temperature solar thermal collectors. Because evaporation of water is minimized in the separation, the energy penalty associated with the large enthalpy of water vaporization is sidestepped, resulting in energy savings of 96.2%. The separated ammoniacal nitrogen collected in the permeate stream is suitable for direct application as fertilizer.

Keywords: Ammonia, urine, membrane
INTRODUCTION

The current once-through approach of nutrients utilization is unsustainable. Nitrogen is fixated and phosphorus is mined at considerable costs, and energy and chemicals are further consumed for nutrient removal in wastewater effluent to prevent environmental and public health problems (Figure 1, red arrows). A more forward looking approach is to take advantage of the favorable high concentrations of urine, and carry out source-separation for decentralized N recovery to close the nutrient loop, thus realizing more sustainable circular economy management (Figure 1, blue arrows).

Membrane distillation is an emergent technology that utilizes low-temperature heat to drive the permeation of volatile compounds across a hydrophobic microporous membrane, while retaining all non-volatile species. This study presents a novel isothermal membrane distillation (IMD) technology for selective and energy efficient separation of ammoniacal nitrogen from source-separated urine.

MATERIAL AND METHODS

Membrane distillation experiments are conducted in a laboratory setup with aqueous solutions to simulate the urine feed stream and permeate stream. Ammoniacal concentration of the permeate stream is analyzed using the colorimetry method to determine the ammonia vapor flux. Water vapor flux is characterized by monitoring the weight change of the bulk solutions.

RESULTS AND DISCUSSION

Figure 2A shows the ammonia and water fluxes of isothermal membrane distillation using a relatively low temperature of 40 °C, compared to conventional direct contact membrane distillation with warm and cool streams at 40 and 20 °C, respectively. The ammonia fluxes of IMD and conventional MD are comparable at 13.5-13.9 mol/m²h. However, undesired water flux is suppressed in IMD (0.15 L/m²h) but not in conventional MD with the 20 °C temperature gradient (8.3 L/m²h). Membrane distillation innovatively utilizes the exponential dependence of ammonia partial vapor pressure on temperature to set up a driving force of NH₃(g) flux. Because the same temperature is maintained on both sides of the hydrophobic microporous membrane in isothermal membrane distillation, the partial pressure of water vapor is effectively identical, thereby eliminating the driving force for water vapor permeation. This results in a relative ammonia:water vapor flux selectivity of 92.8 mol-NH₃/kg-H₂O. In conventional membrane distillation, on the other hand, the temperature gradient of 40-20 °C inevitably sets up a partial water vapor pressure gradient that drives undesired water permeation, resulting in a drastically lower selectivity of 1.63 mol-NH₃/kg-H₂O.
The suppressed water flux and high selectivity for ammonia permeation in IMD is applicable across a wide temperature range (Figure 3). Temperatures as low as 20-20 °C were utilized for the feed and permeate streams, with ammonia flux increasing as the temperature is raised up to 60 °C. Unwanted water vapor flux is, again, effectively kept to a minimal. Relative ammonia:water vapor flux selectivity is enhanced at higher temperatures.

**CONCLUDING REMARKS**

The novel isothermal membrane distillation technology demonstrated promising potential for sustainable nutrient recovery from source-separated urine streams by enabling highly selective separation of ammonia. Because water flux is minimized, the energy penalty associated with the huge enthalpy of water vaporization is inventively avoided. Therefore, IMD is considerably more energy efficient than conventional MD. Additionally, the pioneering technology can utilize inexpensive thermal energy from low-grade heat sources, such as locally-available waste flows or on-site low-temperature solar thermal collectors.
Resource Recovery from Wastewater: INCOVER Project


*Environmental Technology Unit, AIMEN Technology Centre. Polígono Industrial de Cataboi SUR-PPI-2 (Sector 2) Parcela 3, 36418 O Porriño, Spain, jaalvarez@aimen.es, cristina.avila@aimen.es, apascual@aimen.es, rpena@aimen.es, santiago.cuervo@aimen.es, herrero@aimen.es.

Abstract: INCOVER project has been designed to move wastewater treatment from being primarily a sanitation technology towards a bio-product recovery industry and a recycled water supplier. Three added-value case studies treating wastewater have been implemented, assessed and optimised concurrently. INCOVER case studies are implemented at demonstration scale in order to ensure straightforward up scaling to 100,000 PE. INCOVER technologies will generate benefits from wastewater offering three recovery solutions: 1) Chemical recovery (bio-plastic and organic acids) via algae/bacteria and yeast biotechnology; 2) Near-zero-energy plant providing upgraded bio-methane via pre-treatment and anaerobic co-digestion systems; 3) Bio-production and reclaimed water via adsorption, biotechnology based on wetlands systems and hydrothermal carbonisation.

Keywords: Wastewater valorisation, PHA and organic acids from wastewater, anaerobic co-digestion

In spite of the huge figure of the water sector market (33 billion€ per year - WssTP Water Vision 2030-), the 95% of total EU settlements, which generate 47% of the pollution load, need to make substantial efforts to improve their compliance with WFD (EC, 2017). Therefore, the main target of INCOVER is to transform wastewater (WW) from a waste stream into a source of new added-value bio-products contributing to a circular flow economy (EC, 2018). The project innovation comes from the combination of all INCOVER technologies (Figure 1) applied to three different case-studies in order to obtain complementary and/or alternative solutions to conventional WW treatment providing water reuse and added-value products from municipal, agriculture and industrial WW.

CASE STUDY 1 – BARCELONA, SPAIN A microalgae-based system is tested for WW treatment and resource recovery. The plant consists of 3 semi-closed horizontal tubular photobioreactors (PBR) using agricultural runoff and municipal WW as feedstock. The operational conditions are adjusted in order to select cyanobacteria, microalgae able to accumulate PHA, which can be used for bioplastic production. The algae biomass (21 gVS/m²d) is harvested and used for biogas production by means of anaerobic co-digestion (AcoD) with secondary sludge. The biogas is upgraded in an absorption column to increase methane concentration (94-99% CH₄). The digestate from the AcoD is further stabilised and dewatered in a sludge treatment wetland, producing a bio-fertilizer. On the other hand, WW is post-treated in a solar driven ultrafiltration and disinfection system, and in nutrient recovery columns filled with a novel adsorption material. Eventually, the reclaimed water is applied in an agricultural field to grow crops by means of a smart irrigation system.
CASE STUDY 2 – CHICLANA & ALMERIA, SPAIN In Almería, WW is treated by a 3000 m² High Rate Algae Pond and tertiary treatment composed of 250 m² planted filter with natural material for enhancing P recovery. Irrigation water is finally obtained and reused with a solar anodic disinfection system. In Chiclana, PHA production is through a two-stage anaerobic phototrophic purple bacteria pond system, obtaining up to 25 gPHA/m³d. Two 500 m² HRAPs treat WW and the algae biomass is harvested and transformed into biogas through thermal pre-treatment and AcoD. Biomethane is provided (8 m³/d) by an innovative biogas upgrading system and a 250 m² evaporative system is used for the digestate stabilisation and nutrient recovery with zero liquid discharge.

CASE STUDY 2 – LEIPZIG, GERMANY Food industry WW and bio-waste are treated by a three-step process:
1) Up to 170 kg/m³ citric acid (CA) is produced by a non-conventional yeast *Yarrowia lipolytica* under non-sterile condition from waste frying oil as carbon rich source and kitchen cleaning WW from a canteen operating. This yeast-based bioprocess is performed in a modified conventional 1 m³ container system. The produced CA will be used for cleaning or descaling purposed.
2) The residual yeast biomass from CA bioprocess in combination with waste frying oil is digested through AcoD to produce biogas in a range of 0.85-1.0 m³/kgVS.
3) The anaerobic digestate is treated by hydro-thermal carbonisation into valuable carbonised products (bio-coal, carbon black, bio-fertilizer) applicable for fertilizing and energy purposes.

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REFERENCES
Membrane-based Nitrogen Recovery from Livestock Wastewater: A Pilot Plant Study


* Agricultural Technological Institute of Castilla y León, Ctra. Burgos, km 119, 47071 Valladolid, Spain. Email address: ita-molsalbe@itacyl.es
** United States Department of Agriculture, Agricultural Research Service, Coastal Plains Soil, Water and Plant Research Center, 2611 W. Lucas St., Florence, SC, 29501, USA

Abstract: Gas-permeable membrane technology that recovers ammonia nitrogen from livestock wastewater was tested at pilot scale in a swine farm. The technology recovered up to 38 g ammonia nitrogen per m² of membrane per day. However, wastewater temperature greatly affected the rate of recovery. The technology not only contributes to reduce ammonia emissions but also recovers nutrients in the form of an ammonium salt, which could be used as fertilizer.

Keywords: Swine manure, Ammonia recovery, Gas-permeable membranes

Agriculture is nowadays the largest source of ammonia (NH₃) emissions in Europe, so that reducing these emissions together with increasing nutrient recycling are two major environmental goals. Gas-permeable membranes present several potential advantages over other nitrogen recovery technologies. For example, the process is carried out at low-pressure and the addition of alkali is avoided. Ammonia passes through the microporous hydrophobic membrane by diffusion and an acidic solution is used as a trapping solution to recover it as a valuable (NH₄)_2SO₄ solution, which can be used as a fertilizer. This technology has been successfully demonstrated at laboratory scale to recover nitrogen from a variety of ammonia-rich wastewaters, such as livestock wastes or anaerobic digestates. This study was conducted at pilot scale in a swine farm under different seasonal temperatures. It evaluated in-situ the effect of wastewater temperature variations on the total ammonia nitrogen (TAN) recovery rate. To the best of our knowledge, this is the first study reporting experimental results of a pilot-scale plant using gas-permeable membranes to recover nitrogen from livestock wastewater (i.e. swine manure) (Fig 1.).

Figure 1.1 Schematic of the pilot plant. Wastewater feeding pump (1), reactor (2), blower (3), wastewater mixing pump (4), trapping solution tank (5), acidic solution recirculation pump (6), heating blanket (7), membrane module (8).
The pilot plant consisted of a wastewater reactor of 5.85 m$^3$ that contained 16 membrane modules in vertical configuration (Fig. 1.1). The total membrane surface was approx. 13 m$^2$. The membrane was made of e-PTFE with an outer diameter of 5.2 mm, a wall thickness of 0.64 mm and a density of 0.95 g cm$^{-3}$. A solution of 1N H$_2$SO$_4$, used as a trapping solution, was contained in a 250 L-tank and it was continuously recirculated through the membrane. A PLC system controlled the pilot plant. Aeration in on/off cycles of 180 seconds each was provided to increase the pH in the wastewater. The wastewater was mixed in cycles of 20 seconds on and 10 seconds off. The pH in the trapping solution was maintained below 2 by adding concentrated H$_2$SO$_4$ whenever the pH of the trapping solution increased up to 2.

**Table 1.1** Temperatures in livestock wastewater (i.e. swine manure), TAN recovery rates and final TAN concentrations in the trapping solution during the pilot plant operation.

<table>
<thead>
<tr>
<th></th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature livestock wastewater ºC</td>
<td>26.4</td>
<td>28.0</td>
<td>26.1</td>
<td>21.2</td>
<td>21.7</td>
</tr>
<tr>
<td>TAN recovery rate g TAN m$^{-2}$ day$^{-1}$</td>
<td>29.5</td>
<td>38.2</td>
<td>37.0</td>
<td>12.9</td>
<td>16.9</td>
</tr>
<tr>
<td>Final TAN in acidic solution mg TAN L$^{-1}$</td>
<td>27479</td>
<td>32101</td>
<td>23541</td>
<td>8484</td>
<td>12107</td>
</tr>
</tbody>
</table>

Five batch experiments of 7 days each were carried out, namely B1, B2, B3, B4 and B5, respectively (Table 1.1). The average temperature in the livestock wastewater varied from 21.2 to 28.0 ºC, corresponding to seasonal variations in air temperature. TAN recovery rates varied from 12.9 to 38.2 g TAN m$^{-2}$ day$^{-1}$. A high positive relationship ($R^2 = 0.92$) between the temperature in the livestock wastewater and the TAN recovery rate was observed (Fig. 1.2A). Consequently, a high positive relationship ($R^2 = 0.99$) was also observed between the temperature in the livestock wastewater and the TAN concentration in the trapping solution after 7 days of operation.

**Figure 1.2** Relationship between wastewater temperature and TAN recovery rate (A) or TAN concentration in the trapping solution (B).

In conclusion, livestock wastewater treatment by gas-permeable membrane technology in a pilot plant was greatly affected by temperature in the wastewater. Maximum recovery rate obtained was 38 g TAN m$^{-2}$ day$^{-1}$. Besides its contribution to NH$_3$ emissions reduction, this technology contributes to the recovery of nutrients in the form of a valuable product.

The study is of significant importance for the topic of this conference on resource recovery. Specifically, this presentation would perfectly fit on the specific topic “pilot scale demonstration of innovative resource technologies”.

This work has been funded by the European Union under the Project Life+ AMMONIA TRAPPING (LIFE15-ENV/ES/000284) “Development of membrane devices to reduce ammonia emissions generated by manure in poultry and pig farms”.

Ammonium Recovery and Conversion Path by the Immobilization of *Scenedesmus obliquus* in Alginate Beads from Biogas Slurry

X. Liu, K. Wang*
State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, PR China

Abstract: Microalgae growth coupling biogas slurry treatment was viewed as a promising strategy to produce biomass. In order to cell harvesting, microalgae was immobilized in alginate bead matrix and the relevant parameters were optimized by the response surface methodology (RSM). The results showed that the maximal mean removal efficiencies of 86.35±1.83%, 96.57±0.12% and 65.16±4.45% for ammonium (NH$_4^+$-N) after 5 days of cultivation applied at three NH$_4^+$-N initial concentrations (30, 50 and 70 mg/L). Compared to the free-living microalgae system, immobilized microalgae had greater ability to treat biogas slurry with high concentration of NH$_4^+$-N. Assimilation was the principal conversion path with the production of glutamate and proline. These results will provide a theoretical foundation for the recycling handles of biogas slurry.

Keywords: Ammonium recovery; immobilized microalgae; biogas slurry

INTRODUCTION The increasing energy demand and potential fossil fuel depletion have become major concerns around the world. The renewable energy, such as biogas, has been considered as an alternative environment-friendly fuel source and currently widely used. However, the untreated biogas slurry contains plenty of nitrogen (N) and phosphorus (P), which would lead to water eutrophication and further threaten human health. Ammonium (NH$_4^+$-N) is abundant in biogas slurry, which represents the preferred source of nitrogen for eutrophication (Wang et al., 2019). Researchers have focused on the use of microalgae-based technology for removing it (Lam and Lee, 2012). Microalgae have a potential to assimilate it from biogas slurry for its growth and have been seen as one of the most promising candidates for the synthesis of bioactive compounds (lipids, proteins, carbohydrates). However, cell harvesting is the main obstacle restricting this application. Immobilization is proposed as a feasible technique to simplify the separation of free-living cell from liquid phase. Therefore, the main objectives of this study are to (1) optimize the parameters for microalgae immobilization; (2) assess the potential of NH$_4^+$-N recovery by microalgae beads; (3) analyze the recovery mechanism of NH$_4^+$-N combined with the adsorption of surface functional groups of cell, chemical oxidation and assimilation. These results are essential for subsequent scale-up treatments of the biogas slurry in the framework of a technological process aimed at addressing the demands of both energy and environmental sustainability.
MATERIAL AND METHODS *Scenedesmus obliquus* was immobilized in alginate bead matrix according to the modified procedure of Lam and Lee (2012). In the logarithmic growth phase, the microalgae cells were harvested by centrifugation at 3500 rpm for 10 min at 4 °C (himac CR22N, Japan) and washed twice with sodium bicarbonate solution (15 mg/L), then resuspended in nitrogen-free BG-11 medium for 3-day culture in a 250-mL Erlenmeyer flasks. After that, the cells were centrifuged again under the same conditions and then washed three times with sterilized distilled water and finally resuspended in sterilized distilled water to form a concentrated algal suspension. The algal suspension was mixed with a 5% sodium alginate (SA) solution at a volumetric ratio of 1:1 and stirred for 15 min. The alginate-alga mixture was dropped into a sterile 2% CaCl2 (w/v) solution from a height of 20 cm above by using a sterile syringe (60 mL). For every 35 mL of microalgae-alginate mixture titrated, 1000 microalgae beads of approximately 4 mm diameter per bead were produced. Free-living microalgae and immobilized microalgae were cultured in 250-mL Erlenmeyer flasks filled with 140 mL biogas slurry with different NH4+-N concentrations (30, 50 and 70 mg/L). A total of 36 experimental units were carried out, consisting of 3 replicates of each treatment group. The initial cell density of free-living microalgae for each flask was $1 \times 10^6$ cells/mL, and 400 beads were randomly added to the immobilized treatment groups to ensure that the initial biomass in every flask was consistent.

RESULTS AND CONCLUSIONS Response surface methodology (RSM) analysis indicated that the optimal parameters including the concentration of SA, the concentration of CaCl2 and the crosslinking time for microalgae immobilization were 5%, 2% and 16 h, respectively. As shown in the Figure 1.1, the maximal mean removal efficiencies of 86.35±1.83%, 96.57±0.12% and 65.16±4.45% for NH4+-N after 5 days of cultivation applied at three initial concentrations (30, 50 and 70 mg/L). Compared to the free-living microalgae system, immobilized microalgae had greater ability to treat biogas slurry with high concentration of NH4+-N. However, when applied at initial concentration of 30 mg/L, the removal efficiency of 97.83±0.55% for NH4+-N by the free-living microalgae after 3 days of cultivation.

![Figure 1.1](image-url) Changes in NH4+-N concentrations in the various treatments under batch culture conditions, free-living microalgae (a), immobilized microalgae (b).

The conversion path of NH4+-N by microalgae were analyzed by the function of surface functional groups of cell (Figure 1.2), chemical oxidation (Figure 1.3) and assimilation (Figure 1.4). The results indicated the assimilation was the principal conversion path during the total recovery process with the production of glutamate and proline.
Figure 1.2 FTIR spectra of free-living microalgae (a), immobilized microalgae (b) after 5 days of cultivation during the treatments with different concentrations of NH₄⁺-N

Figure 1.3 Changes in nitrate (NO₃⁻-N) and nitrite (NO₂⁻-N) in microalgae-based systems, left: free-living microalgae, right: immobilized microalgae

Figure 1.4 Amino acid variation during the assimilation of microalgae for NH₄⁺-N

REFERENCES
Monday, 9th September 2019

Session 2

PHOSPHORUS RECOVERY: NOVEL TECHNOLOGIES
Biologically Induced Struvite Production in Wastewater

S. Leng*, A. Soares*
*Cranfield Water Sciences Institute, Cranfield University, Cranfield, Bedfordshire, MK43 0AL UK
(E-mail: sleng2013@126.com, a.soares@cranfield.ac.uk)

Abstract: Biologically induced mineral formation can be exploited to recover phosphorus from liquid streams and wastewater through struvite production. Selected microorganisms were able to grow in wastewater and remove up to 91% ortho-phosphate. B. antiquum removed ortho-phosphate from initial concentrations of 5.4 mg/L to ≤1 mg/L. Biological struvite (bio-struvite) (identified by morphological, XRD and elemental analysis) could be isolated as a salt when the wastewater contained ≥19.7 mg ortho-phosphate/L, compared with ≥62.4 mg ortho-phosphate/L for abiotic struvite precipitation after pH adjustment. The bio-struvite recovered presented high purity and contained low heavy metal contents, which enable the bio-struvite to meet proposed regulations for inorganic fertilizers. Overall, bio-struvite production presented important advantages, in comparison with abiotic struvite, and the process should be further developed for implementation at pilot and full scale.

Keywords: biological struvite, phosphorus removal, heavy metal, urine, struvite purity

INTRODUCTION Biological crystal formation of phosphorus compounds (e.g.: struvite; magnesium phosphate, etc.), has been demonstrated to be a by-product of the metabolism of specific bacteria that can be found frequently in the environment. The ability of selected bacteria to produce bio-struvite from sludge dewatering centrifuge liquors and activated sludge liquors has been (Soares et al, 2014) demonstrated at Cranfield University. The implications of this study are substantial as it opens a completely new route to recover phosphorus as mineral salts from wastewater (Leng and Soares, 2018).

MATERIALS AND METHODS Selected bacteria (Halobacterium salinarum, Bacillus pumilus and Brevibacterium antiquum) were incubated in real wastewater with the composition defined in Table 1.1 to reproduce different [P]:[Mg]:[N] molar ratios. The intact cell counts in microbial culture were estimated with a flow cytometer. Struvite was identified by struvite (bio-struvite) (identified by morphological, XRD and elemental analysis) and nutrients and heavy metals were analysed using standard methods.

RESULTS AND CONCLUSIONS The lag phase of microbial growth was observed during the first 12 h incubation, followed by exponential phase of growth until 48 h. The intact cell counts of the tested microorganisms were then maintained at a constant level from 48 to 192 h incubation, indicating a stationary phase. The capability of microorganisms to remove PO4-P from wastewater varied with the microbial strains: 67-97% for B. antiquum, 51-89% for B. pumilus, 11-89% for H. salinarum.
Table 1.1. Characteristics of the raw wastewater collected from a municipal WWTP and the wastewater with different concentrations of NH4-N and PO4-P (average ± standard deviation of duplicates) used to investigated struvite precipitation

<table>
<thead>
<tr>
<th>Raw wastewater</th>
<th>Wastewater with different concentrations of PO4-P and NH4-N tested</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO4-P (mg/L)</td>
<td>5.4±0.3</td>
</tr>
<tr>
<td>NH4-N (mg/L)</td>
<td>35.0±0.6</td>
</tr>
<tr>
<td>Mg2+ (mg/L)</td>
<td>8.2±0.5</td>
</tr>
<tr>
<td>SCOD (mg/L)</td>
<td>150 ±5</td>
</tr>
</tbody>
</table>

* containing 0.5 g/L BSA, equivalent to 600 mg/L SCOD

Biological struvite (bio-struvite) (identified by morphological, XRD and elemental analysis) could be isolated as a salt crystal in the wastewater starting from 19.7 mg ortho-phosphate/L, compared with ≥62.4 mg ortho-phosphate/L for abiotic struvite precipitation after pH adjustment. The raw wastewater contained various heavy/toxic metals (Table 1.1). However, the amount of heavy metal Cr, Ni, Cu, As, Cd, Pb and Hg in both bio-struvite and abiotic struvite met the EU maximum limitation (ESPP, 2015; FOMA, 2014; FWG, 2014).

Table 1.2. Quantification of macronutrients and heavy/toxic metal in bio-struvite and abiotic struvite (average ± standard deviation of triplicates)

<table>
<thead>
<tr>
<th>Macronutrient</th>
<th>B. antiquum</th>
<th>B. pumilus</th>
<th>H. salinarum</th>
<th>Abiotic struvite</th>
<th>EU permissible levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO4-P (g/kg)</td>
<td>122.6±3.3 (12.3% P)</td>
<td>121.9±3.9 (12.2% P)</td>
<td>121.7±1.9 (12.2% P)</td>
<td>127.2±3.6 (12.7% P)</td>
<td>1% (total P2O5)bd</td>
</tr>
<tr>
<td>NH4-N (g/kg)</td>
<td>57.7±0.2 (5.8% N)</td>
<td>56.2±1.1 (5.6% N)</td>
<td>57.1±0.4 (5.7% N)</td>
<td>52.4±0.3 (5.2% N)</td>
<td>2% (total N)bd</td>
</tr>
<tr>
<td>Mg (g/kg)</td>
<td>97.7±0.9 (16.2% MgO)</td>
<td>96.2±0.3 (16.0% MgO)</td>
<td>97.1±0.7 (16.2% MgO)</td>
<td>96.0±1.2 (16.0% MgO)</td>
<td>NYD</td>
</tr>
<tr>
<td>K (g/kg)</td>
<td>0.8±0.0</td>
<td>0.7±0.0</td>
<td>0.7±0.0</td>
<td>0.2±0.0</td>
<td>1.5% (water-soluble K2O)bd</td>
</tr>
<tr>
<td>Ca (g/kg)</td>
<td>0.2±0.0</td>
<td>0.2±0.0</td>
<td>0.2±0.0</td>
<td>0.8±0.0</td>
<td>NYD</td>
</tr>
<tr>
<td>Al (mg/kg)</td>
<td>18.5±0.7</td>
<td>12.0±0.4</td>
<td>22.9±0.8</td>
<td>31.2±0.9</td>
<td>NYD</td>
</tr>
<tr>
<td>Fe (mg/kg)</td>
<td>2.65±0.23</td>
<td>2.19±0.62</td>
<td>&lt;LOD</td>
<td>8.69±0.38</td>
<td>NYD</td>
</tr>
<tr>
<td>Cr (mg/kg)</td>
<td>0.17±0.02</td>
<td>0.23±0.03</td>
<td>0.15±0.01</td>
<td>0.38±0.00</td>
<td>2 mg/kgbd</td>
</tr>
<tr>
<td>Ni (mg/kg)</td>
<td>0.11±0.00</td>
<td>0.08±0.04</td>
<td>0.07±0.01</td>
<td>1.19±0.10</td>
<td>120 mg/kgbd</td>
</tr>
<tr>
<td>Cu (mg/kg)</td>
<td>0.31±0.19</td>
<td>0.53±0.18</td>
<td>0.18±0.02</td>
<td>0.42±0.03</td>
<td>200 mg/kgbd</td>
</tr>
<tr>
<td>As (mg/kg)</td>
<td>0.36±0.01</td>
<td>0.30±0.02</td>
<td>0.32±0.01</td>
<td>0.07±0.02</td>
<td>60 mg/kgbd</td>
</tr>
<tr>
<td>Cd (mg/kg)</td>
<td>0.06±0.05</td>
<td>0.66±0.01</td>
<td>&lt;LOD</td>
<td>0.00±0.00</td>
<td>60 mg/kg (if P2O5&gt;5%)bd</td>
</tr>
<tr>
<td>Pb (mg/kg)</td>
<td>0.18±0.03</td>
<td>0.32±0.04</td>
<td>0.11±0.01</td>
<td>0.40±0.02</td>
<td>150 mg/kgbd</td>
</tr>
<tr>
<td>Hg (mg/kg)</td>
<td>0.03±0.01</td>
<td>0.11±0.05</td>
<td>0.03±0.01</td>
<td>0.00±0.00</td>
<td>2 mg/kgbd</td>
</tr>
</tbody>
</table>

LOD - limit of detection; NYD – not yet defined

Some preliminary tests have also been completed in urine as a feedstock. Urine is rich in phosphate, ammonia, calcium etc. and it is practically sterile. The bio-mineral formation bacteria were investigated in Leng an Soares (2018) had two major communalities - urease production and ability to grow at high pHs (>8-10). Urease hydrolyses the urea in urine to ammonia and carbon leading to an increase in pH. The urea hydrolysis and the resulting high pH constitute serious limitations for resource recovery technologies in urine streams that can be potentially be overcome by bio-mineral formation bacteria.

REFERENCES
Iron-reducing Biocathode for PO$_4^{3-}$ Remobilization from FeP Complexes Contained in Wastewater Sludge

D. Sun, X. Chen, X. Zhang, P. Liang, X. Huang*

State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China, E-mail: sdy930928@163.com
*Corresponding author, E-mail: xhuang@tsinghua.edu.cn, Tel: +86-10-62772324, Fax: +86-10-62771472

Abstract: Phosphorus remobilizing from the wastewater sludge produced in chemical phosphorus removal process is a key challenge for nutrient resource recovery in future wastewater treatment plants (WWTPs). In this study, the proof-of-concept of an electrical potential induced iron-reducing biocathode is demonstrated, aiming to reduce Fe$^{3+}$ and release PO$_4^{3-}$ from the FeP complexes contained in the wastewater sludge. Compared with non-potential applied biocathode, the PO$_4^{3-}$ release efficiency could be improved by more than 45% in the iron-reducing biocathode. The kinetic equation of Fe$^{3+}$ reduction in iron-reducing biocathode could be expressed as: $\frac{da}{dt} = k'(1 - a)^{2/3}$. The cyclic voltammetry (CV) curves and microbial community analysis indicated that the applied potential could benefit the electron transfer during the Fe$^{3+}$ reducing process.

Keywords: Phosphorus recovery; biocathode; sludge treatment

INTRODUCTION

In the future WWTPs which would act as energy and phosphorus factories (Nowak et al., 2011; Li, 2005), PO$_4^{3-}$ and COD would be synchronously removed by adding Fe salt as coagulant, and thus generate concentrated sludge. Such sludge could be further digested to produce biogas, and after which PO$_4^{3-}$ is supposed to be recovered from the digested sludge. But how to release PO$_4^{3-}$ from the FeP complexes contained in the digested sludge is remained to be investigated (Wilfert et al., 2015). In this study, a novel iron-reducing biocathode combining biological and electrochemical processes was proposed to remobilize PO$_4^{3-}$ from the FeP complexes contained in the sludge. Fe$^{3+}$ could be reduced to Fe$^{2+}$ through a microbial reaction chain in the biocathode and thus release PO$_4^{3-}$ into the supernatant. Different electrical potentials were applied on the biocathodes to explore the performance of Fe$^{3+}$ reducing and PO$_4^{3-}$ releasing. The feasibility of iron-reducing biocathode was verified by the comparison with non-potential applied biocathode which utilized organic as the sole electron donor. The reaction kinetic of Fe$^{3+}$ reduction was also analysed. CV curves and microbial community analysis were conducted to investigate the electron transfer and Fe$^{3+}$ reduction mechanisms.

RESULTS AND DISCUSSION

Electrical potential induced biological reduction

As shown in Fig. 1A and C, Fe$^{3+}$ reduction and PO$_4^{3-}$ release both were affected by the applied cathode potential. Higher cathode potential resulted in faster Fe$^{3+}$ reduction and PO$_4^{3-}$ release. After 3 days’ operation, the maximum Fe$^{2+}$ production (76.9 mg/L) and PO$_4^{3-}$ dissolution (58.8 mg/L) were achieved at the cathode potential of 650 mV. It was anticipated that cathode potential could affect how much energy was available for
electricity production (Ter Heijne et al., 2010). Thus, higher cathode potential would lead to higher current and more electrons that Fe$^{3+}$ could accept to transform into Fe$^{2+}$. The control experiment using the same type of biocathode but without external potential application was conducted, utilizing sodium acetate as the sole electron donor. The Fe$^{3+}$ reduction and PO$_4^{3-}$ release (Fig. 1B and C) both were inferior to the previously talked performances in the potential-applied group. The highest release proportion of PO$_4^{3-}$ was only 6.2 % in non-potential applied biocathode during the 3-day operation, which could barely reach 1/8 of that achieved in the iron-reducing biocathode, 51.7 % (Fig. 1C). Microbial community analysis was conducted after all the experiments finished. Compared with the control group, cathode potential stimulated the enrichment of Geobacter in the iron-reducing biocathode. Geobacter is a representative exoelectrogenic bacteria which could transfer intracellular and extracellular electrons to reduce Fe$^{3+}$. The electron transport chain composed of cytochromes c played an important role in the electron transfer process (Fig. 1E). A higher reduction peak current of biocathode was achieved in the CV curve of the potential-applied group than that achieved in the control group, indicating a higher concentration of cytochromes c contained in the biofilm.

Figure 1. Fe concentrations change in the biocathode with the applied potential of +50, +200, +350, +500, +650 mV vs. SHE (A), and that for the non-potential applied biocathode with COD dosing of 7, 30, 60, and 150 mg/L (B); PO$_4^{3-}$ release proportion in FeP complexes (C); the ln(da_Fe/dt) - Inc_Fe curve (D); schematic of Fe$^{3+}$ reduction and PO$_4^{3-}$ remobilization mechanisms in the iron-reducing biocathode and non-potential applied biocathode (E); P1-P4: different FeP complexes particle sizes, P1>P2>P3>P4.

Reaction kinetic analysis

Fe$^{3+}$ reduction in the biocathode is a non-autocatalytic reaction. Based on the calculation of experimental data, $ln(a_Fe/dt)$ was linear ($r > 0.99$) to $Inc_Fe$ (Fig. 1D) when different particle sizes (P1-P4) of FeP complexes were tested, which suggested that the Fe$^{3+}$ reduction rate was only relevant with the total concentration of Fe$^{3+}$ in FeP complexes under constant temperature ($T$), particle size and biocathode potential. Therefore, the Fe$^{3+}$ reduction in the iron-reducing biocathode was hypothesized to be an n-order reaction. However, the reaction kinetic equation could have theoretical significance only when the value of n is 0, 1/2, 2/3 or 1 (Criado, 1977). To confirm the reaction order, the constant $k'$ was calculated based on the experimental data with different values of n. Ultimately, the best linearity was obtained when n=1 ($r > 0.99$), and the kinetic equation of Fe$^{3+}$ reduction would be: $da/dt = k'(1 - a)^{2/3}$, where $a$ is the reacted fraction of Fe$^{3+}$ in FeP complexes, $k'$ is the reaction rate constant (d$^{-1}$), $t$ is the operation time (d).

Relations to the conference

In this work, the iron-reducing biocathode was proved to be an effective and energy-efficient way for PO$_4^{3-}$ release and recovery from the FeP complexes contained in
wastewater sludge, which would help to tackle the phosphorus recycle challenge in the future WWTPs.

REFERENCES


Phosphorus Recovery from Sewage Sludge - P Leaching Behaviour from Various Types of Post-Precipitated Tertiary Sludge


* University of Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA), Bandtaele 2, 70569 Stuttgart, Germany, cristina.monea@iswa.uni-stuttgart.de
** University of Kaiserslautern, Department of Civil Engineering, Resource Efficient Wastewater Technology, Paul-Ehrlich 14, 67663 Kaiserslautern, Germany
*** Tallinn University of Technology, Centre for Biorobotics, Akadeemia tee 15A-111, 12618 Tallinn, Estonia

Abstract: Phosphorus (P) is an essential element for life and a key nutrient for agriculture and global food security. However, P resources are finite and this is one of the most important reasons to think about P-recovery from secondary sources. Most of the studies so far looked at the P recovery potentials from anaerobically digested sludge or activated sludge. Tertiary sludge has not been the focus of the studies yet. In this work Al- and Fe-containing tertiary sludges from different sewage treatment plants were investigated in terms of their P-leaching potential. The dissolution rate of P but also of Al and Fe was systematically investigated in the acidic and alkaline pH range. All experimental results were compared against data obtained from the leaching of anaerobically digested sewage sludge and synthetically precipitated sludge. After the P-dissolution, the recovery of phosphorus can take place through the precipitation of struvite, which is a valuable fertilizer and can be applied directly on agricultural fields.

Keywords: P-leaching; Al- and Fe-containing sludge; P-recovery

Phosphorus (P) is an irreplaceable element of life and a non-renewable natural resource, essential for modern agriculture and global food security. However, phosphate rock is a finite resource (Cordell and White, 2015) and the remaining reserves often contain high concentrations of toxic elements, e.g. cadmium and uranium, implying that production costs will increase in the future (Pizzol et al., 2014).

P-recovery from digested sewage sludge or sludge ash is the most preferred pathway because of highest recovery potential (max. 90% of the inflow P to WWTPs). The main disadvantage is that the phosphorus bound into the sludge or sludge ash needs to be released through enforced dissolution via wet chemical leaching or other extraction techniques. This leads to undesired co-dissolution of metals, resulting in additional costs to prevent their co-precipitation in the final recovered P-products. An alternative approach would be the P-recovery from tertiary sludges generated during P-elimination via chemical post-precipitation with metal salt coagulants after the secondary clarifier of the biological treatment. Thus, the P sequestration will be only in the form of mineral metal-phosphate precipitates, i.e. inorganic tertiary sludge, without mixing it with the biomass in the activated sludge tank. Compared to excess activated sludge containing mainly organic biomass, the
tertiary sludge has a significantly lower volume and less contamination with undesired pollutants (Wiechmann et al., 2013) which is a major advantage for any subsequent P-recovery process. Most of the published studies so far focus on P-leaching from primary sludge, activated sludge and anaerobically digested non-thickened or thickened sludge (Egle et al., 2016), but never on post-precipitated chemical sludge. An exception is the so called “RAVITA” process (Heinonen, 2018).

Thus, in this study several types of Al- and Fe-containing tertiary sludge were tested at lab-scale and their P-leaching efficiency was compared against that of anaerobically digested sewage sludge and synthetic sludge precipitates as a reference. The feasibility to re-dissolve the phosphorus bound into the sludges was investigated systematically by applying acidic or alkaline leaching. For the Al-containing sludge, the efficiency of PO$_4$-P re-dissolution after acidic leaching was ~95% at pH 2.0 (Fig. 1.1a). For the Fe-containing tertiary sludge, ~80% efficiency could be reached only after significant acidification to pH 1.5 (Fig. 1.2a). The alkaline leaching at pH 13 showed considerably lower potential for PO$_4$-P re-dissolution with ~70% efficiency for the Al-containing and ~40% for the Fe-containing tertiary sludge (Fig. 1.1a and 1.2a). Additionally, the co-dissolution of the associated Al and Fe metals was analyzed as well (Fig. 1.1b and 1.2b), and all experimental results were compared against data obtained from the leaching of anaerobically digested sewage sludge and synthetically precipitated sludge (Fig. 1.1 and 1.2).

![Figure 1.1. Leaching efficiency (% of: a) phosphorus and b) aluminum from Al-containing sludge samples in the range pH 2-13.](image1)

![Figure 1.2. Leaching efficiency (% of: a) phosphorus and b) iron from Fe-containing sludge samples in the range pH 1.5-13.](image2)

A common approach for P-recovery from sewage sludge, which could potentially be applied on tertiary chemical sludge as well, is wet-chemical leaching causing P-dissolution followed by P-precipitation in the form of high-value fertilizer product, e.g. struvite. Struvite can be used directly in agriculture as a high-quality long-term fertilizer. During plants experiments, it could be shown that the yield and nutrient uptake of the plants were higher compared to commercial fertilizers (Meyer et al., 2018).

REFERENCES


Phosphorus Stripping of Bio-P Sludge and Enhanced Nutrient Recovery

B.M. Gonzalez Silva*, D.B. Fiksdal, C. B. He, S. Sægrov, S.W. Østerhus **
Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU), N-7491 Trondheim, Norway.

*blanca.g.silva@ntnu.no
** stein.w.osterhus@ntnu.no

Abstract: Phosphate from bio-P sludge can precipitate uncontrolled in the sludge treatment line and decrease the potential for phosphorus recovery. The presence of an anaerobic unit (or equivalent) before the pre-dewatering stage could favor early release of phosphorus and avoid uncontrolled struvite precipitation. Through a series of kinetic experiments of P stripping, a Michaelis-Menten curve was calculated. The use of Vmax and Km can then determine the potential release of phosphorus for any given Bio-P sludge. A strong correlation between PO₄-P and Mg²⁺ release and changes in conductivity was found. The results of this work can contribute to generate and optimize P-rich streams and enhance the phosphorus recovery.

Keywords: Wastewater; Bio-P sludge, phosphorus recovery

INTRODUCTION The optimization of the sludge treatment line is important when Enhanced biological phosphorus removal (EBPR) process is implemented as secondary treatment in the wastewater line. The main challenge is the unwanted precipitation of phosphorus as struvite (MgNH₄PO₄•6H₂O) in the sludge treatment lines (Fattah 2012). Especially in the anaerobic digestion process, phosphorus and magnesium from Poly-P hydrolysis and from organic matter degradation are released, increasing the orthophosphate and magnesium content in the system and, therefore, the potential for phosphorus precipitation (Marti et al. 2008a).

The conventional configuration of a sludge treatment line (i.e., separate thickening of primary and EBPR sludge) does not enhance the early release of phosphorus in the treatment line due to the lack of volatile fatty acids (VFA) (Marti et al. 2008b). As the release requires uptake of such substrates, the Bio-P sludge needs to be mixed with sludge from the primary settler containing VFAs (Marti et al., 2008a; Marti et al., 2008b) or with externally supplied carbon. The presence of an anaerobic unit (or equivalent) before the pre-dewatering stage could favor the early release of phosphorus and avoid uncontrolled struvite precipitation later in the sludge treatment process. In the present research, a series of anaerobic kinetics experiments with Bio-P sludge and different substrate concentrations were performed. The phosphorus release rates were fitted to a Michaelis-Menten curve where the maximum release rate (Vmax) and the affinity constant of substrate (Km) were calculated. Investigation of the correlation of the P-release versus magnesium release and conductivity change was determined. The result of this work can be used as a tool to identify ideal operating parameters to enhance the phosphorus and magnesium stripping from the Bio-P sludge before anaerobic digestion units.
MATERIAL AND METHODS

The Bio-P activated sludge used in this study was enriched in a sequencing batch reactor (SBR) operated in 8-hour cycle. Fresh domestic wastewater together with a dose of acetate and phosphate were used to feed the SBR. Settled sludge from this reactor was used for the kinetic experiments. The experimentation was performed in an anaerobically mixed unit with a working volume of 1.6L. Different kinetics experiments with P and Mg$^{2+}$ stripping were performed at different temperatures and various addition of acetate and sCOD from fermented primary sludge supernatant. The P-release rate was calculated. Analysis of Mg$^{2+}$, NH$_4$-N, TP, PO$_4$-P, and sCOD was determined. The conductivity was determined using the Hach HQ440d Laboratory Multi-Meter.

RESULTS AND DISCUSSION

Series of kinetic experiments with P stripping at different concentration of acetate as carbon source was performed using an anaerobic unit. A Michaelis-Menten curve with a correlation of 0.96 was calculated based on the phosphate release rate of each experiment (Figure 1.1A). The release rate of each experiments was normalized to mgTP/mgTS. By using the maximum P release rate (Vmax) and the affinity to substrate constant (Km), the theoretical phosphorus release rate can be calculated for any sludge quality and VFA dose. Typical curves predicting a potential P-release at different VFA concentration were generated (Figure 1.1B).

![Figure 1.1 Mathematical modeling with the Michaelis-Menten type equation of the phosphorus release rate at different concentrations of acetate (A). Potential P-release based on different acetate concentrations (B).](image)

A strong correlation between PO$_4$-P release and changes in conductivity was found. The conductivity is more affected by Mg$^{2+}$ and K$^+$ ions (Levin, 2010). However, by using P-release as a parameter, the Mg$^{2+}$ and K$^+$-release will also be included as their release is a direct consequence of P-release when dealing with Bio-P sludge. In this work, the ideal operating parameters were identified when an anaerobic mixer was used to strip phosphorus and magnesium early in the sludge treatment line. The results of this work can be used as a tool to predict the theoretical P-release rate for any sludge quality and VFA/fermented primary sludge supernatant dose when an anaerobic unit (or equivalent) is implemented. This may be used to generate and optimize P-rich streams early in the sludge line and thereby enhance the phosphorus recovery.

REFERENCES


Newly Developed Materials for Phosphorus Removal, Recovery and Reuse in Decentralized Wastewater Treatment


* Aarhus University, Department of Bioscience, Aarhus, Denmark. solvei.mundbjerg@bios.au.dk, hans.brix@bios.au.dk, carlos.arias@bios.au.dk.
** Sino-Danish Center for Education and Research, Aarhus, Denmark.
*** WATEC, Aarhus University, Aarhus, Denmark.
**** Danish Technological Institute, Aarhus, Denmark. fhb@teknologisk.dk, hsl@teknologisk.dk.

Abstract: A screening of >20 materials submitted to engineered coating processes to increase the phosphorus (P) sorption capacity has been running for the past year. The resulting materials are being tested using adsorption isotherm experiments and revealed materials with promising P removal potential, which are currently being further investigated with column experiments, as well as, with external filters installed in real scale wastewater treatment plants. Since one of the objectives also was to recover and reuse nutrients, experiments are currently being performed to assess if the P bound to the material is bioavailable, for use as a nutrient source for plant uptake. The development of the materials constitutes a useful technology in decentralized wastewater treatment systems, which may promote a more circular nutrient cycle, hence, linking removal closer to recovery and reuse.

Keywords: Decentralized wastewater treatment; phosphorus recovery; bioavailable phosphorus.

Decentralized wastewater systems are engineered solutions targeting pollutants in waters affected by anthropogenic activities. The systems must be robust, reliable, easy to maintain and require low external energy input, and these systems have proven efficient at removing certain pollutants (Wu et al. 2014). However, up to now, sustained phosphorus (P) removal has proven elusive regardless of the system. In a global perspective the removal, recovery and reuse of P is important, as the global supply of mineral P is becoming exhausted, while P demand is increasing (Rittmann et al. 2011). The available strategies in P removal include media adsorption, chemical precipitation, sedimentation, and vegetation uptake with subsequent harvest (Kadlec and Knight 1996), and the strategies have been evaluated with diverging success.

In the present work, one of the objectives was to evaluate P sorption by newly engineered materials to improve P removal. We screened more than 20 materials by testing P removal potential using adsorption isotherm experiments, and the screening determined P binding capacities ranging from -0.3 to 35.8 mg P g⁻¹ dw. Figure 1.1 shows the isotherms results from a selection of six of the tested materials. After the removal potential was confirmed, the materials with P removal capacity were submitted to different engineered coating processes to improve the P binding capacity,
the mechanical characteristics, and ensuring hydraulic performance. Once coated, the improved materials were also tested using isotherms experiments to confirm P removal potential.

Subsequently, long-term column experiments are currently being performed on selected materials from the screening process to determine total P binding capacity. The experiments are still running, and for one and half year, results have revealed consistent P binding capacities. New P loading campaign are currently being performed to explore the removal potential of the materials.

Two coated materials that showed the highest potential, hence, high P binding capacity, good hydraulic and mechanical performance, are currently being tested under real operational conditions. Two external 1 m³ filters, each filled with one of the materials, have been installed at two different wastewater treatment plants in Spain. Both filters have been receiving secondary treated wastewater with a P concentration of up to 10 mg L⁻¹, and have consistently been producing effluent concentration below 1.5 mg L⁻¹, hence, P removal rates of approx. 90 %.

Additionally, since one of the objectives was to recover and reuse nutrients, the bioavailability of sorbed P have been evaluated. Two of the promising materials have been exposed to water spiked with KH₂PO₄ in order to P saturate the materials. Once the material was P saturated, a mesocosm experiment using corn and the material as a fertilizer was established, and results is currently being analysed to determine if the P bound to the material was bioavailable for plant uptake.

Results from the column experiments, the filters at the wastewater facilities and experiment with bioavailable P is still under preparation, but this technology may promote a more circular nutrient cycle in decentralized wastewater treatment systems, by linking nutrient removal closer to recovery and reuse of nutrients.

REFERENCES


Optimization of a Pilot Bioacidification Reactor to Increase the Potential for Recovery of Phosphorus from Municipal Wastewater Sludge

S. Kolakovic*, J.M.M. Santos**, M. A. M. Reis***

UCIBIO, REQUIMTE, Department of Chemistry, Faculdade de Ciencias e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
* s.kolakovic@campus.fct.unl.pt; ** jmm.santos@campus.fct.unl.pt; *** amr@fct.unl.pt

Abstract: This work aims to study the impact of different pH levels, organic loading rates and types of sludge on the performance of a pilot bioacidification reactor. This unit process is integrated with the Struvia™ technology to produce brushite or struvite in a new scheme implemented at full-scale conditions within the scope of the PhosForce project. The results achieved demonstrate the potential of using a bioacidification step to release more than 50% of phosphorous (P) from sludge and reduce 30% the content of volatile suspended solids (VSS) at 32°C. The framework developed for the start-up of the reactor and acclimatisation of the acidogenic culture under different operational conditions will enable the replication of the PhosForce scheme to any municipal WWTP.

Keywords: phosphorus recovery; bioacidification; municipal wastewater sludge

INTRODUCTION Phosphorus (P) is a limited resource especially in Europe that imports around 92% of its needs from politically unstable regions like North Africa and Middle East. Due to this reason, legislations (Water News Europe, 2016), (European Sustainable Phosphorus Platform, 2017) in some European countries (Switzerland, Germany) have been obliging large WWTPs to develop and optimise P recovery concepts to be implemented in the following years. The PhosForce project has been working on the scale-up of a novel P recovery process scheme in the WWTP sludge stream, which combines an anaerobic bioacidification reactor and anaerobic digestor with the Struvia technology to produce brushite or struvite at neutral pH. For more details, readers are referred to (Phos-Force project). This work aims to study the impact of different operational conditions on the performance of the bioacidification reactor, which is considered the rate-limiting step of this scheme, to simultaneously increase the efficiencies of hydrolysis, P release and production of volatile-fatty-acids (VFAs).

MATERIAL AND METHODS

Bioacidification pilot reactor operation

A reactor of 150 L with the characteristics shown in Table 1.1 has been operated in semi-continuous mode in the WWTP of Frielas (Lisbon, Portugal). The reactor was inoculated with sludge from the anaerobic digestor of the WWTP and acclimatised for enrichment of acidogenic culture. Whenever the ratio of soluble P per Total P (mg P-PO4/mg TP), VSS reduction (%) and the degree of acidification [g COD VFAs produced/(g COD total-g COD VFAs influent)] are greater than 50%, 30% and 10%, respectively, the organic loading rate (OLR) is increased.

Kinetic studies

A bench reactor of 5 L was inoculated with sludge from the pilot reactor and operated for 20 days in each step of acclimatisation. These tests have two objectives: 1) determine the efficiencies and
kinetics of the parent reactor and 2) study the impact of different pH levels and types of sludge from Frielas WWTP and Schönebeck WWTP (Germany). Table 1 summarises tests parameters.

Table 1.1 Operating conditions of the bioacidification pilot reactor and list of the kinetic studies performed at bench-scale.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Step 1</th>
<th>Step 2</th>
<th>Step 3</th>
<th>Step 4</th>
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<tr>
<td>Type of sludge</td>
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<td></td>
<td></td>
<td></td>
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<td>Fe-based activated sludge (Frielas WWTP)</td>
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<tr>
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<tr>
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<td>3.0</td>
<td>4.0</td>
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Bioacidification Pilot reactor (150 L)

<table>
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<tbody>
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<td>-EBPR activated sludge</td>
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</table>

RESULTS AND TAKE-HOME MESSAGES The results presented in Figure 1.1 demonstrate the potential of using a bioacidification step to release P from sludge. After 26 days of operation, the ratio of soluble P per Total P, P release yield, VSS reduction and the degree of acidification were greater than 70%, 50%, 30% and 10% respectively. The outcomes of this study will enable the replication of the PhosForce scheme to any municipal WWTP and present a viable solution for phosphorus recovery problem.

![Image](image1.png)

Figure 1.1 A) Total P and soluble P in the bioacidification pilot reactor and B) efficiencies of test 1 fed with Fe-based activated sludge and inoculated with sludge from the pilot reactor collected on day 26.

ACKNOWLEDGMENTS This research work is supported by PhosForce – KIC Raw Materials project. Furthermore, authors would like to thank National company Aguas de Tejo, Portugal, for providing sludge inoculum to perform laboratory tests.

REFERENCES
Phos-Force project website: https://eitrawmaterials.eu/project/phosforce/
Adsorption-Desorption Mechanism and Kinetic Study of Synthesized Iron Incorporated Zeolite-A for Phosphate in Aqueous Phase

S. Md*, K.S. Kim**,+

*University of Science and Technology (UST), Daejeon, Rep. of Korea, saifuddin@kict.re.kr
**+, University of Science and Technology (UST), Daejeon, Rep. of Korea, kskim@kict.re.kr

Abstract: Fe-zeolite-A was synthesized using the sol-gel hydrothermal method. SEM, EDS, XRD, XPS, and FT-IR were performed to confirm Fe-zeolite-A synthesis and decipher adsorption and desorption mechanism. Fe-zeolite-A adsorbed/desorbed PO₄³⁻ faster than any other reported material. The XPS peak shift, FT-IR band shift, and intensity change (–OH) confirmed ligand-exchange mechanism. The EDS data, Si-O-Al band shift and intensity change in FT-IR and XPS peak and intensity change proved the involvement of Al in the sorption process. Na⁺ ion got exchanged with H⁺ ion in the aqueous phase. The adsorption data fitted well with the Langmuir isotherm and the pseudo-second-order kinetic model. The amount of PO₄³⁻ adsorbed by the metal ions was 382.296 mg PO₄³⁻/g Fe and 56.296 mg PO₄³⁻/g Al.

Keywords: phosphate; adsorption; mechanism

INTRODUCTION Zeolite-A is an adsorbent with scientific and technological value due to their ability to interact with atoms, ions, and molecules at their outer surfaces besides throughout the inner pores. Phosphate can be removed from water using various forms of iron such as sponge iron, goethite, akaganeite, iron ore and many other iron-based adsorbents. These iron-based adsorbents showed high phosphate adsorption capabilities, but have a longer removal time and HRT. Because of the sharp reduction in the available phosphorus resource, both phosphorus removal and recovery are considered. The mechanism of phosphate desorption by zeolite has not adequately been clarified yet. This paper focuses on the efficiency of the synthesized iron zeolite to adsorb/desorb phosphate, its kinetic study and deciphering the mechanism.

MATERIALS AND METHODS Zeolite-A and Fe-zeolite were synthesized using the sol-gel hydrothermal method. The removal of phosphate from an aqueous solution was performed by adding 2 g PO₄³⁻/L of Z-A and Fe-zeolite-A separately and compared. XRD, SEM, EDS, FTIR and XPS characterization techniques were used to decipher the adsorption-desorption mechanism.

RESULTS AND DISCUSSION The characteristic peak of zeolite-A appeared in both zeolite-A and Fe-zeolite-A. A slight decrease in the intensity of the Fe-zeolite-A XRD peak was observed due to the dispersion of iron. After the adsorption experiment, the surface of zeolite turned from crystalline to amorphous. The SEM image also shows the fresh zeolite to be crystalline whereas phosphate adsorbed and desorbed to rough. The hexahedron shape was still intact. On the basis of EDS, the atomic compositions of both the samples are analysed.

XPS data suggests that the Fe ion got incorporated into the zeolite-A framework in the sites of Si, Al, and Na. The peak shift of Fe-2p and O-1s in the XPS, as well as the band shift and change in intensity in the FT-IR spectra of the zeolite backbone corresponding to –OH bending and stretching confirmed the involvement of ligand exchange mechanism. In the working pH, H₂PO₄⁻ acted as a ligand and formed a surface complex with Fe through OH bond, whereas at alkaline pH it was
desorbed into the solution in the form of HPO$_4^{2-}$. The EDS data, Si–O–Al band shift and intensity change in FT-IR, along with the change in peak and intensity of Al-2p in XPS proved the involvement of Al in adsorption through precipitation and desorption by releasing the free aluminium in the form of AlPO$_4$. As zeolites are more selective to H$^+$ ion, it exchanged its Na$^+$ ion in the phosphoric acid medium due to reaction with acid. It was confirmed by EDS data, XPS peak intensity and constant increase in pH of the solution towards neutralization due to the decrease in H$^+$ ion. In the desorption phase, the H$^+$ ion in the zeolite got exchanged with Na$^+$ due to the addition of adequate NaOH to maintain alkalinity. Amorphicity of the surface generated more active centres for PO$_4^{3-}$ to adsorb and desorb. The Langmuir’s isotherm demonstrated a better fit with correlation coefficient values higher than Freundlich isotherm. In addition, the value of Qm was significantly higher. The adsorption data fit well with the pseudo-second-order kinetic model and referred that the amount of adsorbed depends on the surface area of adsorbent regardless of the concentration.

CONCLUSION Adsorption was carried out by ligand-exchange mechanism and precipitation. The experimental data fitted well in the pseudo-second-order kinetic model. The amount of PO$_4^{3-}$ adsorbed by the metal ions are 382.296 mg PO$_4^{3-}$/g Fe and 56.296 mg PO$_4^{3-}$/g Al. The adsorption rate was found to be 5.216 mg/g Fe∙min and 0.54 mg/g Al∙min.

<table>
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Table 1.1 EDS data of fresh Fe-zeolite-A

Figure 1.1 SEM images of fresh zeolite-A, Fe-zeolite-A and p adsorbed and desorbed Fe-zeolite-A

Figure 1.2 XPS spectra of metal ions in the fresh zeolite-A, fresh Fe zeolite-A and phosphate adsorbed and desorbed Fe-zeolite-A

Figure 1.3 Explains the mechanism behind adsorption and desorption of phosphate from the surface of iron incorporated Fe-zeolite-A zeolite

REFERENCES


Struvite Production by Using Raw Seawater - How to Improve the Economics and Keep the Product Quality?

S. Shaddel *, S.W. Østerhus**

* S. P. Andersens veg 5, 7031 Trondheim, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU) Trondheim, Norway, sina.shaddel@ntnu.no
** S. P. Andersens veg 5, 7031 Trondheim, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU) Trondheim, Norway, stein.w.osterhus@ntnu.no

Abstract: Seawater is an alternative magnesium source which potentially improves the overall economic and environmental footprint of struvite production compared to the use of pure magnesium salts. However, presence of other ions in seawater can reduce the phosphorus recovery potential and the simultaneous precipitation of other compounds may reduce the quality of produced struvite. The objective of this study was to keep the quality of final product and reduce the simultaneous precipitation of other compounds. The thermodynamic equilibrium modelling followed by lab-scale crystallization experiments by using seawater and MgCl₂. The results showed that acceptable phosphorus recovery (80-90%) is achievable by using seawater. Further, the coprecipitation of calcium phosphates was successfully controlled and minimized by optimum selection of reaction pH and seawater volume (i.e. Mg:P and Mg:Ca molar ratios). The experimental results and economic evaluation showed that seawater could be a feasible alternative for pure magnesium sources in struvite production.

Keywords: Phosphorus recovery; struvite; seawater; economics; environmental footprint

The transition towards circular economy and recovery of resources from waste is a prominent action worldwide (Shaddel et al., 2019a). The mineral rocks are the main source for phosphorus, and it is expected that the quality and quantity of them, as the main source of phosphorous, will be reduced in coming decades [2]. However, the recovery of phosphorus from waste streams can reduce the conventional mining and moderate the expected future shortage of phosphate rocks used to produce phosphorus fertilizer (Cordell et al., 2011). Struvite (magnesium ammonium phosphate hexahydrate, MgNH₄PO₄·6H₂O) is a proper compound for P-recovery from wastewater. However, application of pure magnesium source for struvite production (i.e. MgCl₂) may stress the total sustainability and economic feasibility of the process (Shaddel et al., 2019b). The cost of struvite production is mainly influenced by chemical cost, especially the cost of magnesium source that can contribute up to 75% of overall costs. Therefore, a critical challenge for sustainable phosphorus cycle is to make phosphorous recovery economical by using alternative low-cost magnesium sources, while ensuring the quality of final product.

The above-mentioned challenges prompted us to evaluate the feasibility of using seawater as an alternative magnesium source from municipal wastewater. For this purpose, a comparative approach is employed by using seawater and MgCl₂ as magnesium sources and real and synthetic reject water.
The results of this study showed both the potential of seawater as an alternative magnesium source for struvite production and the optimization of operational conditions for enhancing phosphorus recovery and product purity. The minimal reduction of phosphorus recovery by using seawater compared to MgCl₂ indicates the good potential of seawater for struvite production. It was concluded that the coprecipitation of other compounds would not significantly compromise the struvite purity in the final product. The particle size of the obtained crystals was highly dependent on supersaturation (Shaddel et al., 2019c). The presence of suspended solids has not important impact on the phosphorus recovery while they reduce the final product quality by making difficult the separation of final product from suspended solids. According to the economic calculation in this study, the chemical costs for struvite production can be reduced to great extent (30-50 %) by using seawater instead of MgCl₂.

Figure 1.1: A,B) The measured P-recovery in crystallization experiments by seawater and MgCl₂, C) The measured particle size in crystallization experiments by seawater and MgCl₂

Figure 1.2: The XRD spectra of obtained precipitates with MgCl₂ and seawater

Figure 1.3: SEM image of obtained struvite crystals with MgCl₂ and seawater at different experimental conditions (the yellow scale bar is equivalent to 100 µm)

REFERENCES


Role of Iron in Phosphorus Immobilization in a Novel
vUCT-MBR System for Sewage Treatment


*Beijing Key Laboratory for Source Control Technology of Water Pollution, Beijing Forestry University, Beijing 100083, China, xcheng@bjfu.edu.cn
**Water Research Center, School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia

Abstract: An Fe-retrofitted UCT-MBR system was developed to induce in situ crystallization of vivianite (Fe₃(PO₄)₂·8H₂O) for recovering phosphorus (P) from sewage. The transformation of Fe in the system was particularly investigated to clarify its role in immobilizing P. Iron(III) bioreduction was effectively enhanced by establishing a relatively separated sludge phase in the anaerobic chamber. The generated Fe²⁺ and anaerobically released phosphate gave a value of saturation index (SI) for vivianite formation varying around 4, which is within the metastable zone favorable for the crystallization of this mineral. Analyses of the Fe phases indicate that vivianite was the only crystalline mineral detectable in the sludge. The vivianite crystals were able to endure oxygenated environments when being transported with sludge along the chambers with a tendency to accumulate in the MBR chamber as the vigorous aeration likely separated them from sludge flocs.

Keywords: Iron; phosphorus immobilization; vivianite

Phosphorus (P) reserve is depleting fast in supporting the world food production, whereas it has been mined and used with huge inefficiencies. Since most of the P consumed in urban areas ends up in sewage, recovery of sewage-carrying P is expected to be indispensable in future wastewater treatment plants (WWTPs). Phosphate crystallization from P-rich streams in WWTPs was widely studied and also tested in pilot and full scales to generate valuable P products. A particular challenge confronted for this technology is to balance between reward of P products and incurred costs including that for constructing additional facilities (e.g., crystallizers) and increased operating costs (e.g., from chemical dosing).

By mimicking vivianite (Fe₃(PO₄)₂·8H₂O)-involving P immobilization in Fe-rich natural environments (e.g., lake sediments) and some Fe-dosed WWTPs, we developed a retrofitted UCT-MBR system (named as vUCT-MBR), in which Fe(III) was supplemented and its reduction was enhanced for in situ vivianite crystallization to recover P (Figure 1.1). This work investigated the transformation of Fe in the system in order to discuss the role of Fe in immobilizing sewage-P by vUCT-MBR.

As demonstrated by a continuous operation for > 600 d, Fe(III) reduction was effectively enhanced by minimizing the agitation and adding biocarriers in the anaerobic chamber to establish a relatively separated sludge phase. Aqueous Fe²⁺ was observed at mostly 1 – 4 mg/L and, with PO₄-P being released anaerobically, a saturation index (SI) for vivianite formation averaging 4 was maintained in the
anaerobic chamber (Figure 1.2), which was reported to be within the metastable zone for this mineral to crystallize. Vivianite was the dominant crystalline mineral detectable in the sludge and the crystals were able to endure oxygenated environments when being transported within the system with a tendency to accumulate in the MBR chamber as the vigorous aeration likely separated them from sludge flocs (Table 1.1).

Table 1.1 Mössbauer parameters computed from spectrum of activated sludge, recorded at 4.2 K

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<th>Subspectrum</th>
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<th>QS (mm/s)</th>
<th>Hyperfine field (T)</th>
<th>Phase</th>
<th>Contribution (%)</th>
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REFERENCES

Critical Conditions of Struvite Growth and Recovery Using Hydrocyclone in Novel Struvite Crystallization Pilot Plant


* University of Science and Technology KICT school, 283, Goyang-daero, Ilsanseo-gu, Goyang-si, Gyeonggi-do, Republic of Korea, bangnari@gmail.com
** Korea Institute of Civil Engineering and Building Technology, 283, Goyang-daero, Ilsanseo-gu, Goyang-si, Gyeonggi-do, 10223, Republic of Korea, wjkim1@kict.re.kr

Abstract: Struvite crystallization process can recover struvite crystal as valuable slow-release fertilizer from side stream of WWTPs. The purpose of this study was to investigate the critical conditions of struvite growth and recovery in a pilot plant. A novel struvite crystallization pilot plant (10 m³/d) was designed with a feeding system of MgO controlled by a pH controller and a hydrocyclone, and operated for 7 days (42 hours). The average removal efficiencies of PO₄-P, NH₄-N reached to 87.5%, 17.0% respectively. The precipitate from hydrocyclone was sifted by standard sieves and analysed by SEM-EDX and XRD. The weight fraction of 300 – 600 μm precipitate increased gradually from 7 to 74% in 3 days (18 hours). As a result of XRD, the crystalline structure of 150 – 600 μm precipitate was revealed as struvite and peaks of MgO, Mg(OH)₂ and MgCO₃ were not observed. It indicated that the critical conditions to recover struvite from side stream of WWTPs were 3 days (18 hours) of operation period and crystal size larger than 150 μm to be sifted.

Keywords: Struvite; hydrocyclone; crystal growth

INTRODUCTION Struvite (MgNH₄PO₄·6H₂O) crystallization is one of the methods in recovering ammonium nitrogen and phosphate phosphorus from wastewater. For struvite crystallization in side stream, it is necessary to adjust pH 8 – 10 and add magnesium source. MgO can be used for pH adjustment and magnesium source simultaneously. However, although MgO for struvite crystallization has been applied over several years, little attention has been paid to the purity and critical size of struvite crystal to recover.

This paper presents a novel pilot plant of struvite crystallization using a feeding system of MgO, a pH controller and a hydrocyclone. The pH controller maintains the value of pH around 8.25 constantly by controlling the feeding volume of MgO slurry. We recovered struvite crystals every day and demonstrated the growth characteristics of crystal for 7 days (42 hours), and analysed them by SEM-EDX and XRD.

RESULT AND CONCLUSION A struvite crystallization pilot plant (capacity of 10 m³/d) has been installed at ‘I’ WWTP (Gyeonggi province, Korea). The influent was digested sludge filtrate containing 17.8 – 38.9 mg/L of Mg²⁺, 120.3 – 133.8 mg/L of PO₄-P and 251.4 – 315.1 mg/L of NH₄-N typically. The conceptual diagram of the pilot plant was shown in Figure 1.1 and it was operated 6 hours a day for a week. Residual Mg²⁺ concentrations of effluent were 28.4 – 60.9 mg/L. The average removal efficiencies of PO₄-P, NH₄-N reached to 87.5%, 17.0% respectively.

The mixture of reactor was classified by the hydrocyclone for 2 minutes every day; the precipitate from bottom was returned to crystallization reactor as the seeds of
struvite; and it was sifted by standard sieves with mesh size of 75, 150, 300, 600 and 1200 μm. The weight fraction according to sieve sizes were shown in Figures 1.2 and 1.3.

The weight fractions of 300 – 600 μm precipitate increased gradually from 7.3 to 73.7% within 3 days (18 hours) and maintained over 70% consistently. Those of 150 – 300 μm maintained over 40% for 2 days (12 hours) and decreased under 20%. Those of 75 – 150 μm maintained over 40% for 1 day (6 hours) and decreased under 10%. Final precipitates of 75 – 150, 150 – 300 and 300 – 600 μm were analysed by SEM-EDX and XRD (Figures 1.4). As a result of analyses, the precipitates of 150 – 600 μm revealed their orthorhombic crystalline structures of struvite, and peaks of MgO, Mg(OH)₂ and MgCO₃ were not observed. However, the precipitates in the range of 75 – 150 μm showed almost amorphous structures; those would not grow itself but be absorbed onto larger crystals. After 3 days (18 hours), the portion of 300 – 600 μm crystals occupied dominant proportion among the precipitates. When the sizes of crystals grow larger than 150 μm, the crystals with struvite structure become to be formed considerably.

ACKNOWLEDGEMENT  This research was financially supported by Korea Institute of Civil Engineering and Building Technology (KICT), project No. 2019-0151.

REFERENCES
Mathematical Model Application for Phosphorus Removal and Recovery Prediction in Continuous Flow Fixed-Bed Columns


*Instituto de Biologia Experimental e Tecnologia (iBET), Portugal (dfc.dias@fct.unl.pt).
**UCIBIO-REQUIMTE, Department of Chemistry, Faculty of Sciences and Tech. Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal (jmm.santos@campus.fct.unl.pt)
***Water Sciences Institute, Cranfield University, Cranfield, Bedfordshire, MK43 0AL UK (samuela.guida@cranfield.ac.uk, a.soares@cranfield.ac.uk).
**** University of Bologna, Via Zamboni, 33, 40126 Bologna BO, Italy (giorgia.rubertelli2@unibo.it)
*****School of Chemical Engineering, The University of Queensland, St Lucia, QLD, 4072, Australia

Abstract: This work focused on modelling a demonstration scale ion exchange (IEX) process for phosphorus (P) removal and consequent recovery from tertiary wastewater. P was removed by a column packed with a hybrid anion exchanger (HAIX) and regenerated with sodium hydroxide (NaOH). The coefficients of the Thomas model were calibrated and then validated for P removal, while recovery with the NaOH solution was also calibrated and validated. The Thomas model adjusted well to the experimental data. This approach for the model setup can be used as a tool for designing, optimising and ultimately predicting potential P removal and recovery in existing WWTP, therefore estimating the economic advantage of such a process compared with traditional processes as well as revenue of P recovery.

Keywords: Phosphorus removal and recovery; ion exchange; mathematical modelling.

INTRODUCTION Ion exchange (IEX) adsorption columns are an excellent means to remove nutrients for tertiary treatment instead of resource hungry treatment units (e.g. biological). The ion exchange media has high affinity to remove the ions from the wastewater, that can then be recovered, therefore gaining economical value when compared with traditional methods (Martin et al., 2009). Dynamic adsorption occurs when a solution continuously flows through a fixed packed column (open system) filled with the adsorbent media (Xu et al., 2013). Modelling of breakthrough and saturation curves is important to describe experimental data and predict behaviour. Nevertheless, the mathematical complexity behind some models make them impractical, as a range of parameters are required from different experiments (Trgo et al., 2011). Consequently, different empirical models have been suggested.

This study aims at applying the empirical Thomas model (Thomas, 1944) to describe P removal from tertiary wastewater (WW) on a fixed-bed of a hybrid anion exchanger (HAIX). P Recovery was based on an empirical model. Calibration and validation were performed with 1 year of data.

METHODS Experimental research was conducted at Cranfield University with a demonstration scale ion exchange process. The column (93.9 cm) was filled with 25 kg
of HAIX and treated 10 m³.d⁻¹ of tertiary WW. It was regenerated with NaOH prior to recommencing treatment. The Thomas model is shown in Eq. 1.1 (C): Effluent concentration (mg.ml⁻¹); C₀; Influent concentration (mg.ml⁻¹); kₜh; Thomas constant (ml.min⁻¹.mg⁻¹); q₀; Maximum adsorption capacity (mg.g⁻¹); m: Media mass (g); Q: Flow rate (ml.min⁻¹); t: time (mins)). The model was calibrated with autosampler data (30 min sampling intervals) and validated with data with from seven months of continuous sampling (less points per cycle). P mass in the regenerant after column regeneration is shown in Eq. 1.2 – P_recovery. P in the regenerant (g); P_sim: P simulated in the column; k and y: coefficient.

\[
\frac{C}{C_0} = \frac{1}{1+e^{(k_{th}q_0/m)C_0(t)}}
\]

\[
P_{\text{recovery}} = k_{th}P_{\text{sim}}
\]

RESULTS AND DISCUSSION Calibration with varying C₀ and t resulted in a pair of kₜh and q₀ coefficients from each run (independent data), presenting excellent fitting (Table 1.1 – partial result set shown due to page limitations). Applying the average model parameters (Fig. 1.1 (A)) in the model allowed to validate it with continuous sampling data. The area above the curves in Fig. 1.1 (A) (average, 95% confidence interval (CI)) represents the mass of P removed in the column, where the calibrated model can predict P removal with good accuracy (Table 1.1 – P_obs vs P_sim). Fig. 1.1 (B) and (C) represents the model validation of cycle 13 for continuous sampling, while the P_recovery (calibration) model predicts most of the observed P in the regenerant (P_{NaOH}) within the 95% confidence interval, respectively. P_sim was overestimated compared to P_{NaOH} (not all recoverable), therefore the coefficients in Eq. 1.2 were calibrated to represent the simulation of P_recovery in the regenerant (Fig. 1.1 (C)). MTZ depends on the BT, with lower times resulting in greater MTZs and consequently greater column saturation, independently of C₀ (Table 1.1).

### Table 1.1 P column operating conditions, model parameters, model fitting and breakthrough (BT) curve parameters.

<table>
<thead>
<tr>
<th>AS run</th>
<th>Operating conditions</th>
<th>Model parameters</th>
<th>BT curve parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C₀ (mg.l⁻¹)</td>
<td>Run (min)</td>
<td>P (g) NaOH</td>
</tr>
<tr>
<td>2</td>
<td>5.73</td>
<td>1260</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>5.08</td>
<td>900</td>
<td>29.0</td>
</tr>
<tr>
<td>7</td>
<td>5.51</td>
<td>2580</td>
<td>35.2</td>
</tr>
<tr>
<td>10</td>
<td>5.28</td>
<td>1080</td>
<td>22.3</td>
</tr>
<tr>
<td>11</td>
<td>5.33</td>
<td>1200</td>
<td>30.7</td>
</tr>
<tr>
<td>16</td>
<td>4.91</td>
<td>1245</td>
<td>34.7</td>
</tr>
<tr>
<td>17</td>
<td>5.27</td>
<td>1125</td>
<td>33.3</td>
</tr>
<tr>
<td>Mean</td>
<td>5.30</td>
<td>1281</td>
<td>-</td>
</tr>
</tbody>
</table>

P_{obs}: P recovery observed in NaOH; P_{rec}: P removal calculated from observed data; P_{sim}: P removal calculated from model simulation with average coefficients; RMSE: Root Mean Square Error; MTZ: Mass transfer zone; BT: Breakthrough time 5% C₀.

**Figure 1.1** (A) Calibrated P curve with average values (C₀, kₜh, q₀); (B) Validated cycle 13; (C) P_recovery calibrated.

The Thomas model was calibrated with success with experimental data from a continuous flow fixed-bed HAIX column removing P from tertiary WW. P recovery range broadens when P_sim increases (Figure 1.1 (C)), therefore the model for longer columns (more media) will increase its confidence interval. This study shows that the
Thomas model calibrated with a multitude of runs, with a 95% CI, is a useful tool when designing, optimising and ultimately predicting P removal. Therefore, the coverage properties for the models estimating P removal from WW and potential P\textit{recovery} in NaOH are improved, opposed to calibrating one single run or not considering a CI.

**ACKNOWLEDGMENT** This work was supported by ‘SMART-Plant’ Innovation Action that has received funding from the Europe Union’s Horizon 2020 research and innovation programme under grant agreement No 690323.

**REFERENCES**


Cometabolic Production of Unusual Poly-β-Hydroxyalkanoates using Enhanced Biological Phosphorus Removal Process in Sequencing Batch Reactors

C. Le*, L. Wang**, Y. Zhou***

*Advanced Environmental Biotechnology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, Singapore 637141, Singapore; ccle@ntu.edu.sg
** Interdisciplinary Graduate School, Nanyang Technological University, 21 Nanyang Link, Singapore 637371, Singapore; WANG1176@e.ntu.edu.sg
*** School of Civil and Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore; ZhouYan@ntu.edu.sg

Abstract: Poly-β-hydroxyalkanoates (PHAs), a family of biodegradable polyesters that intracellularly synthesized by a wide range of bacteria as a reserve of carbon and energy, have gained global attention as sustainable alternatives to petroleum-based material. In this study, we employed different carbon substrates (acetate, propionate, butyrate and valerate) on the enhanced biological phosphorus removal (EBPR) biomass developed with either acetate or propionate as the sole carbon source to biosynthesize PHAs under the cometabolic condition. Using gas chromatography-mass spectrometer (GCMS), three unusual PHA monomers were discovered qualitatively and quantitatively in addition to other known monomers. This paper, for the first time, demonstrated the metabolic complexity and flexibility of non-axenic cultures in sequencing batch reactors to produce many novel high-value-added polyesters.

Keywords: Cometabolism; enhanced biological phosphorus removal; poly-β-hydroxyalkanoate

Polyhydroxybutyrate (PHB) was the first PHA to be identified as a storage compound in Bacillus megaterium in 1926 (Lemoigne, 1926), it remained as the only known constituent of bacterial PHA until other hydroxyalkanoic acid (HA) monomers were discovered in different axenic cultures. It was also only recently by directed investigations, which mainly used the feeding of precursor substrates that exhibited structures related to the constituents revealed an overwhelming and unexpectedly significant number of new HA as constituents (Steinbuchel, 2001). The expanding diversity further contributes to PHAs' enormous ranges of applications in various sectors from consumable goods to the medical field due to their broad range of structural, thermal and mechanical properties (Li et al., 2016). Furthermore, PHAs present a considerable replacement potential over conventional petrochemical plastics due to its inherent biodegradability. The production of PHAs from various microorganisms including wild type and engineered bacteria thus has been extensively investigated (Lee, 1996).

In the last few decades, study has been mainly focused on the development of alternative production processes aiming to decrease the cost. One such option is the utilisation of cost-effective and sustainable open mixed microbial culture (MMC). The possibility of operating MMCs for PHA production derives from the ability of bacteria to store PHA in periods of excess external carbon as energy reserves. Several systems have then been engineered to select for PHA accumulating MMCs. EBPR is
one of these promising technologies because it can treat wastewater with high carbon and phosphorus concentration, and acclimated to accumulate PHA and polyphosphate for potential recovery simultaneously. Additionally, sludge reduction was achieved, and the costs for PHA production and sludge disposal were subsequently decreased.

Among the researches focused on the PHA recovery from EBPR systems, numerous studies have carried out to examine the PHA accumulation potential and their response on the different type of carbon substrates for polyphosphate-accumulating organisms (PAOs). There is, however, limited attention paid to the type of volatile fatty acids (VFA) and their effect on PHA accumulation under cometabolic condition. At the same time, it is crucial to examine the metabolic process of glycogen accumulating organisms (GAOs), a competitive microbial coexist with PAOs in EBPR system, and their response on the PHA accumulation using various VFAs as carbon sources.

Thus, in this study, we employed different carbon substrates [acetate (C2), propionate (C3), butyrate (C4), valerate (C5) and their isomers (Iso-C4 and Iso-C5)] singly or in combination on the EBPR biomass developed with either acetate or propionate as the sole carbon source to biosynthesise PHAs under the cometabolic condition in SBR. Derivatised monomers of vital PHA fraction were determined both qualitatively and quantitatively using GCMS.

Table 1.1 Production of various PHAs by biomass developed with either acetate or propionate as the sole carbon source fed with various substrates singly or in mixed substrate

<table>
<thead>
<tr>
<th>PHA</th>
<th>Single substrate</th>
<th>Mixed substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td>3HB</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>3HV</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>3H2MV</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>3H4MV</td>
<td>○</td>
<td>●</td>
</tr>
<tr>
<td>3HHx</td>
<td>●</td>
<td>○</td>
</tr>
<tr>
<td>3H2MHHx</td>
<td>●</td>
<td>○</td>
</tr>
</tbody>
</table>

Note: ● PHAs that were produced by biomass developed with C2; ○ PHAs that were produced by biomass developed with C3

Table 1.1 shows the different PHA monomers that were qualitatively and quantitatively determined by GCMS for each substrate. Two most common monomer units detected were hydroxybutyrate (HB) and 3-hydroxy-2-methylvalerate (3H2MV). It is noteworthy that three unusual monomers [3-hydroxy-4-methylvalerate (3H4MV), 3-hydroxyhexanoate (3HHx) and 3-hydroxy-2-methylhexanoate (3H2MHHx)] were produced only when butyrate or its isomers were used as the substrate. Their presence was also confirmed when mixed substrates were used.

In conclusion, cometabolism opens up new biosynthesis route to ‘tailor design’ new functional polyesters. These distinctive methyl-branched monomers not only can offer unique biomaterials properties; they also constitute a new class of non-natural PHAs.

REFERENCES


Monday, 9th September 2019

Session 3

VALUE ADDED PRODUCTS AND BIOPOLYMERS RECOVERY
From Research to Full Scale Practice in Biopolymers Recovery

Rene Rozendal
PAQUES BV, The Netherlands

Abstract: It is crucial to highlight the complexities involved when trying to bring scientific discoveries to full-scale implementation, particularly in the field of resource recovery. His experiences include scaling up the production of PHA from wastewater, but also “lessons learned” from other resource recovery technologies (e.g., methane, sulphur, metals).

Keywords: Biopolymers; resource recovery; scale-up
Self-extinguishing Property of Biopolymers Recovered from Waste Aerobic Granular Sludge


*Mechanical Engineering Department, University of Auckland, Auckland, New Zealand, nam.kim@auckland.ac.nz
**Department of Biotechnology, Delft University of Technology, Delft, the Netherlands, Yuemei.lin@tudelft.nl

Abstract: To convert waste sludge in municipal wastewater treatment plant into a resource and contribute to a circular economy, new biobased flame resistant material was developed by recovering biopolymers from aerobic granular sludge. The self-extinguishing property of the recovered biopolymer has been evaluated by following ISO and Federal Aviation standard tests. The biopolymer achieved self-extinguishment under severe heat radiation and after direct flame application due to its protein based structure.

Keywords: Extracellular biopolymer; aerobic granular sludge; flammability

INTRODUCTION Wastewater treatment is widely implemented to protect the environment and recover clean water. The main problem is the large amounts of waste sludge that is generated which needs further disposal. From a circular economy point of view, wastewater treatment should be combined with producing resources from the waste compounds in the sewage. A novel biological wastewater treatment process using granular sludge has emerged as new standard for sewage treatment. It stimulates micro-organisms to form granular biofilms (called “granules”) rather than the traditional flocs in the process. It was found that a significant amount of biopolymers can be recovered from aerobic granular sludge, i.e. about 25% of granular sludge dry weight. Therefore, there is great potential to use this biopolymer as a resource for developing high performance bio-based new materials and contribute to a circular economy. In this research, the self-extinguishing property of the recovered biopolymer has been evaluated by following ISO and Federal Aviation standard tests, to prove its potential as the fire resistant biomaterial.

MATERIAL AND METHODS Aerobic granular sludge was collected from the municipal wastewater treatment plants in the Netherlands. The biopolymer was extracted according to (Lin et al. 2018). To make the biopolymer into a foam, biopolymer water solution (3% w/v, 300 ml) was put into an aluminium mold (25 cm×25 cm×10 cm) and freeze-dried for 72 h. Biopolymer water solution (3% w/v, 300ml) was also sprayed evenly on pieces of flax fabrics by using a chromatography sprayer and dried at ambient temperature and humidity for 72 h.

Chemical structures of the biopolymers were identified by IR-Prestige-21 spectrometer. Moreover, weight loss of the biopolymers with temperature increase was measured by thermogravimetric analyser TGA-50 to investigate thermal
decomposition. In order to investigate flammability of the biopolymers, a cone calorimeter was selected to measure fire reaction properties, such as peak heat release rate and total heat release, under 50 kW/m² heat flux. Test procedure was followed by ISO 5660. In addition, 60 s and 12 s Bunsen vertical burn tests according to Federal Aviation Regulation were carried out to observe burning behaviour of the biopolymer foam and flax fabrics coated by the polymer, respectively.

RESULTS AND DISCUSSION The FTIR spectrum of the biopolymer is shown in Fig. 1. A broad band at 3700 – 3100 cm⁻¹ with peak value at 3280 cm⁻¹ is assigned to hydroxyl group (–OH); a peak at 1630 cm⁻¹, indicating the dominant protein secondary structure is beta sheet; a band at 1200-940 cm⁻¹ with the peak value at 1080 cm⁻¹, implying that there are both carbohydrates and PO₄³⁻ group. The spectrum is similar with the composite of silk I + hydroxyapatite (71.39% of similarity) (Fig.1.1).

The solid residue of 37.4 % remains after the heating temperature reaches 850 °C, which is higher than those of wool (24.1 %) and ammonium polyphosphate flame retardant (29 %) (Kim et al., 2018). 60 s vertical burn test of the biopolymer showed immediate self-extinguishment after the flame removal. Furthermore, the flax fabric coated by the biopolymer substance demonstrated the self-extinguishment without any drips and afterglow, which reaches to Federal Aviation standard for flame resistant material.

CONCLUSIONS The extracellular biopolymer foam, which has successfully been produced from aerobic granular sludge, showed the effective char formation due to its specific protein secondary structure. Furthermore, the excellent self-extinguishing behaviour of the flax fabric with biopolymer coating suggested that the biopolymer recovered from the waste sludge has great potential to be applied as flame resistant bio-based materials in aviation.

REFERENCES

Abstract: This work reports the results obtained by the long-term operation of the Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR) system at demonstration scale. The system consisted on the production of volatile fatty acids (VFAs) by mesophilic (37°C) acidogenic fermentation from cellulosic primary sludge by means of raw wastewater sieving at 350 µm. On the other hand, the process accomplished the partial ammonia oxidation of anaerobic reject water at relatively high nitrogen loading rate (vNLR 1.5 kgN/m³ d) and a PHA-driven denitrification by means of aerobic-feast and anoxic-famine regime. The overall nitrogen removal achieved was 85% while the selected biomass was able to accumulate up to 56% of PHA, which resulted to an overall production of 1-1.2 kgPHA/capita per year.

Keywords: Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR), PHA, biological nitrogen removal; external carbon source; Horizon 2020 – Smart-Plant

The world population growth leads to inevitable increase of wastewater being produced with increasingly energy consumption and Greenhouse Gas (GHGs) emitted for its treatment and reclamation (Cakir & Stenstrom, 2005). According with the new strategies of the EU to deliver circular bioeconomy, the new challenges for the water sector represents the sustainable conversion of the current wastewater treatment plant (WWTPs) into biorefineries for bio-based resource recovery. Recent studies demonstrated the potential benefits of combined recovery of added value products such as cellulose (Ghasimi et al., 2016), nutrients, organic building blocks (like, Short Chain Fatty Acids, SCFA) (Crutchik et al., 2018, Longo et al., 2015) and polyhydroxyalkanoates (PHAs) from the wastewater treatment (Frison et al., 2015). On the other hand, the Innovation Action Horizon 2020 – Smart-Plant aimed the scale-up of the PHAs production combined with the short-cut nitrogen removal from reject water at demonstration scale in Carbonera WWTP (Treviso, Italy). The main steps involved in the SCEPPHAR system were:

1) Pre-concentration of municipal wastewater through the sieving at 350 µm and recovery of cellulosic primary sludge (CPS) accomplished by a rotating belt dynamic filter (RBDF) (type SF1000 Salsnes Filter, Norway);
2) Controlled fermentation of CPS at 37°C in a sequencing batch fermentation reactor (SBFR) with a working volume 2.6 m³ to produce VFAs. The fermentation liquid (FL) containing VFAs was recovered by a solid/liquid separation using a ceramic membrane;
3) Struvite crystallizer with a working volume of 50 litres where Mg(OH)₂ is added to enhance the crystallization;
4) Ammonia oxidation via-nitrite from the anaerobic supernatant in a 1.5 m³ sequencing batch reactor (N-SBR). The SRT was maintained at 15-20 days;
5) Selection of PHA storing biomass by feast/famine regime in a 2.9 m³ Sequencing Batch Reactor (S-SBR) under aerobic/anoxic conditions. The applied SRT was maintained at around 5 days;
6) PHA accumulation in the biomass-cells was carried out in a 1 m³ SBR, where up to 5-8 pulse-addition of VFAs were accomplished in 5-6 hours.

The fermentation liquid (FL) had a SCFA concentration of 8-12 gCOD/L where ammonia and phosphate were released up to 283 mgN-NH₄/L and 68 mgP-PO₄/L respectively. The via-nitrite pathway in the N-SBR was fully achieved operating at around 25°C, vNLR of 1.5 kgN/m³d and 25 days of SRT. The resulted specific ammonium oxidation rate (sAUR) was 20 mgN/gMLVSS h. By shorten the SRT at 15 days, the sAUR was improved (up to 25 mgN/gMLVSS h) but the treatment capacity of the system decreased to 1.2 kgN/m³d with 85% of ammonia oxidation efficiency.

![Figure 1.1](image)

**Figure 1.1** a) SF1000 Salsnes Filter; b) Fermentation unit; c) Membrane, crystallizer, Nitritation SBR, Selection SBR, Accumulation SBR)

The S-SBR operated at SRT of 5-7 days, vNLR ranged between 0.50 - 0.54 kgN/m³ d, while the denitritation efficiency was higher than 85%. VFAs were added at the beginning of the cycle according with a COD/N ratio of 2.5-3.0 gCOD/gN. The carbon source was initially acetate solution and later the FL was used.

The higher actual COD/N resulted by the acetate during the accumulation (around 50 gCOD/gN) determined higher PHA storage yield (up to 0.60 gPHACOD/gVFACOD) and polymer content in the biomass reached the 56 ± 6% of volatile fraction. When FL was replaced the PHA storage yield reduced to 0.41-0.62 gPHACOD/gCOD anyway the PHA was constituted by a co-polymer of hydroxybutyrate (HB) and hydroxyvalerate (HV). The average performances of accumulation batches were reported in Table 1.1.

<table>
<thead>
<tr>
<th>Carbon source</th>
<th>PHA content % PHA/VSS</th>
<th>Storage yield (gPHACOD/gCOD)</th>
<th>PHA productivity (kgPHA/m³ reactor)</th>
<th>HV % (HV/PHA w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetate</td>
<td>56 ± 6 %</td>
<td>0.51 ± 0.13</td>
<td>1.3 ± 0.2</td>
<td>nd.</td>
</tr>
<tr>
<td>FL</td>
<td>42 ± 19 %</td>
<td>0.49 ±0.11</td>
<td>0.8 ± 0.2</td>
<td>42 ± 19 %</td>
</tr>
</tbody>
</table>

According with the findings obtained during the long-term period, the potential PHA production capacity of the SCEPPHAR process accounted for 1-1.2 kgPHA/capita per year.

**REFERENCES**


Producing Polyhydroxyalkanoates in HRAP Retrofitted for Wastewater Treatment with Phototrophic Purple Bacteria

J.C. Fradinho*, J. Almeida*, E. Serrano**, A. Oehmen*,†, E. Lara**, M.A.M. Reis*

* UCIBIO-REQUIMTE, Department of Chemistry, Faculty of Sciences and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal (j.fradinho@campus.fct.unl.pt)
** FCC Servicios Ciudadanos, Av. del Camino de Santiago, 40, edificio 3, 4ª planta, 28050 Madrid, Spain (ELaraC@fcc.es)
† Present address: School of Chemical Engineering, University of Queensland, Brisbane, QLD, 4072, Australia

Abstract: Phototrophic mixed cultures (PMCs) were recently proposed as new microbial systems for polyhydroxyalkanoates (PHA) production. These cultures are enriched in phototrophic purple bacteria (PPB) that can obtain energy from light and therefore, do not require aeration to accumulate PHA, leading to more cost-effective PHA producing systems. The present work evaluated for the first time the possibility of retrofitting already existing High Rate Algae Ponds (HRAP) used for wastewater treatment, adapting their operation for PHA production with PPB, under local outdoor conditions. By operating the ponds under a carbon feast and famine strategy, the initial algae culture was successfully converted into a PMC enriched in PHA producing PPB. The first results at demonstration scale showed that the culture could attain up to 30% PHA/VSS content, indicating that PHA can be produced under natural illumination conditions in outdoor systems while treating real wastewater.

Keywords: Polyhydroxyalkanoates (PHA); phototrophic purple bacteria (PPB); demonstration scale

With the goal of decreasing PHA production costs, phototrophic mixed cultures (PMC) have been proposed as new PHA producing systems. Under illuminated conditions and in the presence of volatile fatty acids (VFA), these systems become enriched in phototrophic purple bacteria (PPB) that can obtain energy from light and therefore, do not require aeration to produce PHA [1]. Currently, PMC are being studied under the Horizon 2020 European project INCOVER. This project is run at demonstration scale and aims to retrofit High Rate Algae Ponds (HRAP) for PHA production and determination of the advantages of using already installed facilities and replacing the currently used algae communities by PHA producing phototrophic bacterial communities.

To do so, domestic wastewater from El Torno Wastewater treatment plant in Chiclana (pre-treated with sand screening, oil/grease removal and sieved in 1 mm rotary filter) was mixed with molasses residues (0.5% molasses in wastewater) and fermented in demonstration scale anaerobic reactors (20 m³ UASB) to obtain a VFA rich stream. This effluent was fed to two HRAP operated at El Torno retrofitted for PHA production (total 64 m² of illuminated surface and working volume of 19 m³). Both ponds were operated under a feast and famine strategy with the feast phase occurring during the day time and the famine phase occurring during the night. During the day the ponds were fed with the UASB effluent and were illuminated with natural sunlight (anaerobic light phase). During the night the ponds were aerated
(aerobic dark phase). The ponds were subjected to the typical variability in illumination and temperature conditions experienced at Chiclana.

Results indicated that the fermentation in the UASB of the 0.5% molasses in wastewater led to an effluent mostly composed of valeric acid (46%), butyric acid (25%), ethanol (10%), acetic acid (11%) and propionic acid (8%). By feeding this VFA rich stream to the ponds it was possible to convert the initial algae culture into PMCs enriched in PHA accumulating purple bacteria (Fig. 1.1).

During the 2018 summer campaign, the ponds achieved a stable operation, being attained a PHA content of 30% PHA/VSS (Fig. 2).

Fig. 1.2 indicates that PHA production occurs during the day time when the sunlight availability enables PPB to take up organic acids and accumulate them as PHA. At the end of this stage, part of the biomass is harvested and directed for polymer extraction. Afterwards, in the night, the pond is aerated which allows the consumption of PHA by the remaining bacteria, establishing a feast and famine profile that promotes the continuous selection of PHA storing bacteria. In this new phototrophic process, the high costs with aeration that typically occur in aerobic mixed cultures during the feast phase are eliminated and only minimal aeration is required during the famine/night phase. These results indicate that phototrophic mixed cultures can lead to a more cost-effective and environmentally sustainable PHA production process.

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REFERENCES
An Urban Biorefinery for Food Waste and Biological Sludge Conversion into Polyhydroxyalkanoates and Biogas


*Department of Environmental Sciences, Informatics and Statistics, University Ca’ Foscari of Venice, Via Torino 155, 30172 Venice Mestre, Italy, giulia.moretto@unive.it
**Department of Chemistry, “La Sapienza” University of Rome, P.le Aldo Moro 5, 00185, Rome, Italy
***Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134, Verona, Italy

Abstract: This study deals with the implementation of an urban biorefinery technology chain in the Treviso municipality territorial context (70,000 PE). Added-value bioproducts (i.e. polyhydroxyalkanoates, PHA) and bioenergy production have been assessed from the mixture of the two most representative urban waste streams: the organic fraction of municipal solid waste (OFMSW) and the biological waste activated sludge (WAS).

Keywords: Urban Organic Waste; Biorefinery; Bio-products; Polyhydroxyalkanoates.

This study focuses on the application of the concept of circular economy, where added-value marketable products and energy are created from organic waste and environmental impacts are minimized (Demichelis et al., 2018). Within this purpose, an urban biorefinery technology chain has been developed at pilot scale in the territorial context of the Treviso municipality (northeast Italy) for the production of biopolymers (polyhydroxyalkanoates, PHA) and biogas from waste of urban origin. The highly efficient waste separate collection (87.9% on total waste, ISPRA, 2017) ensures a high quality OFMSW, which is sent to mechanical pre-treatment with a screw-press for the separation of the liquid squeezed stream from the solid one. The liquid part (15-20% TS) is sent to anaerobic co-digestion (ACoD) with WAS at the Treviso full scale WWTP (70,000 PE) for biogas production only.

The piloting system (100-380 L) comprised the following units: a) acidogenic fermentation for volatile fatty acids (VFA) production; b) two solid/liquid separation steps by means of a centrifuge and a tubular ultrafiltration membrane; c) Sequencing Batch Reactor (SBR) for PHA-storing biomass production; d) fed-batch PHA accumulation reactor; e) ACoD unit for biogas production from the residual bio-waste and excess WAS (Figure 1.1). The squeezed OFMSW and WAS were mixed in a volumetric fractions of 30-35% and 65-70% respectively. The acidogenic fermentation was conducted after a preliminary thermal pre-treatment (72°C, 48 h), in batch mode (5 days) under mesophilic conditions (37°C). The thermal pre-treatment favored a high substrate solubilization, enhancing VFA production, with an overall yield in the range of 0.41-0.44 g COD$_{VFA}$/g VS$_{Fed}$. Moreover, the pH maintained itself between 5.0-5.5 since the acidification process was balanced by the WAS buffering capacity. This allowed obtaining a VFA level around 30 g COD$_{VFA}$/L and a high COD$_{VFA}$/COD$_{SOL}$ ratio (0.84 ± 0.02) in the fermented liquid phase. This pivotal
feature enhanced the PHA-storing biomass selection in SBR by reducing the growth of non-storing microbial population. Under fully aerobic feast-famine regime, the selection reactor was continuously operated for more than 8 months at OLR range 3.2-4.0 g COD/L d, and short HRT (1 day, equal to SRT). The selected biomass was able to accumulate up to 60% g PHA/g VSS. An overall production yield of 107 g PHA/kg VS was estimated. The mesophilic ACoD process (HRT 13-14 days, OLR 2-2.5 kg VS/m³ d) allowed recovering biogas from the solid-rich overflows with a specific gas production (SGP) of 0.4 m³/kg VS. The scaled-up version (70,000 PE) of the present pilot biorefinery is characterized by a production of 114 tons PHA/year, 2314 m³ biogas/d and 5.9 MWh/d of electrical energy. Compared to the actual ACoD scenario, this scheme can be more profitable, provided that an efficient strategy for polymer recovery/purification is applied. The resolution of this bottleneck, together with a detailed market exploitation can easily overcome the economic loss from that fraction of biogas not produced in the biorefinery, being part of the initial COD diverted to biopolymer synthesis and not fully used for biogas production.

**Figure 1.1** Pilot scale bio-refinery developed at Treviso WWTP.

The application of a biorefinery technology chain in which two added-value products were obtained (PHA and biogas) was fully examined and assessed. The integration of different organic waste treatment allowed reducing environmental problems associated with their traditional disposal while valorizing them and generating marketable products and energy.

**REFERENCES**


Combined Wastewater Treatment and Bioflocculant Recovery


*Wetsus – Centre of Excellence for Sustainable Water Technology, Leeuwarden, The Netherlands
(E-mail: victor.ajao@wetsus.nl; hardy.temmink@wetsus.nl)

**Sub-department of Environmental Technology, Wageningen University and Research, Wageningen, The Netherlands
(E-mail: harry.bruning@wur.nl; huub.rijnaarts@wur.nl)

Abstract: Here, we demonstrate the recovery and use of extracellular polymeric substances (EPS) from industrial wastewater as effective and eco-friendly flocculants. In this study, EPS were produced and extracted from two bioreactors, respectively treating fresh and saline wastewater. Increasing the carbon/nitrogen ratio (applying nitrogen limitation strategy) in the fresh and saline reactors enhanced EPS recovery (g EPS-COD/g COD influent) from 4 and 9 % (at COD/N 5) to 54 and 36 % (COD/N 100), respectively. These natural flocculants showed high flocculation performances (>75 % turbidity removal and a maximum of 92 %) using (saline) kaolin clay suspension as a model to mimic saline and non-saline (waste) water.

Keywords: Biodegradable flocculants; extracellular polymeric substances; wastewater valorisation

INTRODUCTION Bioflocculants, due to their eco-friendliness, have gained increasing attention as promising alternatives to oil-based synthetic flocculants which suffer slow biodegradability and may cause harmful pollution (Salehizadeh and Yan, 2014). One of the less harnessed bioflocculants are microbial EPS. These are biopolymers (typically polysaccharides and proteins) formed by microbial biochemical secretion. More often than not, single-type EPS (usually polysaccharides) are produced by the enrichment of isolated microbial strains (Salehizadeh and Yan, 2014). Although this strategy yields biodegradable polymers, the disadvantage is that axenic conditions are required, and the cultures need to be fed with expensive and unsustainable carbon sources. A more sustainable approach is to utilise microbial mixed cultures from wastewater to produce mixed-EPS as cheap and eco-friendly flocculants.

In this study, we aimed at maximising EPS recovery from fresh and saline industrial wastewater (with simultaneous wastewater treatment) via nitrogen limitation strategies. The effect of carbon/nitrogen (in form of COD/N) ratio was investigated on the yield, properties, and application of EPS as bioflocculants.

MATERIALS AND METHODS Two lab-scale submerged membrane bioreactors, MBRs (3.3 L each) were operated in parallel under freshwater (FW) and saline (Sal, 30 g/L NaCl) conditions, fed with glycerol and ethanol as carbon sources (1 gCOD/L) to mimic biodiesel and bio(ethanol) wastewater, NH₄Cl as main nitrogen source and other nutrients (P, K, Ca, Mg). MBRs were operated at a solids retention time of 3 days and COD/N ratios of 5, 20, 60 and 100. Soluble (S) and bound (B) EPS fractions
were extracted from waste sludge by centrifugation and using a cation exchange resin
(Ajao et al., 2018), purified by dialysis, and flocculation tests were carried out with
lyophilised EPS. Kaolin clay suspension was used to model wastewater (since both
possess net negative surface charges) to investigate flocculation potential of the
different EPS fractions. This was done in a jar test flocculation unit and the
supernatants’ turbidity were determined using a turbidimeter measured in
Nephelometric Turbidity Unit (NTU). Flocculation efficiency was calculated as:
\[ \text{NTU}_{\text{control}} - \text{NTU}_{\text{test}} / \text{NTU}_{\text{control}} \] 

RESULTS AND DISCUSSION
High COD removal efficiencies (94 - 96 %) were
achieved at the operated COD/N ratios, signifying the negligible effect of nitrogen
limitation on the COD removal. Remarkably, nitrogen limitation enhanced EPS
recovery to a maximum of 54 and 36 % at COD/N 100 under freshwater and saline
conditions, respectively (Figure 1.1). Microorganisms are able to spill excess energy
for synthesis of secondary metabolites such as EPS (Russell, 2007). This excess
energy under nitrogen-limited condition is converted to extracellular polymers,
especially polysaccharides (60-70 wt%), possibly as a means to store carbon under
unbalanced carbon to nitrogen ratios (Flemming and Wingender, 2010).

Moreover, higher molecular weight EPS were produced under nitrogen-limited
condition compared to EPS from nitrogen-rich source (result not shown),
demonstrating that nitrogen limitation also stimulates microorganisms to build longer
chain biopolymers compared to the nitrogen-rich counterparts.

The high molecular weight of these EPS coupled with their charged nature (Ajao et
al., 2018) make them attractive polyelectrolytes for particle removal from (waste)
water. Flocculation tests with kaolin clay reveal that EPS produced from both fresh
and saline wastewater at COD/N 100 showed better flocculation performances than
the corresponding EPS at COD/N 20 (Figure 1.2).

The high recovery and flocculation efficiencies (84 - 90 %) at such a high COD/N
ratio give an interesting benefit for wastewater treatment plants to combine biological
industrial wastewater treatment with the production of effective natural flocculants,
thereby saving (energy) costs, and contributing to a circular economy.

References
Ajao, V., Bruning, H., Rijnaarts, H., Temmink, H., 2018. Natural flocculants from fresh and saline
Biotechnol. 13, 1–11.
Adv. 32, 1506–1522.
Rapid and Selective (Electro)Catalytic Removal and Recovery of Sulfide from Wastewater

N. Sergienko*, J. Radjenovic**
* Catalan Institute for Water Research (ICRA), 17003 Girona, Spain, nsergienko@icra.cat
** Catalan Institute for Water Research (ICRA), 17003 Girona, Spain, jradjenovic@icra.cat

Abstract: Sulfide is recognized as a major problem in municipal and industrial wastewater treatment and collection systems due to its toxicity, malodour and biogenic corrosion. Here we propose a low-cost in situ method for sulfide removal using electrochemical cell equipped with MnOx-coated electrodes, which not only allows robust sulfide oxidation to sulfur, but also enables sulfur recovery in the form of concentrated sulfide solution and complete separation from the wastewater. Sulfide removal mainly occurs due to catalytic reaction between MnOx and sulfide ion. Anodic polarization of the material not only slightly enhances the process performance, but enables continuous regeneration of the MnOx after the oxidation of sulfide. Sulfur deposited at the electrode could be easily recovered by cathodic polarization of the loaded material, which helps to avoid material passivation without affecting stability of MnOx coating and yields a concentrated sulfide solution.

Keywords: Sulfide removal, sulfur recovery, manganese

INTRODUCTION Removal of hydrogen sulfide from wastewater is a major concern because it is toxic and highly corrosive. For example, only in Germany the costs of concrete sewers replacement due to corrosion by H2S was estimated at €100 millions (Romanova et al., 2014). Taking into account the increasing pressure to incorporate principles of sustainability in wastewater treatment, traditional sulfide control by dosing nitrate, oxygen or alkali needs to be reconsidered and improved in terms of reducing operational costs and enabling resource recovery. Electrochemical treatment is an autonomous, chemical-free technology that can fulfill all these requirements (Pikaar et al., 2015). Electrochemical sulfide removal by anodic oxidation to sulfur requires extremely low applied potentials, and thus has low energy consumption, and offers the possibility of value-added chemicals recovery such as hydrogen and sulfur (Adewale et al., 2016). Carbon based electrodes have been widely used for selective sulfide oxidation to sulfur at high coloumbic efficiency (Ateya et al., 2007). Nevertheless, complete recovery of sulfur from carbon electrodes is difficult to achieve, and observed rates of sulfide removal are rather slow.

In this study, we developed a novel MnOx-coated porous, flow-through electrode. MnOx was electrodeposited on graphite felt (GF) as conductive and low-cost material with high surface area. MnSO4 precursor solution (0.02-0.2 M) with added surfactant Triton X-100 was used for electrodeposition at a constant potential of 1.4 V vs Ag/AgCl. Subsequent calcination at 500 °C enabled the formation of crystalline Mn3O4 oxide coating, which was subjected to structural and morphological analyses.

RESULTS AND DISCUSSION Excellent catalytic properties of MnOx coating towards sulfide oxidation to sulfur were obvious from the results from the open circuit (OC) experiments conducted without applying the current/potential (Figure 1.1). The
reaction between MnOx and 2ulphide ion was instantaneous and the observed sulphide removal rates were enhanced 25 times compared to pristine GF. Further optimization of the MnOx coating showed that higher concentrations of precursor MnSO4 solution yielded a coating of higher porosity and higher surface area (Figure 1.2), and thus superior (electro)catalytic activity towards sulfide oxidation. XRD showed that calcination made amorphous MnOx coating more crystalline, which also had positive impact on sulfide oxidation. Nevertheless, subsequent cycles of sulfide removal at the MnOx-coated GF showed a slow deactivation of the material due to depletion of manganese sites available for catalytical reaction. Application of low anode potentials (0.2-0.4 V vs Ag/AgCl) yielded similar sulfide oxidation rates to the ones observed in the OC experiments. However, anodic polarization of MnOx-coated electrode enabled a continuous recovery of the Mn oxide active sites and thus avoided material deactivation observed in the absence of potential.

MnOx-coated electrodes were able to achieve selective oxidation of sulfide to sulfur. Cathodic polarization (i.e., -1 – (-1.5) V vs Ag/AgCl) was successfully applied to recover the deposited sulfur by reducing it back to sulfide, and at the same time regenerate the surface of the MnOx-coated electrode.

**CONCLUSIONS**
This study demonstrates for the first time an exceptional potential of the MnOx-coated electrodes for sulfide removal, and more importantly sulfur recovery from wastewater due to their excellent (electro)catalytic activity, electrochemical stability and selectivity towards sulfur as the final oxidation product. Due to facile and reversible transition between different Mn oxidation states, MnOx coating exhibited excellent stability under electrode polarity reversal, which ensured cathodic dissolution of the deposited sulfur and its recovery in the form of concentrated sulfide solution. The observed energy consumption in laboratory batch reactors was only 10 Wh/m3. Current efforts are focused on the technology scale-up to a flow-through continuously operated pilot-scale reactor.

**REFERENCES**


Sulfur Recovery in Biomethane Upgrading Plant

O. Burzi*, D. Scaglione**, D.A. Ravezzani***, L. Pedrazzi****

* Suez Trattamento Acque SpA, Via Benigno Crespi 57, Milano, ottavia.burzi@suez.com
** CAP Holding SpA, Via del mulino 2 – Edificio U10, Assago (Mi), davide.scaglione@gruppocap.it
*** Suez Trattamento Acque SpA, Via Benigno Crespi 57, Milano, davide.ravezzani@suez.com
**** Suez Trattamento Acque SpA, Via Benigno Crespi 57, Milano, luca.pedrazzi@suez.com

Abstract: Sulfur is an essential element for life, in the form of organosulfur compounds or metal sulfides. It is one of the core chemical elements needed for biochemical functioning and an essential macronutrient for all living organisms. Sulfur deficiency has become widespread in many countries in Europe: its importance and future scarcity encouraged the development of an idea for its recovery in the biogas treatment line through a chemical H2S oxidation with biological regeneration of the solution. The main project driver is the resource recovery: transforming a waste into a product, a potential issue/problem into a new resource/opportunity. The possibility to recover sulfur can be exploited in almost every biogas treatment line once the presented technology for desulfurization is implemented.

Keywords: Biomethane; circular economy; desulfurization; fertilizer; recovery; sulfur

1. H2S removal technology for subsequent treatment in a biogas upgrading plant

The importance of a strong and reliable H2S removal is essential when a valorization system of the biogas is placed downstream in the biogas line. The principle of the analyzed desulfurization technology is chemical H2S oxidation with biological regeneration of the solution. The process takes place in a weak alkaline environment and NaOH dosing is therefore foreseen. In practice, biogas enters a scrubber column filled with supports media where the washing solution (mainly containing Fe3+) drives H2S to HS−. The liquid phase is recovered from the bottom of the tower and sent to the biological reactor where air injection allows the oxidation of the Fe2+ back to Fe3+ thus regenerating the washing solution. Process control is performed through pH and redox measurement. The mixture is then sent to the settler where a stability agent is added to enhance the separation of the elemental sulfur. Other byproducts of the process in the discharge are sulfur salts and NaCl. This type of desulfurization and therefore the potential sulfur recovery are independent from any treatment step placed downstream.

2. The idea and its development

The separation of elemental sulfur from the washing solution is performed in the settler in order to recover and recirculate the solution to the oxidation tower. This regeneration allows operational savings because it reduces the need for dosing an additional solution, it contextually avoids a significant amount of exhaust solution to go to disposal and it therefore reduces the amount of wastes produced in the wastewater treatment plant.
Moreover, it allows to reduce the NaOH consumption whose precipitates should easily clog the filling elements of the column causing operational issues and high request for maintenance. The separation is very efficient because the elemental sulfur resulting from the oxidation of H₂S settles fast due to its almost solid nature.

When observing the phenomenon and taking care of the generated wastewater, the intense yellow color and apparent purity of the “discharged” sulfur gave us the idea to try and find a valorization pattern for this by-product. The idea was to generate a final product starting from a pollutant, thus having a closed loop that is perfectly aligned with a concept of circular economy.

This kind of recovery of sulfur does not require any material nor energy input, thus constituting a complete “zero impact” process.

3. The implementation: Bresso WWTP case study

Bresso WWTP was built in 1991 and it has a capacity of 200000 PE. The sludge line is provided with anaerobic digestion and CAP Holding - the operator - decided to add a biogas upgrading treatment through membranes in order to produce biomethane. Suez won the design & build Tender and the plant start-up was performed in March 2019. Bresso is the first WWTP in Italy that produces and delivers biomethane to the SNAM grid.

The layout of the upgrading plant is the following: the biogas produced in the anaerobic digestion process undergoes a first biological desulfurization stage in order to remove H₂S and a subsequent activated carbon step to remove primarily VOC and siloxanes. Both processes are meant to protect polyimide membranes from occlusion thus increasing their lifetime. Filtration is performed in three steps and the process is adjusted in real time according to biogas inlet characteristics, thus allowing an efficiency (expressed as percentage of methane) higher than 99.5 %. The scheme of the plant is shown in Figure 1.

According to the design data, the elemental sulfur from H₂S oxidation that can be valorized in agriculture is 90% of the total sulfur contained in biogas. Considering that the guaranteed operating hours of the desulfurization technology are 8000 h/year, in the case of Bresso WWTP that potentially makes 5.9 kg of elemental sulfur recovered per day. CAP Holding contacted the Consorzio Agrario di Cremona in order to obtain the specification of the sulfur to be valorized in agriculture. The only
requirement is a minimum 40% in weight of sulfur thus complying with the national fertilizer legislation for the “sulfur in aqueous suspension” and this has therefore become the target for the project. Since June 2018 CAP Holding has been listed in the national register of the fertilizer producers.

The goal of the experimentation was to achieve enhanced settling performances without adding any kind of compound in order to have a product as pure as possible and not to create any operational costs for its recovery. A study on the settling velocity was performed and as a consequence the discharge timer was set to achieve the maximum amount of elemental sulfur.

4. Possible market and application

The Consorzio Agrario di Cremona is just one of the possible Clients for the recovered sulfur: since fertilizers containing sulfur are more and more used and becoming more costly, many farmers and small producers might be interested in this alternative nutritive element. The high level of purity achieved allows this sulfur to be suitable for human consumption.

At the time being the main project driver is the resource recovery: transforming a waste into a product, a potential issue/problem into a new resource/opportunity. The market value of this product, that of course is essential for any business plan, is something continuously evolving in parallel with legislation and stakeholders.

5. Further development

The growing need of sulfur in agriculture makes it also valuable a more simple recovery such as driving the waste liquid stream directly on the centrifuge thus increasing the fertilizing power of the sludge that is destined to agriculture.

The possibility to recover sulfur can be exploited in almost every biogas treatment line if the presented technology for desulfurization is implemented. A specific study should be carried out case by case. The number of biogas plants has been constantly increasing in the last 20 years along with the innovative biogas upgrading technologies: as a consequence, the need for removing H\textsubscript{2}S to higher and higher extent has a key role in those plant exploitation. This idea has almost zero costs and it is a good example of implementing a full material recovery technology in a WWTP.

REFERENCES


Salt and Humic Substances Recovery as a Solution to Anion Exchange Brine Management

E. Vaudevire*, I. Daniel**, J. Post***, W. van der Meer****

*Dijkweg 1, 1619HA Andijk, evaudevire@pwnt.com
**itd21@bath.ac.uk
***Jan.Post@wetsus.nl
****walter.van.der.meer@oasen.nl

Abstract: This paper highlights the main discoveries from six years of R&D effort toward developing a treatment solution for a waste brine from a drinking water plant using anion exchange for NOM removal. Due to the nature of NOM in the brine i.e. humic (HA) and fulvic acid (FA), which find a number of applications in the agriculture industry, their recovery as a secondary product was assessed on pilot scale; in addition to the recovery of monovalent salts for onsite recycling. The research considers the technologies for secondary product extraction, the potential application of HA and FA as well as the regulatory quality requirements.

Keywords: Brine management, humic substances recovery, salt recycling

The implementation of new technologies in the drinking water industry forces the utilities to adapt to dealing with unfamiliar kinds of waste streams. This has been the case in Andijk (the NL) after the construction of a novel anion exchange plant for direct treatment of the IJssel lake water. The technology uses anion exchange resin beads in suspension for the adsorption of low molecular weight aquatic NOM, and regenerates them with a sodium chloride solution, which after use turns into a NOM rich effluent brine to dispose of (Galjaard and Koreman, 2015). This brine is characterized by a high conductivity due to left over sodium chloride along with inorganic anions from the surface water (NO₃, SO₄, HCO₃) and colour due to the specific fraction of NOM adsorbed: the humic (HA) and fulvic (FA) acids or together referred to as humic substances (HS); which restricts the use of many conventional discharge sites. A temporary arrangement was made to inject the brine to deep aquifer onsite; however, an extended research program was started to improve the sustainability of the plant through separation of compounds and creation of secondary products for reuse onsite or in circular economies. This paper summarises six years of the ongoing R&D effort aiming at:

- Assessing on pilot scale the technologies applicable to brine treatment in view of salts and HS separation and recovery.
- Exploring potential industrial applications for the HS extracted from the brine and their quality requirements.

In this three-part research, the first challenges consists in exploring the technological options for the separation of: 1) the monovalent ions dominated with NaCl to be
recycled in the resin regeneration, from 2) the NOM and among which the HS, which
can serve in several industrial applications, and 3) the multivalent salts which have so
far been seen as disposable but could be re-employed as well. Results from the
technologies assessment carried out on pilot scale has favoured the use of
electrodialysis (ED) with monovalent selective membranes over nanofiltration (NF) for
the recovery of NaCl. For similar separation properties (table 1), ED offered the
recovery of concentrated salts and a superior resistance to organic fouling. For the
recovery of NOM however, ED with standard membranes faced several issues related
to water passage and osmosis forces, which hampered demineralization. In addition,
market studies carried out regarding potential industrial applications of the HS
comprised in the brine highlighted the need for a more refined product that could be
directly incorporated in existing formulas of, for example, animal feed products or a
crops bio-stimulant. This resulted in the development of an extraction column using
scavenger resin to extract specifically HA and FA at low inorganic contamination (table
1). The second challenge is proving the efficiency of the recovered secondary products
for a given application. Characterization on lab scale highlighted a few key properties
of the HS molecules. Cultivation trials carried out on basil and potato crops with the
addition of HS purified with ED indicated an improved growth at lower dosages but
depending on soil, a detrimental effect could be observed above 50 mg HS /L soil. This
was attributed to the insufficient removal of sodium feasible with ED. The improved
quality of HS obtained with elution over the scavenger resin are not only expected to
perform better in aiding crop growth, but opened new trial possibilities as a piglet diet
supplement. The third technical step before the certification of HS extracted from the
brine under feed supplement or bio stimulants regulations requires looking at the levels
of trace pollutants (Vaudevire et al., 2019). Heavy metals lead, arsenic, mercury,
cadmium and iron are particularly on the watch. While the last three were not present
in the HS solution above the regulatory limits, arsenic and lead reduction strategies
were investigated with ED, ion exchange resin, activated alumina or softening pellets.

Table 1.1: Impression of secondary products obtained using NF, ED, scavenger resin in g/L (influent brine quality
varies)

<table>
<thead>
<tr>
<th></th>
<th>Na</th>
<th>Cl</th>
<th>SO₄</th>
<th>HCO₃</th>
<th>NO₃</th>
<th>NOM</th>
<th>usage</th>
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<tr>
<td>NF perm</td>
<td>12</td>
<td>16</td>
<td>0.4</td>
<td>3.8</td>
<td>0.013</td>
<td>0.012</td>
<td>resin regeneration</td>
</tr>
<tr>
<td>ED₁ conc</td>
<td>24</td>
<td>30</td>
<td>0.4</td>
<td>9</td>
<td>0.4</td>
<td>0.01</td>
<td>resin regeneration</td>
</tr>
<tr>
<td>ED₂ dilu</td>
<td>0.8</td>
<td>0.02</td>
<td>0.65</td>
<td>0.5</td>
<td>-</td>
<td>0.47</td>
<td>not defined</td>
</tr>
<tr>
<td>col eluate</td>
<td>0.4</td>
<td>0.02</td>
<td>0.2</td>
<td>-</td>
<td>-</td>
<td>3.3</td>
<td>commercial application</td>
</tr>
</tbody>
</table>

At the current state, further process and product development are still required to
transform HS into a valuable secondary product on large scale. However, this research
has highlighted the potential for resources recovery from a low quality source like the
anion exchange brine as well as the double benefit of creating solution for waste
management.

REFERENCES


Vaudevire, E., Radmanesh, F., Kolkman, A., Vughs, D., Cornelissen, E., Post, J., van der Meer, W., 2019. Fate and
removal of trace pollutants from an anion exchange spent brine during the recovery process of natural organic matter
Biotechnological Removal of $\text{H}_2\text{S}$ Under Haloalkaline Conditions

K. Kiragosyan, J.B.M. Klok, P. Roman, A.J.H. Janssen
Wetsus, European Centre of Excellence for Sustainable Water Technology, Oostergoweg 9, 8911 MA Leeuwarden, the Netherlands, karine.kiragosyan@wetsus.nl

Abstract: Removal of sulfur containing compounds from sour gas streams plays a crucial role in environmental protection by decreasing sulfur dioxide emissions into the atmosphere. Among all available desulfurization technologies, biological processes are the most sustainable technologies for hydrogen sulfide removal. Besides $\text{H}_2\text{S}$, sour gas streams can contain volatile organic sulfur compounds, such as thiols. Both organic and inorganic sulfur compounds are toxic, characterized with the obnoxious smell and potential corrosive effects. A recent pilot study showed that with the addition of anaerobic bioreactor sulfur selectivity increased and the process did not abrupt with thiols addition. The added anaerobic bioreactor enabled selective pressure for sulfide oxidizing bacteria which are able to oxidize sulfide more efficiently. However, further insight into the underlining processes is required to fully understand work of newly proposed line-up.

Keywords: Biodesulfurization; sour gas; sulfur recovery; sulfur-oxidizing bacteria
FAMEs, Estolides and Methyl-10-Hydroxystearate: Sewage Sludge as Possible Source of Biodiesel and Bio-lubricants of New Generation

L. di Bitonto*, S. Todisco**, V. Gallo**, C. Pastore*†‡
†CNR-IRSA, Water Research Institute, via De Blasio 5, 70132, Bari, IT
‡DICATECh, Dipartimento di Ingegneria Civile, Ambientale, del Territorio, Edile e di Chimica, Politecnico di Bari, via Orabona, 4 – 70125 Bari
*Email Address: carlo.pastore@ba.irsa.cnr.it

Abstract: In this work, a detailed characterization of the lipid component of sewage scum and primary sludge was reported. Samples up-taken from several wastewater treatment plants (WWTPs) were processed, and lipids were efficiently extracted, recovered and analysed. The most important component were found to be free fatty acids (FFAs, 75-80%wt), whereas glycerides (mono-, di- and triglycerides) resulted almost absents. Besides FFAs, estolides and 10-hydroxystearic acid were also identified and quantified. Extracted lipids were reacted with methanol through a direct esterification process, allowing the complete conversion of starting FFAs into fatty acid methyl esters (FAMEs, yield > 99%) under very mild conditions (345 K, 6h) to be obtained. At the end, pure FAMEs can be efficiently separated from estolides and methyl-10-hydroxystearate through a vacuum distillation, definitively completing the valorisation of the overall separated lipid phase.

Keywords: Biodiesel; estolides; (R)-10-Hydroxystearic acid; sewage sludge valorization,

INTRODUCTION Production of Fatty Acid Methyl Esters (FAMEs), namely biodiesel, will remain one of the main important European targets in terms of renewables in transport fuels for the next 2020. In order to limit the use of renewables which have a high environmental impact, alternative sources, such as waste cooking oils or animal fats have been more and more privileged. Sewage scum and primary sludge can be considered innovative sources of biodiesel, that respect the criteria of sustainability. In addition, 10-hydroxystearic acid and estolides were also found therein, which could represent valid bioderived and biodegradable alternatives to conventional fossil lubricant (Isbell et al., 1992).

![Figure 1.1. 10-Hydroxystearic acid and Estolides.](image)
Nowadays, the annual European demand of lubricants is around 5 Mt, and fortunately most of this is actually recoverable, while 1.5 Mt/year needs to be replaced and manufactured, since lost. In addition, the use of bioderived and biodegradable lubricants could represent a key aspect for an environmental concern.

The obtainment of biodiesel from sewage scum and primary sludge was already investigated or converting lipids preliminarily extracted with organic solvents (Yi et al., 2016) or directly reacting sewage scum with sulphuric acid and methanol (Bi et al., 2015). But all these approaches produce a contamination of the starting sewage scum, by generating a new waste wet of organics, or mineral acid or both. On the other side, valorisation of sewage sludge addressed to the obtainment of bio-lubricants, actually has never been reported.

RESULTS AND DISCUSSION In this work, lipids recovered from sewage scum without adding any solvents and neither acids (di Bitonto et al., 2016) were reacted with AlCl₃·6H₂O and methanol by adopting the optimized condition for direct esterification (Pastore et al., 2015). A vacuum distillation allowed FAMEs, estolides and methyl-10-hydroxystearate to be efficiently separated and selectively recovered. The reactive conditions to convert methyl estolides into FAMEs and methyl-10-hydroxystearate through a catalysed methanolysis were also optimized.

In addition, a deeper investigation was also conducted on the nature of the absolute configuration of the chiral C-10 center of methyl-10-hydroxystearate: diastereomeric derivatization with (S)-1-Phenyl-propyl-isocyanate and GC-FID/NMR analysis of the resultant diastereomers, put in evidence that the “R” isomer resulted the most prevalent species (ee >95 %).

CONCLUSIONS In this work, new clean and sustainable methods are proposed to exploit the potential of the lipid component in sewage scum and primary sludge, by producing biodiesel (FAMEs), bio-lubricants (estolides) and fine chemicals ((R)-methyl-10-hydroxystearate). In detail, according to this study, from sewage sludge, over 2.5 Mton of biodiesel and 0.5 Mton of bio-lubricants can be potentially recovered in an European context, which represent the 50 % and the 30 % of the actual continental demand respectively.

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REFERENCES
Cyrene™ as a New Bioderived Green Solvent for Membrane Preparation

A. Figoli*, T. Marino*, A. Molino**, F. Russo*, F. Galiano*

*Institute on Membrane Technology (CNR-ITM), Rende (Italy)
**Research Centre of Portici (ENEA), Napoli (Italy)

Abstract: In this work, Cyrene™ was used for the first time for the preparation of polyethersulfone (PES) and poly(vinylidene fluoride) (PVDF) membranes via phase inversion technique. The morphology of the membrane could be tailored by varying the exposure time of the nascent film (from 0 to 5 min) to humidity prior immersion in the coagulation bath. Membranes were fully characterised in terms of morphology, thickness, porosity, contact angle, pore size and water permeability. Ultrafiltration and microfiltration membranes were obtained showing the potentiality of this new green solvent for producing membranes for water treatment applications.

Keywords: Cyrene™; green solvents; membranes

The use of toxic and hazardous solvents in the chemical industry poses serious risks for the human health and the whole environment. Moreover, the more and more stringent regulations applied at national and international level limit or ban the use of some specific solvents in order to meet the principles of sustainability (Clarke et al., 2018; Henderson et al., 2011). Membrane processes are regarded as a green and eco-friendly technology able to perform purification and separation operations with lower energy consumption and without the requirement of chemical additives. However, the solvents which are normally employed by the companies for membrane fabrication such as N-Methyl-2-pyrrolidone (NMP), dimethylformamide (DMF) and N,N-dimethyl acetamide (DMA) are not sustainable at all (Figoli et al., 2017; Figoli et al., 2014). In this work, we investigated, for the first time, the possibility of using the new bioderived green solvent Cyrene™ for the preparation of membranes using two of the most common polymers employed for membrane production: PES and PVDF (Marino et al., 2019). Cyrene™ synthesis starts from cellulose and passes through the 1,6-anhydro-3,4-dideoxy-D-glycero-hex-3-enopyranos-2-ulose (or Levoglucosenone) intermediate. The interest of Cyrene™ arises from the fact that its physical-chemical properties are similar than those of NMP, DMF and DMA (solvents normally employed in membrane preparation). However, in comparison to these traditional solvents, Cyrene™ has a good eco-toxicological profile.

Membranes were prepared by using both polymers and combination of vapour induced phase separation (VIPS) and non-solvent induced phase separation (NIPS). By varying the exposure time to the humid environment (from 0 to 5 minutes) different morphologies were obtained. PES membranes exhibited mainly a macrovoid structure while PVDF membranes were principally characterized by a bicontinuous architecture (Figure 1.1). The pore size of PES membranes varied from 0.12 to 0.02
μm, while for PVDF from 0.03 to 0.55 μm. Depending on the polymer used hydrophilic (in case of PES) or hydrophobic (in case of PVDF) membranes were produced finding possible applications in water treatment processes such as MF, UF or membrane distillation. Membrane water permeability was found highly dependent on the preparation conditions adopted. Membranes prepared by VIPS-NIPS (with exposure time higher than 0 min) presented the highest values of permeability as a consequence of their larger pore size. For PVDF membranes, additional DSC and Fourier transform infrared spectroscopy analysis were performed in order to investigated its crystalline form where the presence of both α and β-phase was demonstrated.

The results obtained showed that Cyrene™ can be successfully used for the preparation of polymeric membranes opening new perspectives for a more eco-compatible and sustainable membrane fabrication process.

![Figure 1.1 SEM pictures of cross-section of PES a) and PVDF b) membrane prepared at the same exposure time to humidity (2.3 min)](image)

**REFERENCES**


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Session 4

NUTRIENTS RECOVERY AND REUSE
Nutrient Upcycling from Wastewater Treatment - Technical & Non-Technical Roadmap: From Science to Practice


*maria.albuquerque@veolia.com
**celine.bouchereau@veolia.com
*Veolia R&I; **Veolia Wasser Deutschland GmbH; **** T&P Veolia Environnement SA; ***** Krüger

Abstract: The water utilities sector has witnessed the eve of a paradigm shift from dissipative treatment to resource recovery. Even more broadly, an ecosystemic link exists between water cycle management and agriculture, the later providing a number of ecosystem services (or dyservices) with impact to water cycle and food security. Acutely aware of this link and engaged toward resource recovery, Veolia has developed a comprehensive research and development program that combines disciplines such as process design, systems analysis, simulation, multi-objective optimization, agronomic sciences, economics and social studies aiming at supporting value chain transition strategies and developing decision support tools.

Keywords: Three keywords separated by; semi-colons

Resource recovery from wastewaters has been around for a long time, but in recent years the water utilities sector has witnessed the eve of a paradigm shift from dissipative treatment to resource recovery - with wastewater treatment plants being viewed as “energy positive” – given energy recovery from WWT – and more recently as RRfW (Resource Recovery from Wastewater) facilities able to facilitate the recovery of water, energy and a number of value added components.

Furthermore, it should be noted that water utilities (drinking water production and wastewater treatment) have an ecosystemic link with agriculture and the food supply chain. On one hand – resource recovery from wastewater (and in some cases organic waste treatment) can provide inputs to agriculture and the food supply chain: (i) The #1 resource that can be recovered from WW is water; (ii) By-products from wastewater treatment are intrinsically loaded with nutrients, such as nitrogen and phosphorus, since one of the goals of WW treatment is to remove these from wastewater streams and prevent nutrient pollution to natural water bodies – nutrients which are also a valuable input to agricultural systems. (iii) By-products from wastewater and waste treatment are intrinsically loaded with organic matter, which if appropriately stabilized, can provide stable exogenous organic matter (EOM) to soils, thereby promoting the regulatory functions of soils and improving their water resilience, filtration capacity, climate regulation functions, etc. On the other hand, agricultural soils, provide a number of ecosystem services including food and fibre provision but also climate regulation, water cycle regulation (both flow and pollution regulation), support for biodiversity, etc. Services that can be either enhanced or impaired depending on the type of agricultural practices carried out. Hence, agricultural practices, and in particular fertilization and amendment strategies – can have significant benefits or dysbenefits to water resource protection and water cycle management.
Veolia is both acutely aware of this ecosystemic link between water utilities and agriculture and also fundamentally engaged in reorganizing its water (and waste) treatment routes so has to synergistically couple resource recovery and pollution treatment services from Veolia’s activities and business lines.

This paper intends to describe a comprehensive research program including: (i) the development and characterization of the performance of a number of processes and technologies enabling nutrient (N, P) recovery from WW; (ii) the eco-conception of process lines, and in particular of WWTP process lines, using simulation and multi-objective optimisation able to articulate environmental (reject standards, life cycle analysis), economic (capital cost, operation cost), governance (recovery targets) and agronomic (performance of final product) indicators; (iii) the development of a product-based approach to RR facilities – characterization of product quality and performance from an agronomic standpoint – namely long term field tests have been conducted for over 20 years to develop knowledge on agronomic performance and health & safety impacts of recycled amendments and fertilizers; (iv) the understanding of non-technological levers or barriers to the development of alternative recycled fertilizers and amendments – namely acceptability within farmer communities, as well as new business models and market design aspects regarding nutrient upcycling and water resource protection.

Ultimately the goal of this research and development program is to be able to optimize the recovery and valorisation of all intrinsic value of WWT by-products with regards to agriculture – water, organic and nutrient rich streams -, within a given territory based on resources available from environmental services utilities on one hand and agricultural and energy needs on the other hand. The working group includes a number of entities within the Veolia group including Research & Innovation, Technical & Performance Department, constructor business units such as Krüger and operator business units such as Veolia Wasser Deutschland GmbH, as well as business units involved in valorisation activities such as SEDE Environnement.

This paper is articulated with two other papers – also submitted – that will describe more precisely R&D works on unit operation process development – namely on nitrogen recovery from digestates and phosphorus recovery from sewage sludge or incinerated sewage sludge ashes – and process line conception – using systems analysis, simulation and multi-objective optimization to be able to combine multiple objectives and constraints (reject standards, recovery targets, total cost, environmental performance) to develop decision support tools, namely on how to integrate phosphorus recovery routes on municipal wastewater treatment.

The main focus of the present paper is to highlight the need for a transverse, multi-disciplinary approach to develop successful strategies for nutrient upcycling and also, through concrete case-studies share the practical experience from business units implicated. The combined disciplines and as well as the shared experience between research and practice is helping shape the way toward a global strategy including the following steps: (i) assess potential from different processes and technologies to enable process line and plant optimization; (ii) use simulation and multi-objective optimization (with multiple criteria: environmental, economic, territorial specificities - bridge territorial needs and resources) to optimize process lines and plants; (iii) consider impacts of integrating resource recovery both upstream and downstream of wastewater treatment, and namely being able to anticipate product specifications or even integrate a product based approach to process line development; (iv) integrate business model and market design considerations.
High-solid Thermophilic Anaerobic Digestion with Ammonia and Phosphate Recovery

M. Takashima*, J. Yaguchi**

*Department of Architecture and Civil Engineering, Fukui University of Technology, 3-6-1 Gakuen, Fukui 910-8505, Japan, takasima@fukui-ut.ac.jp
**Department of Industrial Systems Engineering, National Institute of Technology, Hachinohe College, 16-1 Uwanotai, Tamonoki, Hachinohe 039-1192, Japan, yaguchi-z@hachinohe-ct.ac.jp

Abstract: This study investigated high-solid thermophilic anaerobic digestion fed with sewage sludge of 9–10% total solids. Ammonia stripping in a side-stream configuration and selective adsorption by porous iron hydroxide were introduced to digested sludge, respectively, for ammonia and phosphate recovery. The laboratory anaerobic digester performed well at the hydraulic retention time of 20 days and loading rate of 3.96 gVS/L-d, showing VS destruction of 57.8% and gas production of 0.522 NL/gVS. The stripping device was operated batchwise at 70°C and initial pH of 9.0 for 2 hours, recovering 20.7% of influent nitrogen as ammonia and keeping total ammonia to 1,760 mgN/L in digester. Also, 42.3% of influent phosphorus was recovered as phosphate by the selective adsorption, when conducted at the pH of 4–5 for 24 hours. The lower pH was advantageous for saving the amount of cationic polymer added and improving the dewatering characteristics of digested sludge.

Keywords: Ammonia stripping; anaerobic digestion; phosphate adsorption

INTRODUCTION High-solid anaerobic digestion can improve its cost-performance, as digester volume and operating costs are reduced. At higher influent concentrations, however, the metabolites, particularly ammonia, phosphate and carbonate in thermophilic operation, often show adverse effects, such as inhibition to microorganisms, inorganic precipitation in digesters and pipes, and difficulty in dewatering digested sludge. In this study, high-solid thermophilic anaerobic digestion of sewage sludge was investigated at 9–10% influent total solids (TS). The system employed ammonia stripping of digested sludge and its return to digester to alleviate inhibition and recover ammonia, as well as selective adsorption to recover phosphate.

METHODS The experimental system is drawn in Figure 1.1. The anaerobic digester was a completely-mixed type (2.0 L), fed with 9–10% sewage sludge concentrated by centrifugation (approx. 5,000 g, 5 min), and maintained at 55°C, 15 rpm and 20 days hydraulic retention time (HRT). Centrifugal dewatering of digested sludge (1,200 g, 15 min) was conducted with a cationic polymer (KP-201G, Mitsubishi Chemical). Capillary Suction Time (CST; Type 304B, Triton Electronics) and water content of dewatered sludge were measured.

![Figure 1.1 Anaerobic digestion system employed in this study.](image-url)
Ammonia stripping of digested sludge was combined as a side-stream configuration with no alkali added. Once a week, after decarbonisation of digested sludge, the ammonia stripping device (Figure 1.2) was operated batchwise for 2 hours, approximately at 70 °C, initial pH of 9 and a gas flow rate of 12 L/min. The stripped ammonia was absorbed in the bottle with 100 mL of 2 mol/L H2SO4 solution.

For phosphate adsorption, 50 mL of digested sludge was weekly mixed with 4.0 g DW of porous iron hydroxide (Takahashi Metal Industries) at pH 4–5 with HCl for 24 hours. Then, the adsorbent was separated by centrifugation (approx. 600 g, 5 min), and phosphate adsorbed was released with 10 mL of 10% NaOH solution.

RESULTS AND DISCUSSION The experimental results for anaerobic digestion and dewatering are summarized with average values in Table 1.1. The results show VS destruction of 57.8% and gas production of 0.522 NL/gVS at the loading rate of 3.96 gVS/L-d. Therefore, the digester was operated well, even though the loading rate was high for municipal anaerobic digestion. The dewatering of digested sludge was performed at pH 4–5 after the phosphate adsorption. This saved the amount of polymer added, as a cationic polymer is consumed by bicarbonate, and enabled efficient dewatering without using any other dewatering agents.

Prior to the ammonia stripping, decarbonisation of digested sludge was combined, which increased the pH to about 9.0. On average, the total ammonia nitrogen (TAN) concentration in digester was kept at 1,760 mgN/L, which is below the inhibitory levels of 2,000–2,500 mgN/L for thermophilic digestion. The removal of TAN from digested sludge was 53.6%, which corresponds to 20.7% recovery of influent nitrogen as ammonia.

The phosphate adsorption at pH 4-5 for 24 hours was conducted successfully, achieving 220.4% of phosphate removal from digested sludge. This excellent removal efficiency is due to solubilisation of particulate phosphate in digested sludge at the acidic pH, and is equivalent to 42.3% recovery of influent phosphorus as phosphate. The release of phosphate adsorbed was almost complete with 10% NaOH solution. The adsorbent can be repeatedly used after regeneration with a dilute HCl solution. Therefore, this method can be an alternative for direct and selective phosphate recovery from digested sludge.
Pilot scale studies on nutrient and biochar recovery from wastewater and sewage sludge

L., Rossi*, A., Kainulainen**
*Hernepellontie 24, 07100 Helsinki, Finland, laura.rossi@hsy.fi
**Ilmalantori 1, 00240 Helsinki, aino.kainulainen@hsy.fi

Abstract: Wastewaters are a valuable sink of nutrients and other substances. A lot of research has been done to recover these resources more efficiently. Helsinki Region Environmental Services HSY is developing a nutrient recovery process called RAVITA where phosphorus is recovered directly from water phase as its own stream. This gives more flexibility to biological sludge treatment for example through pyrolysis. Furthermore, RAVITA can be combined to nitrogen recovery from reject waters. Products from these processes are phosphoric acid and ammonium phosphate and sludge-derived biochar.

Keywords: biochar; phosphorus recovery, resource recovery

INTRODUCTION Wastewaters contain valuable nutrients and other resources. If these compounds could be recovered more efficiently, unsustainable consumption of natural resources could be decreased and circular economy increased.

Phosphorus is one of the main interests to be recovered from wastewaters because the amount of phosphate rock is becoming scarcer and largest reservoirs are located only in few countries. Nitrogen, on the other hand, is an abundant element and can be recovered from the atmosphere. The drawback is that production of N fertilizers through Haber-Bosch processes is extremely energy intensive and has a high CO2 footprint (Mehta et al. 2015). In addition to nutrients, also carbon recovery from sewage sludge has raised interest. Research has shown that the utilization of pyrogenic organic materials as organic amendments is beneficial in terms of carbon storage as well as soil fertility (Glazer et al., 2002).

Helsinki Region Environmental Services Authority (HSY) has started two projects on nutrient and carbon recovery. The object is to find the most suitable processes for wastewater treatment plants without impairing good treatment results.

RESULTS AND DISCUSSION In 2015, the development work of nutrient recovery process called RAVITA started at HSY. The main idea in RAVITA is to recover phosphorus directly from the water phase by post-precipitation and the formed chemical sludge is processed to phosphoric acid. The process can also be linked to nitrogen recovery from reject waters resulting ammonium phosphate. (Rossi et al., 2019)

Phosphorus recovery part of RAVITA has been developed both in laboratory and pilot scale. A 1000 population equivalent (PE) RAVITA pilot plant is built at Viikinmäki WWTP (1 000 000 PE) and optimization of post-precipitation and
dewatering has been done. Analysis from dewatered chemical sludge have shown that concentrations of trace metals are below miniREC limits (Schenk, 2018) and organic micropollutant concentrations are low as well. In Spring 2020, the whole process will be in pilot scale which will increase the technical readiness level. In addition, more accurate energy and cost calculations can be done.

With the RAVITA process, phosphorus can be recovered more efficiently and as it is recovered as its own stream it gives more flexibility for the biological sludge processing. Since 2015, HSY has also studied novel sludge processing options for biological sewage sludge. Comparison of technologies based on product quality (organic pollutants etc.) and the sustainability of the process (energy consumption, waste and side-streams) revealed pyrolysis as the most suitable process for HSY. The char obtained from pyrolysis is a safe material for soil conditioning and current research focuses on the end use of the sludge-derived biochar as a soil amendment agent. In February 2019 HSY decided to invest in a pilot-scale sludge pyrolysis plant. The capacity of the pilot plant is 3 000 metric tonnes/year of digested and dewatered sludge (TS 30%), which amounts to 10 % of the planned capacity of the possible full-scale plant. The pilot plant should be in operation in 2020.

An optimal solution for nutrient and carbon recycling in wastewater treatment could be obtained by combining the RAVITA process with a subsequent pyrolysis of the sludge (Figure 1.1).

![Figure 1.1. Combination process of RAVITA and sludge pyrolysis.](image)

**REFERENCES**


Fractionating Various Nutrient Ions for Phosphate Recovery from Swine Wastewater Using Selective Electrodialysis


*No. 1799 Jimei Road, Xiamen City, Fujian 361021, China, zlye@iue.ac.cn
**Spoorwegstraat 12, 8200 Brugge, Belgium, boudewijn.meesschaert@kuleuven.be

Abstract: This study aimed to fractionate various nutrient anions and cations in swine wastewater synchronously, including PO$_4^{3-}$, SO$_4^{2-}$, Mg$^{2+}$ and Ca$^{2+}$, into two streams. The recovered streams were further paired together for phosphorus recovery. A novel electrodialysis process was developed by integrating monovalent selective anion and cation exchange membranes into an electrodialysis stack. Results revealed that the separation of nutrient ions was achieved effectively by fractionating PO$_4^{3-}$ and SO$_4^{2-}$ into the anionic product stream, whereas bivalent cations (Mg$^{2+}$ and Ca$^{2+}$) were extracted in the cationic product stream. Further experiments were conducted for phosphorus recovery by pairing the recovered product streams, which revealed that phosphate precipitation could be achieved by using inherent Ca$^{2+}$ and Mg$^{2+}$ in the wastewater without dosing external cation sources.

Keywords: Electrodialysis; Nutrient; Phosphorus recovery

BACKGROUND Recovering phosphorus from livestock wastewater has been regarded as an important mean of retarding the depletion of phosphorus reserves worldwide. However, the recovery efficiency is normally limited, since the phosphate concentrations in the waste streams are not sufficiently high (20-50 mg/L), which subsequently results in much more alkali addition to reach extreme high pH values (Xie et al., 2016). Besides, dosing divalent cation (Mg$^{2+}$ or Ca$^{2+}$) chemicals for phosphate precipitation is another limiting factor, since it may contribute up to 55% of the total costs (Hövelmann et al., 2016). From another point of view, the digestive wastewater contains abundant Ca$^{2+}$ and Mg$^{2+}$ with relatively lower concentrations, which can be used as the potential sources for phosphate precipitation.

In the present study, a novel electrodialysis process was developed by integrating monovalent anionic and cationic exchange membranes into an electrodialysis stack, and was employed for fractionating phosphate and bivalent cations (Mg$^{2+}$ and Ca$^{2+}$) into two different streams synchronously. Furthermore, the two streams were mixed for phosphate precipitation without dosing external bivalent cation sources.

MATERIALS AND METHODS Simulated digestive swine wastewater was referred to previous researches. An electrodialysis stack was constructed by integrating standard cation (PC-SK) and anion (PC-SA) exchange membranes, monovalent selective anion (PC-MVA) and cation (PC-MVK) exchange membranes. The configuration of the stack was shown in Figure 1.1.
RESULTS

Figure 1.2 Concentration variations of PO$_4^{3-}$ and SO$_4^{2-}$ (A) in the anionic product stream, Mg$^{2+}$ and Ca$^{2+}$ (B) in the cationic product stream.

Results revealed (Figure 1.2) that PO$_4^{3-}$ and SO$_4^{2-}$ were effectively fractionated in the anionic product stream, whereas bivalent cations (Mg$^{2+}$ and Ca$^{2+}$) were extracted in the cationic product stream and monovalent cations (K$^+$ and NH$_4^+$) were concentrated in the brine stream. Further experiments were conducted for phosphorus recovery by pairing the anionic and cationic product streams. As shown in Table 1, phosphate precipitation could be achieved by using inherent Ca$^{2+}$ and Mg$^{2+}$ in the wastewater without dosing external cation sources.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>PO$_4^{3-}$ Avr.</th>
<th>Mg Avr.</th>
<th>Ca Avr.</th>
<th>SO$_4^{2-}$ Avr.</th>
<th>P:Ca Molar ratio</th>
<th>Calcium phosphate (%)</th>
<th>Magnesium phosphate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 V</td>
<td>0.76</td>
<td>0.30</td>
<td>0.08</td>
<td>0.93</td>
<td>1:0.40:1.23</td>
<td>75.3%</td>
<td>24.7%</td>
</tr>
<tr>
<td>8 V</td>
<td>0.80</td>
<td>0.20</td>
<td>0.13</td>
<td>1.11</td>
<td>1:0.25:1.38</td>
<td>85.7%</td>
<td>14.3%</td>
</tr>
</tbody>
</table>

* unit of concentration, mmol/g; Avr., average; sd., standard deviation; ND., undetected.

SIGNIFICANCE

This study develops a novel method which can not only concentrate phosphate ion effectively, but also provide a choice of using inherent Ca$^{2+}$ and Mg$^{2+}$ in the wastewater as the cation sources for phosphate recovery.

REFERENCES


Optimised Nutrient Recovery from Biogas Digestate by Solid/Liquid Separation and Membrane Treatment

S. Rosenberger*, T. Gienau**

*Osnabrück University of Applied Sciences, Albrechtstraße 30, 49076 Osnabrück, s.rosenberger@hs-osnabrueck.de
** BASF Polyurethanes GmbH, Elastogranstraße 60, 49448 Lemfoerde, Germany

Abstract: Anaerobic digestion products of agricultural biogas plants are characterised by high nitrogen, phosphorus, and potassium content. In three scale-up steps, a membrane based digestate treatment process of solid-liquid-separation, ultrafiltration, and reverse osmosis for nutrient recovery was investigated. Lab-scale trials delivered a very good understanding of fluid properties and subsequent ultrafiltration performance, which is the limiting process step in terms of energy demand and operation costs. In semi-technical experiments, optimisation, and design parameters were developed, which were subsequently applied to pilot-scale tests at two full-scale biogas plants. The process optimisation resulted in 50 % energy reduction of the ultrafiltration step. About 36 % of the sludge volume was recovered as dischargeable water, 20 % as solid N/P-fertiliser, and 44 % as liquid N/K-fertiliser.

Keywords: Digestate, nutrient recovery, ultrafiltration

Agricultural and biowaste biogas plants produce nutrient rich digestate as side products - in Germany approximately 80 million m³ per year. Recent revisions of the fertiliser ordinance in Germany limit field application of organic residues. This provokes cost intensive transportation and a demand for nutrient recovery. A recent solution for volume reduction and parallel production of liquid and solid fertiliser products is a combination of solid/liquid separation and membrane filtration (Figure 1.1). The process chain shows good treatment results but exhibits high operational costs, which are mainly caused by the ultrafiltration step (Chiumenti et al., 2013; Gienau et al., 2018a).

Ultrafiltration performance of digestate strongly depends on its fluid properties and the feeding regime of the biogas plant (Vaneecckhaute et al., 2017; Gienau et al., 2018b). Fingerprints of the organic digestate fraction (oDM, particle size distribution, LC-OCD, biopolymer concentration, etc.) were taken and related to UF flux. Lab-scale experiments in a filtration cell (0.0033 m², Merck Millipore) revealed a clear dependency between UF flux and sludge supernatant viscosity (Figure 1.2), caused by biopolymer concentration.
Semi-technical experiments with a ceramic UF module (1.32 m², Atech, Germany) were used to optimise operation conditions by altering the fluid properties. I.e. the influence of temperature and pressure changes, crossflow velocity, ozonation, acidification, and enzymes was tested. Changing supernatant viscosity and biopolymer structure significantly increased UF performance. Acidification, for example, resulted in a considerable flux increase due to complex formation of the biopolymers (Figure 1.3).

Based on the semi-technical trials, pilot tests with a screw press separator (agriKomp), a decanter centrifuge (GEA), an ultrafiltration loop (A3 water solutions, membrane modules: 7.3 m³, Atech), and a reverse osmosis unit (A3 water solutions, membrane modules: 137.2 m², DOW) were carried out at two full-scale biogas plants of 1.3 and 2.5 MW. The pilot trials confirmed the promising results of the pre-trials and the energy consumption of the ultrafiltration unit was successfully reduced to 50 %.

The simple set-up of the pilot plant enabled 36 % water recovery and production of high value solid and liquid fertilisers (Figure 1.4). The solid fraction (SPs + DECs) contained mainly phosphorus and nitrate, the liquid fraction (ROs and UFes) mainly potassium and ammonia. In full-scale applications, water recovery can be increased to >50 % by recirculation of UF retentate. The results offer potential for further rollout of membrane-based nutrient recovery.

Figure 1.2 UF flux (lab scale) and supernatant viscosity (Gienau et al., 2018a).

Figure 1.3 UF flux (semi-technical scale) of the reference and acidified samples (Gienau et al., 2018b).

Figure 1.4 left: Mass distribution in a pilot scale plant (without recirculation of UF retentate), middle and right: Cumulated separation efficiencies for ammonia and total nitrogen and for potassium and phosphorus, respectively (Gienau et al., 2018c)

REFERENCES
Nutrient Recovery from the Perspective of the Flemish Wastewater Utility

B. Saerens*, F. Meerburg*, S. Geerts*, M. Weemaes*

*Aquafin NV, Dijkstraat 8, 2630 Aartselaar, [bart.saerens; francis.meerburg; sam.geerts; marjoleine.weemaes]@aquafin.be

Abstract: Aquafin, the Flemish wastewater utility, is keen to contribute to the circular economy and put nutrient recovery to practice. This presentation highlights the situations in Flanders: nutrient flows and recovery potential through municipal wastewater, existing initiatives, cost and life cycle assessment, promising technologies, and possible outlook to further implementation.

Keywords: Nutrient recovery; full-scale implementation; regional strategy

In the last decade there has been a paradigm shift from treating municipal wastewater for safe discharge in the environment to using wastewater for recovering resources. In 2015, the European Commission adopted the Circular Economy Package to make the transition to a circular economy where resources are used in a more sustainable way. One of the key commission proposals is waste-based fertilizers from sewage sludge. Modern agriculture strongly depends on mineral fertilizers containing the plant macronutrients phosphorus (P), nitrogen (N) and potassium (K). These fertilizers depend on geological resources: N fertilizer production needs fossil fuels, and both P and K are obtained by mining. Municipal wastewater is a valuable alternative resource of P, N and K; Recovery would fit perfectly in a circular economy. In Flanders, the Northern part of Belgium, Aquafin is responsible for the municipal wastewater treatment. Operating more than 300 WWTPs and treating the wastewater of more than 5.5 million people, Aquafin has a privileged position to put nutrient recovery to practice. Aquafin has embedded circularity in its corporate social responsibility vision, e.g. in 2030 all Aquafin’s processes have to be fossil fuel free. Implementation of nutrient recovery involves infrastructural changes, which require planning and financing. Not only cost is important, but also the global environmental impact (LCA) and legislation. The drivers for recovery, promising technologies, and possible implications are presented for each macronutrient, from the perspective of a wastewater utility.

Phosphorus is a critical raw material in the EU and phosphate rock is also often contaminated with cadmium and radioactive metals. Regulations for mandatory phosphorus recovery from municipal wastewater already exist in Germany and Switzerland, and are under discussion in Sweden and Austria. Several studies indicate that P-recovery from sludge (liquor) and incinerated sewage sludge ashes (ISSA) are the most interesting with respect to cost and LCA (Amann 2018). Aquafin currently has a full scale struvite plant to recover phosphorus directly from digested sludge (Marchi 2015) and a small demonstration struvite plant on urine. Recovery form sludge (liquor) as struvite has the highest TRL, but the recovery potential is limited to 15% of the influent P. Biological phosphorus removal and anaerobic digestion are
required, a combination that can only be found in a handful WWTPs in Flanders. The recovery potential from the end products of incineration, pyrolysis or gasification is much higher, but requires mono-treatment. Currently, about 1/3 of the Aquafin sludge is mono-incinerated. Maximizing mono-treatment combined with P-recovery seems the most promising route to take, but requires huge investments. P-recovery from sludge can be implemented on sludge that is not used afterwards for mono-treatment, provided bio-P and AD. Almost 4 kton of P enters yearly in the WWTPs in Flanders, which is more than twice the amount that is used for crop production.

Nitrogen is abundant in the atmosphere. Large amounts of nitrogen (100 Mt) are fixed annually by the Haber-Bosch process to produce nitrogen fertilizers, which accounts for 1–2 % of the global energy consumption. The combination of Anammox and Haber-Bosch consumes less energy than N-recovery with air stripping and \((\text{NH}_4\text{)}_2\text{SO}_4\) production (Matassa 2015), but it is expected that emerging technologies will make N-recovery much more energy efficient. Nitrogen removal converts \(\text{NH}_4^+\) to \(\text{N}_2\), but a part is converted to \(\text{N}_2\text{O}\), a very potent greenhouse gas. It is however not very well known how much is converted to \(\text{N}_2\text{O}\). Measurements are scarce and conversion rates up to 25 % are reported. N-recovery on reject waters from the side stream could be an interesting pathway to reduce \(\text{N}_2\text{O}\)-emissions from WWTPs as it lowers the nitrogen load to the main water line. An estimation for the WWTP Antwerp South shows that N-recovery in the side stream could reduce the global warming potential of side stream N-removal by 50 %. N-recovery is not yet an established technology in municipal wastewater treatment. Classic air stripping and steam stripping have the highest TRL, but are not economically feasible in municipal wastewater treatment. Alternatives such as membrane and vacuum stripping are tested at pilot and demo scale in Europe. Aquafin will perform a thorough assessment of the \(\text{N}_2\text{O}\) emissions in both mainstream nitrification/denitrification and sidestream anammox to be able to quantify the impact on global warming. Aquafin will also test N-recovery at pilot and demo scale to increase the TRL level of emerging technologies.

Potassium, also a macronutrient for plants, receives much less attention compared to N and P. This is likely because potassium does not play a role in eutrophication and rarely poses a threat to the environment. While removal of K from soils often exceeds inputs and the global mining needs to double to replace the amount removed by crops, potash reserves (K-ore) are even more limited than phosphate reserves. The potassium ion, \(\text{K}^+\), is highly soluble. From the estimated 10 kton of K that yearly enter the Flemish WWTPs, 95 % will stay in solution and end up in the effluent. Only about 10 % of the incoming K is present in the sludge liquors. The recovery potential thus seems low, but Aquafin will keep abreast of the latest research results and technologies concerning K-recovery.

REFERENCES


Reusable Magnetic Sorbent Materials for Advanced Wastewater Treatment and Nutrient Recovery


* Tallinn University of Technology, Centre for Biorobotics, Akadeemia tee 15A - 111, 12618 Tallinn, Estonia, asya.drenkova-tuhtan@taltech.ee
** University of Stuttgart, Institute for Sanitary Engineering, Water Quality and Solid Waste Management (ISWA), Bandtäle 2, 70569 Stuttgart, Germany
*** Fraunhofer Institute for Silicate Research (ISC), Neunerplatz 2, 97082 Würzburg, Germany
**** Fraunhofer Project Group Materials Recycling and Resource Strategies (IWKS), Brentanostraße 2a, 63755 Alzenau, Germany
***** University of Kaiserslautern, Department of Civil Engineering, Resource Efficient Wastewater Technology, Paul-Ehrlich-Str. 14, 67663 Kaiserslautern, Germany

Abstract: The use of magnetite (Fe₃O₄) seeded sorbent materials for water purification purposes, pollution control and resources recovery is gaining a growing popularity due to the convenience of their ability to be harvested magnetically, regenerated and reused numerous times. Herewith we propose a technology using magnetic carrier particles (5-25 µm) modified with a tailored adsorbent material for the selective and reversible sorption of phosphorus from pre-treated wastewater (reaching ultra-low effluent concentration < 0.05 mg/L total phosphorus) or from other P-rich media (sludge liquor, industrial wastewaters, etc). The engineered micro-sorbents can be extracted magnetically from water, regenerated in an alkaline solution, where P-desorption and enrichment take place, and reused again. The P-rich solution is a source for further recovery of the valuable nutrient, e.g. via precipitation of struvite. Moreover, we are currently developing regenerable magnetic activated carbon as a reusable resource for the elimination and simultaneous degradation of organic micropollutants from wastewater.

Keywords: Magnetic particles / activated carbon; Micropollutants removal; Phosphorus recovery

In the last few years researchers focused on the more holistic approach of using novel regenerable magnetic sorbents not only for the elimination of hazardous pollutants but also for the recovery of valuable substances from wastewater (Ambashta and Sillanpää, 2010; Mandel, 2013). These are typically core-shell composite materials which consist of magnetic carrier particles (usually magnetite Fe₃O₄) coated or functionalized with a custom selective sorbent, similar to the concept proposed in this work for phosphorus recovery from wastewater. Alternatively, conventional sorbent materials for organic micropollutants removal, such as powdered activated carbon, can be seeded with magnetite to facilitate the easier solid-liquid separation of the carbon fraction from the wastewater. However, none of the investigated studies so far demonstrated any larger technical scale tests, nor a successful long-term regeneration and reuse of the magnetic sorbents, which outlines the novelty of this research work.

Phosphorus (P) is an environmental pollutant commonly removed from wastewater, but it is also an irreplaceable key nutrient for agriculture and global food security. Phosphate rock is a finite resource which back in 2014 was declared one of 20 critical raw materials for the European Union. Hence, providing technologies for P-recovery from secondary P-rich waste sources is of critical importance. The current paradigm shift towards circular economy set the goal to develop a sorption-based technology which can simultaneously remove and recover the valuable nutrient from wastewater.
The scheme in Fig. 1.1 shows a conceptual overview of the proposed technology for reversible sorption of phosphorus using nanocomposite magnetic carrier particles (Mandel et al., 2013), modified with a tailored P-selective adsorbent (Schneider et al., 2017; Drenkova-Tuhtan et al. 2016, 2013).

Earlier research demonstrated the successful proof-of-concept through a pilot test with commercial magnetic separators where the removal, enrichment and recovery of phosphorus from 1500 L spiked secondary effluent were carried out within 20 cycles of particles’ regeneration and reuse (Drenkova-Tuhtan et al., 2017). Other P-rich wastewaters with varying composition and different P-species were tested as well, such as industrial membrane concentrates containing phosphonates (Rott et al., 2018), digested sludge liquor, etc. Overall, good treatment efficiency was achieved in all matrices after adjusting accordingly the process parameters. Particles could be regenerated and reused in numerous loading cycles. Phosphorus could be enriched by a factor of at least 20 in the final reclaimed desorption solution, which was then used for the precipitation of struvite crystals with high purity, as shown in Fig. 1.2. The total efficiency of phosphorus recovery was > 90% under optimal conditions.

Figure 1.1 Conceptual scheme of the proposed technology for phosphorus elimination and recovery with composite magnetic sorbent micro-particles and illustration of their facile magnetic separation (within 20 seconds).

Figure 1.2 Chemical composition of the P-enriched reclaimed desorption solution after 20 cycles of magnetic particles’ reuse and optical microscopy images of the struvite crystals precipitated from the P-rich concentrate.
In ongoing research, a similar concept is developed with powdered activated carbon which is magnetized (by seeding with magnetite Fe₃O₄) and used for the elimination of persistent organic pollutants from secondary effluents. In addition, the catalytic properties of Fe₃O₄ can be used in a modified Photo-Fenton oxidation process for the chemical regeneration of the carbon and simultaneous degradation of the pollutants.

ACKNOWLEDGEMENTS
A. Drenkova-Tuhtan acknowledges the “Mobilitas Pluss” program of the Estonian Research Council and the EU Regional Development Fund for the post-doctoral grant.

REFERENCES
Ambashta, R.D. & Sillanpää, M. 2010 Water purification using magnetic assistance: a review. J. Hazard. Mater. 180 (1-3), 38–49. DOI:


Hydrothermal Carbonization (HTC) for the Nutrient and Energy Recovery from Digested Sewage Sludge

A.K. Hämäläinen*, J. Rintala**, M. Kokko, V. Kinnunen***, T. Hilli****

*anna.hamalainen@tuni.fi, Faculty on Engineering and Natural Sciences, Tampere University
**jukka.rintala@tuni.fi, Faculty on Engineering and Natural Sciences, Tampere University
***viljami.kinnunen@gasum.com, Gasum Oy, Espoo Finland
****tuomo.hilli@fifthinnovation.fi, Fifth Innovation Oy, Tampere Finland

Abstract: Digested sewage sludge (DSS) contains valuable nutrients and organic carbon but has limited potential in agriculture due to possible hazardous contaminants originating from wastewater. In this study, the ability of hydrothermal carbonization (HTC) to preserve the nutrients and increase the energy value of DSS was evaluated. The nutrients and solids were characterised from the liquid filtrates and solid hydrochars. It was also studied if the liquid fraction could be fed back to anaerobic digestion. Hydrochar could be combusted for energy recovery, or used as a soil-additive, depending on its fuel properties and nutrient content.

Keywords: HTC; digested sewage sludge; nutrient recovery

Hydrothermal carbonization (HTC) has recently been considered as a valorising conversion technology and management tool for solid waste streams, such as digested sewage sludge (Berge et al. 2011). HTC is a thermal treatment at moderate temperatures of 180 – 350°C (Berge et al. 2011), which can be optimised to attain most feasible level of operational energy consumption and the characteristics of the products (Duman et al. 2014). HTC converts solid biomass into a carbonaceous residue, i.e. hydrochar, that has potential for agricultural purposes as soil additive or for energy generation as bio-coal (Libra et al. 2011, Smith et al. 2018). Aside from hydrochar, HTC generates also a liquid fraction that contains biodegradable material and nutrients, which can be recovered in biogas digestion process (Rubia et al. 2018).

This paper studied the effect of HTC treatment temperatures of 210, 230 and 250°C at a shorter (0.5 hours) and a longer (2 hours) residence times on digested sewage sludge at moisture content of 75%. The treatment was conducted in a two-litre pressure reactor of titanium (Parr®). Solid and liquid fractions were separated with filtration and the solid hydrochar fraction was evaluated based on the fuel properties and nutrient (N and P) concentrations. For the liquid fractions, nutrients and biomethane potential (BMP) in mesophilic conditions were determined.

Preliminary results show that higher temperatures generated liquids with COD (Fig 1.1). The COD and VFA concentrations increased from those of the digested sludge (10.1 g/L and 0.6 g/L COD, respectively) up to 35-45 g/L and 4-12 g/L COD with the HTC conversion. The BMP of the liquids ranged from 120 to 180 L CH4/g SCOD (Fig 1.3), which is 100-200% higher than for the liquid filtrate obtained from an untreated
sewage sludge digestate. The liquid fractions produced with the 250°C-treatment had ca. 30% lower BMP than the liquid fractions produced at lower temperatures.

**Figure 1.1** TVFA/SCOD ratio in the liquid fractions generated by hydrothermal carbonization from sewage sludge digestate 75%. Treatment temperature and retention times varied from 210 to 250°C and from 0.5h to 2h. DW25 = digested and dewatered sewage sludge of 25% total solids.

**Figure 1.2** The distribution of the liquid and hydrochar weight fractions after HTC at different temperatures and residence times. DW25 = digested and dewatered sewage sludge of 25% total solids.

**Figure 1.3** The biomethane potentials (BMP) of the liquid fractions of digested sewage sludge (DSS) after HTC treatment and filtration with 0.5 hours and 2 hours residence times at 210, 230 and 250°C.

The results show the feasibility of the HTC technology in the recovery of energy from digested sewage sludge. Additionally, the potential of this technology as a waste reduction and nutrient valorisation method is evaluated. The solid hydrochar with lower moisture content (ca. 50-65%) compared to digestate (75%) has smaller volumes and lower transportation costs, which enables more economical downstream uses. The liquid fraction could be fed back to the anaerobic digestion for energy and nutrient recovery, providing a complete recovery of resources from sewage sludge.

**REFERENCES**


High Efficiency Phosphorous Recovery and Sewage Sludge Valorization via Hydrothermal Carbonization

M. Volpe*,**,***, L. Marafioti*, L. Fiori*, G. Andreottola*

*Department of Civil, Environmental and Mechanical Engineering, (DICAM) University of Trento, via Mesiano 77, 38123, Trento, Italy;  
**CARBOREM, piazza Manifattura 1, 38068, Rovereto, (TN) Italy.  
*** Department of Civil and Environmental Engineering, University of Enna, viale delle olimpiadi snc, 94100, Enna, Italy;

Abstract: Hydrothermal carbonization (HTC) of sewage sludge was carried out at 190 and 210 °C and 1 or 3 hours of reaction time to investigate phosphorous segregation into the resulting solid residue (hydrochar) and its subsequent recovery via acid leaching and precipitation. HTC treatment has shown to effectively segregate up to 90 wt% phosphorus for HTC carried out at 190 °C 1 h. Acid leaching, using HCl 4 M at room temperature, followed by sodium hydroxide addition (solution at 5 M) up to pH 9.0, led to the formation of phosphate precipitate ensuring a global phosphorous recovery, when considering the starting material, up to 72 wt% dry basis. ICP-OES analysis showed that the concentration of heavy metals like Al, Cd, Fe, Pb, Mn, Zn etc. into the acid leached hydrochar residues were sensibly reduced, making such residues promising materials to be used as fertilizers.

Keywords: Phosphorous recovery, hydrothermal carbonization, fertilizer;

Nowadays, the growing urban population and thus number of new municipal wastewater treatments plants, together with a more stringent legislation on sewage sludge effluent quality have risen the attention on new processes to reduce the quantity and increase the quality of the excess sludge to be disposed (Ferrentino et al., 2016). Recently, it has been reported that thermochemical treatments as hydrothermal carbonization (HTC) could efficiently reduce the volume of the excess sludge thus reducing the environmental risks connected with its disposal while sensibly affecting the company management costs (Wilk et al., 2019). Sewage sludge contains relevant amounts of nutrients like nitrogen and phosphorous. The latter in particular is a critical raw material for Europe and its recovery from such residues will be soon mandatory. This study demonstrates that HTC, while reducing the amount of excess sewage sludge, can efficiently segregate the phosphorous in the solid HTC residue. Hydrochars are actually considerably more hydrophobic than the starting biomasses thus ensuring an easier water removal and thus a considerable reduction of the volume of the excess sludge to be disposed. Table 1.1 reports the mass yields of solid, liquid and gas residues after HTC at different reaction conditions. Results demonstrate that increasing severities led to a considerable reduction of hydrochar mass yields down to approximately 68.5 wt% (210 °C - 3 h). On the contrary, liquid and gas mass yields sensibly increase with the increase of temperature and residence time.
Table 1.1 Mass yields of solid, liquid and gas residues after HTC at different reaction conditions.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Solid mass yield [%]</th>
<th>Liquid mass yield [%]</th>
<th>Gas mass yield [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>190°C-1h</td>
<td>90.5</td>
<td>5.0</td>
<td>4.5</td>
</tr>
<tr>
<td>190°C-3h</td>
<td>76.2</td>
<td>18.5</td>
<td>5.3</td>
</tr>
<tr>
<td>210°C-1h</td>
<td>76.4</td>
<td>17.9</td>
<td>5.7</td>
</tr>
<tr>
<td>210°C-3h</td>
<td>68.5</td>
<td>25.2</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Recovery of phosphorous was obtained via acid leaching of hydrochars and precipitation of phosphate via alkalinisation (5 M NaOH solution). Figure 1.1 reports the percentages of phosphorous recovered in the hydrochars and in the precipitates at different HTC conditions in respect to the starting material. The results demonstrate that by using HTC treatment it is possible to recover more than 70% of the initial phosphorous at relatively mild conditions of 190 °C and residence times between 1 and 3 hours.

ICP-OES analysis of the hydrochars after acid leaching shows the almost complete removal of Al, Cd, Fe, Pb, Mn, Zn metals initially present in the sewage sludge, thus the so obtained hydrochars are promising materials to be used as fertilizer. In summary, this study demonstrates that HTC is a very appealing technique for sewage sludge treatment and upgrading. HTC, while considerably reducing the volumes for disposal, ensures an efficient phosphorous reclamation and produces a material that could find application in agriculture as fertilizer.

REFERENCES


Simultaneous Nitrogen Removal and Phosphorous Recovery in Anoxic and Microaerobic Biofilm Systems


*Department of Civil, Architectural and Environmental Engineering, University of Naples Federico II, Italy
**Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Italy

Abstract: Simultaneous nitrogen and phosphorous removal was investigated in different biofilm systems, i.e. two packed-bed reactors (PBRs) performing autotrophic denitrification via anoxic pyrite oxidation and two moving bed biological reactors (MBBRs) performing simultaneous nitrification denitrification (SND) under different dissolved oxygen (DO) regimes. Nitrogen and phosphorous removal ≥ 80% was observed in pyrite-packed PBRs via chemical precipitation with Fe³⁺ at HRT ≥ 5. SND in a microaerobic MBBR resulted in biological nitrogen and phosphorous removal above 60% and 70%, respectively. Lower nutrient removal efficiencies were obtained in another MBBR alternating anoxic and aerobic conditions.

Keywords: autotrophic denitrification; biofilm systems; nitrogen removal; phosphorous recovery; simultaneous nitrification denitrification.

Domestic, industrial and agricultural activities lead to the discharge of wastewaters containing nitrogen (N) and phosphorous (P), resulting in the eutrophication of waterbodies (Di Capua et al., 2019). Nutrient removal from wastewater is usually accomplished via biological methods, i.e. sequential nitrification and denitrification for nitrogen removal and the anaerobic/anoxic/oxic (A²/O) and University of Cape Town (UCT) processes for combined nitrogen and phosphorous removal (Chen et al., 2015). Nutrient removal from drinking water can be performed using physical-chemical methods such as ion exchange, reverse osmosis and electrodialysis (Pu et al., 2015), although biological methods represent a promising and convenient alternative. Anoxic and microaerobic bioprocesses can significantly reduce the operational costs of water purification as aeration represents the most expensive process within the plant. Moreover, reducing the number of process stages reduces the capital costs.

In this research, two different biological processes for nutrient removal, i.e. simultaneous nitrification and denitrification (SND) coupled to phosphorous removal and autotrophic denitrification driven by pyrite, were investigated under different dissolved oxygen (DO) conditions in moving bed biofilm reactors (MBBRs) and packed-bed reactors (PBRs), respectively. Two MBBRs were operated for the treatment of synthetic municipal wastewater with different C/N ratios and operated under stable microaerobic DO conditions (1.0 ± 0.2 mg L⁻¹) and intermittent aeration (DO in the ranges of 0.2-2, 0.2-3 and 0.2-4 mg L⁻¹), respectively. Both MBBRs were inoculated with recycle sludge from local municipal wastewater treatment plants.
MWWTPs) and filled with Kaldnes K1 carriers (Veolia, France) at a 40% filling ratio. Stable microaerobic conditions were maintained by adjusting the air flow rate manually, while intermittent aeration at different DO concentration ranges was performed using a Raspberry Pi platform connected with two DO probes (WTW, Germany) and aquarium air pumps. Pyrite-based autotrophic denitrification was performed in two anoxic PBRs (P2 and P3) with an operating volume of 730 mL and an upflow recycle flow of 120 mL/min. The reactors were filled with about 600 mL of 1-2 mm pyrite granules and inoculated with a mixed culture dominated by *Thiobacillus denitrificans* (P2) and a mix of *T. denitrificans* culture and recycle sludge (P3). The potential of the two PBRs to sustain autotrophic denitrification was tested by decreasing the hydraulic retention time (HRT) from 11 to 2 h.

MBBR operation under stable microaerobic conditions and feed C/N ratio of 4.2 resulted in chemical oxygen demand (COD), total inorganic nitrogen (TIN) and P-PO4<sup>3-</sup> removal efficiencies up to 100%, 68% and 72%, respectively. Lower TIN removal efficiencies and unstable performance were observed at feed C/N ratios of 2.7 and 5.6, respectively. Thermodynamic modelling with Visual MINTEQ and stoichiometric evaluations revealed that P removal was mainly biological and can be attributed to the P-accumulating capacity of denitrifying bacteria. Intermittent aeration at DO concentrations in the range of 0.2-3 mg L<sup>-1</sup> resulted in higher P-PO4<sup>3-</sup> removal (> 60%) compared to the other DO ranges tested.

N-NO<sub>3</sub>- and P-PO4<sup>3-</sup> removal ≥ 80% was achieved via pyrite-based denitrification (Eq. 1) in PBRs when operated at HRT ≥ 5 h. Higher removal efficiencies were obtained in the P3, inoculated with a mixture of *T. denitrificans* and recycle sludge, compared to P2. Phosphorous removal in pyrite-filled bio-columns occurs via chemical precipitation as iron phosphate (FePO<sub>4</sub>) (Eq. 2) and adsorption onto iron oxide-hydroxides such as Fe(OH)<sub>3</sub>.

\[
2 \text{FeS}_2 + 15 \text{NO}_3^- + 7 \text{H}_2\text{O} \rightarrow 2 \text{Fe(OH)}_3 + 15 \text{NO}_2^- + 4 \text{SO}_4^{2-} + 8 \text{H}^+ \quad \text{(Eq. 1)}
\]

\[
\text{PO}_4^{3-} + \text{Fe}^{3+} \rightarrow \text{FePO}_4 \quad \text{(Eq. 2)}
\]

Higher pyrite-oxidation rates increase the production of Fe(OH)<sub>3</sub>, resulting in a higher P removal efficiency. The precipitated phosphate can be recovered via periodical column backwashing which is necessary to avoid clogging of pyrite bed due to excess biofilm growth and precipitates.

The study shows that high-efficiency N removal and P recovery from waste and drinking water can be obtained in single biofilm reactors with alternative and cost-effective methods involving microbial metabolism and chemical precipitation.

**REFERENCES**


Monday, 9\textsuperscript{th} September 2019

Session 5

PHOSPHORUS RECOVERY: PILOT, DEMO AND FULL-SCALE TECHNOLOGIES
Self-sustaining Sludge Smouldering: Towards On-Site Complete Sludge Destruction and P Recovery

José L. Torero

Department of Civil, Environmental and Geomatic Engineering, University College London, United Kingdom

Abstract: Incineration has been used for decades as a means to destroy waste water sludge. The ash from incineration can many times deliver compounds that can be used in multiple applications. While the interest in achieving effective recovery has increased and incineration processes have been modified to more effectively deliver valuable compounds, the main loss remains the energy required to evaporate water. Effective recovery of energy from organic waste requires maintaining combustion temperatures above quenching conditions and therefore the presence of large quantities of water requires major addition of supplemental energy. The alternative of pre-incineration water removal is also energy intensive. Thus extinction limits efficiency enhancement resulting in major and unavoidable energy consumption. This presentation will discuss the use of smouldering combustion as the most efficient means of recovering energy from combustion and as an efficient mechanism to incinerate waste water sludge with high water content (>70%). The objective is full resource recovery in the absence of any external energy supply.
Ash2Phos – Clean Commercial Products from Sludge Ash

Y. Cohen*, P. Enfält**, J. Svärd***
Ragn-Sells Group, Sweden

*Yariv.cohen@ragnsells.com
**Patrik.Enfalt@ragnsells.com
***John.Svard@ragnsells.com

Abstract: EasyMining Sweden has developed a process for phosphorus recovery from sludge ash named Ash2Phos. The process is based on wet chemical processing of mono-incinerated sludge ash. Phosphorus is first recovered in form of clean intermediate calcium phosphate. Several options exist for converting the intermediate calcium phosphate into final commercial products. After successful pilot trails, work is ongoing on the engineering of the first full-scale plant in Sweden.

Keywords: Phosphorus, recovery, sludge ash

INTRODUCTION EasyMining, a subsidiary of the Swedish environmental company Ragn-Sells, has developed a process for phosphorus recovery from sludge ash named Ash2Phos. The process is based on wet chemical processing of ash of mono-incinerated sewage sludge. Ragn-Sells is Sweden’s largest sewage sludge handling company treating ca 150 000 tons of dewatered sewage sludge annually. The Ash2Phos process contributes to the goal of a circular and sustainable society by recovering phosphorus, but also aluminium and iron, from ash of incinerated sewage sludge. Mono-incinerated sludge ash is mainly composed of five elements: phosphorus, calcium, iron, aluminium and silicon in form of oxides and other inorganic forms. During the development of the Ash2Phos process, the focus was on separating these five inorganic elements to enable a cost effective phosphorus recovery processes characterized by: high phosphorus recovery rate; high quality of recovered phosphorus product (low heavy metal content); recovery of phosphorus in form of commercial products; favorable mass-balance (cheap raw materials e.g. waste acid, lime); and focus not only on phosphorus but also on recovery of iron and aluminium in form of commercial products.

THE ASH2PHOS PROCESS The process starts by dissolving the sludge ash in acid. Commercial hydrochloric acid is commonly used for that purpose. The process is also adapted to enable the use of waste acid from waste incineration plants such as scrubber acid from flue gas treatment. Dissolution of phosphorus from sludge ash is generally high, exceeding ninety percent (see e.g. Cohen, 2009). Dissolution of aluminium is up to 85% and that of iron is up to forty percent.
The next process step is removal of recoverable elements from the obtained solution. Phosphorus, iron and aluminium are removed from the solution by precipitation steps in a unique combination. Thereafter, the solution is neutralized and treated for removal of heavy metals. The non-dissolved residue which mainly consists of inorganic silicates can after separation and washing be used e.g. in the cement or concrete industries. The recoverable elements are thereafter separated from each other by dissolution and precipitation reactions in a process which is characterized by internal recirculation of chemicals. The main chemical consumed in this process is lime. The recoverable elements are separated into three intermediate products: calcium phosphate, ferric hydroxide and aluminium hydroxide.

The intermediate products can be used as raw materials in the existing fertilizer industry and for production of coagulants which creates a closed loop. Alternatively, every customer can choose which of the intermediates he wants to refine by himself. The intermediate calcium phosphate can be processed into NPK fertilizers, ammonium phosphates, superphosphates, as well as into feed phosphates. Intermediate ferric hydroxide is converted into ferric chloride by reaction with hydrochloric acid. The ferric chloride product can then be used as a coagulant for phosphorus removal in wastewater treatment plants (WWTP).

RECENT ACTIVITIES EasyMining has performed successful large scale pilot runs of the Ash2Phos process in Helsingborg, Sweden. Currently work is ongoing on the engineering of the first full-scale Ash2Phos plant in Sweden. For that purpose, EasyMining has a cooperation with COWI as an engineering partner. EasyMining and the Danish company Biofos have signed a Memorandum of understanding (MOU) for long term processing of Danish sludge ash in the Ash2Phos plant in Sweden. Biofos has today around 280 000 tons of mono-incinerated sewage sludge on their landfills and are producing around 8000-ton ash yearly. The partnership with Biofos will focus on processing 20 000 tons of ash per year for 20 years. EasyMining’s mother company Ragn-Sells has signed a letter of intent with the German utilities company Gelsenwasser AG for cooperation in Germany. In a first step, a pilot study will be carried out with the objective to build a phosphorus recovery from ash plant in Bitterfeld based on the Ash2Phos technology.

![Figure 1](image.png)

**Figure 1.** The pilot plant (left) and recovered calcium phosphate (right)

REFERENCES
4 years of Phosphorus Recovery at WWTP Amsterdam West

A. Veltman*, J. de Danschutter*

*Waternet, PO Box 94370, 1090 GJ Amsterdam, The Netherlands (E-mail: alex.veltman@waternet.nl; jacqueline.de.danschutter@waternet.nl)

Abstract: At the WWTP Amsterdam West (in total 1.6 million people equivalent) with enhanced biological phosphorus removal massive scaling problems occurred after digestion of the primary and secondary sludge. The scaling was identified as struvite. Struvite is magnesium ammonium phosphate, a crystal with commercial value as a fertilizer. During the anaerobic digestion process biologically bound phosphorus is released into the liquid phase and with the present ammonium and magnesium levels struvite formation is very likely.

Keywords: Phosphorus; recovery; struvite; sludge dewatering

Figure 1.1 Massive scaling

In 2011 Waternet conducted a business case on costs and environmental effects of phosphorus removal and recovery at WWTP Amsterdam West (de Danschutter et al., 2011). And after extensive research including pilot tests, Waternet concluded that struvite recovery from digested sludge is the best phosphorus removal and recovery technique for this WWTP.

In the fall of 2013 the so called Airprex® technology was implemented at WWTP Amsterdam West, which combines phosphorus removal with phosphorus recovery as struvite. This technology uses the addition of a magnesium salt and elevation of the pH by aeration in order to produce struvite from the digested sludge. After settling clear crystals of struvite are recovered.
The results show a reduction of 95% of the phosphorus content of the liquid discharge after dewatering of the digested sludge. Also the massive scaling is nearly absent or easy to remove. The sludge dewatering improved considerably, most likely caused by the absence of phosphorus and the elevated magnesium concentration in the digested sludge. The improved dewatering leads to significant reduction of sludge volumes and therefore the costs of final sludge disposal (Bergmans et al., 2014). Production rate of struvite is up from 4 ton per week to 10 ton per week after replacing the initial discharge system of struvite.

The struvite produced is sold to a fertilizer company thereby closing the phosphorus cycle. Incorporating the Airprex® process in the WWTP Amsterdam West in the Netherlands has led to one of Europe’s largest producing facilities of high quality struvite. The described operational management benefits are very useful for similar WWTP’s.

REFERENCES

Thermochemical P-Recovery from Sewage Sludge Ash

T. Schaaf*, J. Ulbrich**, A. Orth***
Outotec GmbH & Co. KG, Ludwig-Erhard-Straße 21, D-61440 Oberursel, Germany
*tanja.schaaf@outotec.com
**julian.ulbrich@outotec.com
***andreas.orth@outotec.com

Abstract: Phosphorus (P)-components can be recovered from sewage sludge ashes (SSA) and be used as fertilizer by improving the bioavailability of P in the ash by means of the AshDec® process. In this process SSA is treated thermochemically at 900 °C with a sodium compound and dried sewage sludge. Critical heavy metal content of e.g. cadmium, lead and arsenic can be reduced significantly. After treatment the present P-compound is not water soluble reduces the risk of runoff, leaching and fixation. Several pot and field experiments showed a similar performance of the AshDec®-product as Triple Superphosphate (TSP). Experiments in laboratory and industrial scale demonstrated that even with variation of process parameters a steady high-quality product was generated.

Keywords: Heavy metal removal; next generation fertilizer, phosphorus recovery; sewage sludge ash

The most urgent issue related to phosphorus* use in agriculture is losses to water bodies and consequential eutrophication. Traditionally, the quality of phosphate fertilisers is largely determined by high P-solubility in water. However, phosphorus compounds with low water-, but high solubility in citric acid or ammonium citrate as Rhenania Phosphate were widely used in the 20th century. In a joint research project, Outotec and the German Federal Institute for Materials Research and Testing have reinvented Rhenania phosphates with their AshDec® process, where sewage sludge ash is used as raw material. Phosphates produced by this process are not water soluble but highly crop available since phosphate is only released in presence of crop root exudates, which is demonstrated by numerous pot and field experiments on European soils.

*Phosphorous is used in this context as common abbreviation for phosphorous compounds (phosphates)
Therefore, losses of Phosphorus by runoff, leaching and fixation may be reduced. Application of the product as a phosphate fertilizer leaves a smaller environmental footprint than using either conventional mineral fertilizers or recycled organic fertilizers.

The AshDec® product was tested in a pot experiment with maize and the results exposed a comparable yield of maize to TSP on both neutral and acidic soils. Figure 1.1 shows the results and a significant difference in fertilization performance between untreated sewage sludge ash and ash treated in the AshDec® process.

AshDec® is a thermochemical process designed to convert the low plant available phosphorus compound in the ash $\text{Ca}_3(\text{PO}_4)_2$ to the highly plant available compound $\text{CaNaPO}_4$ while reducing the heavy metal content. The core process encompasses feeding ash to a rotary kiln where it is mixed with sodium compounds and a reducing agent, preferably sewage sludge (Figure 1.2). The material is treated at around 900 °C for 15-20 min. A noticeable high amount of heavy metals evaporates at the prevalent temperatures. In comparison to conventional fertilizers, concentrations of cadmium and uranium are 80 % - 99 % lower.

![Figure 12 Principle of AshDec® process](image)

With a P-recovery rate of > 92 % of the phosphorus eliminated in the wastewater treatment plant, the process is unrivalled in terms of P-recovery efficiency. Ashes out of sewage sludge from all wastewater treatment plants treated in a (mono-) incineration plant can be handled by the AshDec process, regardless of their chemical characteristics and presence of impurities such as iron and aluminium. The product contains no organic compounds. Organic compounds, which are in sewage sludge before incineration, are eliminated at the combustion temperature of 850 and 950 °C. The minor amount of dried sewage sludge additive is as well totally combusted at temperatures of 900°C in the Ashdec process.

Testing in small batch rotary kiln was performed to optimize the process parameters, like temperature and retention time with different Na-compounds as additives. Additional to that, the production of 1.5 t of AshDec product took place in semi-industrial scale with variation of process parameters. The presented results show that high PNAC – solubility which is an indicator for plant availability, can be reached even with variation of process parameters. The presentation shows the basic concept, as well as the mass and energy balance for the thermal treatment of ashes from sewage sludge.

REFERENCES

The Inhibitory Effects of Free Nitrous Acid and Free Ammonia on the Aerobic Phosphorous Utilization Rate


Sanitary Engineering Laboratory, Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, Athens, Greece

Corresponding author email: andreadakisdimitris@gmail.com

Abstract: Laboratory scale experiments were conducted to study the inhibitory effects of free ammonia (FA) and free nitrous acid (FNA) on the enhanced biological removal (EBPR) process. The aerobic phosphorous utilization rate (PUR) was found to be inhibited by 50% under a FNA concentration of approximately 0.0015 mg/L and was fully inhibited at the FNA concentration of 0.013 mg/L. FA was also found to inhibit phosphorous removal with an observed 50% inhibition of the aerobic PUR under the FA concentration of approximately 8 mg/L.

Keywords: Free Nitrous acid; free ammonia; phosphorous utilization rate

INTRODUCTION The effective removal of phosphorus and nitrogen from wastewater is necessary to prevent eutrophication phenomena and the decline of water quality. During the processing of sewage sludge, reject water containing high nutrient concentrations is produced and its recirculation to the inlet of the wastewater treatment plant (WWTP) may increase nutrient loading by up to 30%. In light of this, the side treatment of reject water has emerged as an attractive option over the past years. Due to the high ammonium nitrogen concentrations of the reject water, nitrogen removal via conventional nitrification/denitrification is implausible as free ammonia will most likely fully inhibit nitrite oxidizing bacteria (NOB). Still, nitrogen removal via nitritation/denitritation may be achieved with the added advantage of lower COD and oxygen requirements. As for the removal of phosphorous, the EBPR process is considered an economical and effective method and is widely applied in WWTPs. However, the application of EBPR in the treatment of reject water may be problematic as nitrite, and more specifically FNA, has been reported to inhibit EBPR (Zhou et al., 2012). To a lesser extent, some studies have also reported on the inhibitory effects of FA on the EBPR process. Therefore, the study of the inhibitory effects of FNA and FA on EBPR is crucial in determining the feasibility of this method in the treatment of reject water.

MATERIALS AND METHODS A 10L laboratory-scale sequencing batch reactor (SBR) was used to cultivate polyphosphate accumulated organisms (PAOs)-enriched sludge. Once stable conditions were achieved, a series of ex-situ batch experiments focused on the aerobic PUR were conducted on sludge retrieved from the SBR. During each experiment the removal of phosphorous under a specific nitrite or
ammonium concentration was examined over 4 hours aeration period following a 1 hour anaerobic phase, under stable pH. The COD source was acetic acid. The parameters measured were temperature, pH, DO, ORP, TSS, VSS, MLSS, MLVSS, PO₄-P, NH₄-N and NO₂-N. All analyses of SBR unit and batch assays were performed in accordance with Standard Methods.

RESULTS AND DISCUSSION The inhibitory effect of various nitrite and ammonium concentrations on the aerobic PUR was studied for the pH values of 7, 7.5 and 8. Figure 1.1 illustrates the effects of FNA and FA on the observed inhibition of PUR.

![Figure 1.1 The effect of FNA and FA on PUR inhibition.](image)

PUR was inhibited by 50% under nitrite concentrations to the order of 10—50 mg/L under the pH values studied. The respective FNA concentration is around 1.5 μg/L. Yoshida et al. (2006) reported that 0.7 μg HNO₂-N/L inhibit non FNA-adapted PAO by 72% and FNA-adapted PAO by 20%. Thus, the results seem more consistent in describing the effects on a FNA-adapted biomass. The Phosphorus utilization rate is inhibited by 50% under a FA concentration of approximately 8 mg/L. Over the duration of the experiments the control’s PUR varied from 3.8 to 10.9 mgP/grVSS.hr.

ACKNOWLEDGEMENTS This work was carried out thanks to the funding from the European Union’s Horizon 2020 research and innovation programme under the SMART-Plant Innovation Action (www.smart-plant.eu grant agreement No 690323).

REFERENCES


Phosphorus and Ammonia Removal and Recovery through Ion Exchange (IEX) Process at Demonstration Scale

S. Guida*, G. Rubertelli**, B. Jefferson*, A. Soares*

*Water Sciences Institute, Cranfield University, Cranfield, Bedfordshire, MK43 0AL UK
(E-mail: samuela.guida@cranfield.ac.uk, b.jefferson@cranfield.ac.uk, a.soares@cranfield.ac.uk )
** University of Bologna, Via Zamboni, 33, 40126 Bologna BO, Italy
(E-mail: giorgia.rubertelli2@unibo.it)

Abstract: The operational performance of a demonstration scale ion exchange process, treating 10 m³/day of secondary treated wastewater, was investigated. For the removal of ammonia and phosphorus, a synthetic zeolite and hybrid anion exchanger (HAIX) were used, respectively. To ensure the economic feasibility of the process, the resins regenerant solutions were re-used and recycled back to the process after the nutrients were recovered. After 1.8 years of operation, the synthetic zeolite removed up to 98% of the initial NH₄-N and regenerant reached 689 mg NH₄-N/L, after being reused 5 consecutive cycles. The recovery of the NH₄⁺ as ammonium sulphate through stripping process was investigated (recovery >90%). The HAIX underwent 56 cycles of adsorption and regeneration without any significant loss in capacity. The sodium hydroxide used as regenerant reached 490-572 mg PO₄-P/L after 9 consecutive cycles and the phosphorus was recovered by precipitation as hydroxyapatite.

Keywords: ion exchange; nutrients; recovery

INTRODUCTION

Traditional biological and chemical technologies used for nutrient removal from wastewater have important drawbacks such as high energy and chemical consumption. On the other hand, the use of ion exchangers for nutrient removal as tertiary treatment processes allows for full control of the effluent quality and for the recovery of the nutrients as valuable product from the concentrated regenerant solutions (Sancho et al., 2017). However, previous studies have just focused on the use of ion exchanger at laboratory scale or pilot-scale for a short operational period of time (Mackinnon et al., 2003; Martin et al., 2009). This study investigated the resilience and long-term management of synthetic zeolite and HAIX to remove nutrients from secondary effluent wastewater at demonstration scale treating 10m³/day under a fixed operational envelope. The recovery of phosphorus and ammonia as marketable products was presented as a solution to maintain the regeneration capacity of the brine solutions and ensuring the economic feasibility of the process.

MATERIALS AND METHODS

The demonstration-plant consisted of a drum filter, an ammonia removal column filled with 69 L of synthetic zeolite (BYK Additives LTD, UK) and a phosphorus removal column filled with 35 L of HAIX, LayneRT (Layne, USA). The regenerant solutions were made of 10% KCl and 2% NaOH to regenerate the synthetic zeolite and the HAIX, respectively. The columns were fed
with secondary treated wastewater (after carbonaceous organic matter removal in a trickling filter) (Table 1.1) taken from a municipal wastewater treatment plant with 2,840 population equivalent (Cranfield, UK) at a flow of 10m$^3$/day. The synthetic zeolite and the HAIX performances were tested at an empty bed contact time of 10 and 5 minutes, respectively.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total suspended solids, TSS</td>
<td>54.91±20.90 mg/L</td>
</tr>
<tr>
<td>Chemical oxygen demand, COD</td>
<td>37.00±12.30 mg/L</td>
</tr>
<tr>
<td>PO$_4$-P</td>
<td>6.04±0.25 mg PO$_4$-P/L</td>
</tr>
<tr>
<td>NH$_4$-N</td>
<td>4.89±2.74 mg NH$_4$-N/L (from 17:00 to 04:00)</td>
</tr>
<tr>
<td></td>
<td>15.65±4.12 mg NH$_4$-N/L (from 05:00 to 16:00)</td>
</tr>
</tbody>
</table>

**RESULTS AND CONCLUSIONS** The ion exchange demonstration plant was operated under stable operational condition for a period of 17 months. Repeating adsorption and regeneration cycles were performed with both the synthetic zeolite and the HAIX. The performance of the synthetic zeolite was influenced by the daily variability of the inlet ammonia concentration (Table 1.1.). Due to the high variability, a representation of the cumulative mass fed, adsorbed and desorbed was preferred to represent the media performance over 7 cycles of adsorption and regeneration (Fig. 2.1a). In the last two cycles, the influent ammonia concentration was more stable at 17.5±2.0 mg/L and the number of BV in between regenerations was 300. The average inlet phosphorous concentration was 6.04±0.25 mg PO$_4$-P/L, the effluent wastewater reached 0.1-0.9 mg PO$_4$-P/L, indicating that 95% of the PO$_4$-P was removed. These results, obtained over 56 cycles of adsorption and regeneration, showed that HAIX can be used with to treat wastewater over a long time while retaining its high capacity of adsorption (Fig. 2.1b).

![Figure 2.1](image1.png)  
(a) Cumulative mass (g NH$_4$-N) fed, adsorbed and desorbed in the ammonia removal column; (b) Performance of adsorption of synthetic zeolite over 6 cycles; (c) breakthrough curve of phosphorus adsorption by HAIX and regeneration cycles number 32-53.

After reusing the KCl 5 cycles, a concentration of 689 mg NH$_4$-N/L was obtained, indicating 90% NH$_4$-N recovery. The NH$_4$-N was converted to a concentrated NH$_3$ solution in the stripping process and recovered as ammonium sulphate precipitate after adding sulphuric acid (Fig. 2.2a and 2.2c). Following dehydration, a recovery of 79 kg per year can be estimated. In case of the 2% NaOH regenerant, after 9 cycles it reached 572 mg PO$_4$-P/L. After addition of hydrated lime, following filtration, a recovery of 25-30 kg of hydroxyapatite per year can be expected (Fig. 2.2c and d).
ACKNOWLEDGMENTS This project has received funding from the Europe Union’s Horizon 2020 research and innovation programme under grant agreement No 690323.

REFERENCES
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Chemical vs Biological Phosphorus Removal: Full-Scale Process Optimisation for Resources Saving

L. Menoni*, G. Bertanza**, R. Pedrazzani***

* DICATAM – Department of Civil, Environmental, Architectural Engineering and Mathematics, Universita degli Studi di Brescia, via Branze 43, 25123, Brescia, Italy, laura.menoni@unibs.it
** DICATAM – Department of Civil, Environmental, Architectural Engineering and Mathematics, Universita degli Studi di Brescia, via Branze 43, 25123, Brescia, Italy, giorgio.bertanza@unibs.it
*** DIMI – Department of Mechanical and Industrial Engineering, Universita degli Studi di Brescia, via Branze 38, 25123, Brescia, Italy, roberta.pedrazzani@unibs.it

Abstract: In this work, the optimisation of phosphorus removal process was carried out at full-scale: both chemical and biological techniques were considered in order to obtain resources saving. Full-scale experimental tests were performed to find the best coagulant and polyelectrolyte (and their dosages) for chemical removal. Moreover, some different alternatives were compared to define the optimal configuration concerning the percentage of the total flowrate to be submitted to tertiary treatments. Finally, the efficiency and costs associated to this optimized chemical phosphorus abatement were compared to the biological removal option. This can be considered as a fundamental starting point for the implementation of resource recovery technologies.

Keywords: resources saving; phosphorus removal; municipal wastewater

Nowadays, the “End-of-pipe” approach for wastewater treatment plants (WWTPs) has been overcome moving towards the “water resource recovery facility (WRRF)” concept. Thus, WWTPs are often asked to produce valuable resources. Today, many options exist for materials and energy recovery (Bertanza et al., 2018(b), Lema and Suarez, 2017). For this reason, the production of valuable resources from WWTPs can easily be obtained in case of new plants to be built. Conversely, retrofitting existing plants is still a big challenge. Actually, resource recovery is still scarcely applied at full-scale in Italy: according to Papa et al. (2017), more than 60% of the analysed plants (600 Italian WWTPs) do not perform any kind of recovery.

In any case, the starting point for the application of resource recovery technologies is virtuous facilities, where process and energy performances have already been optimized. In this work, the optimisation of phosphorus removal process was carried out at full-scale: both chemical and biological techniques were considered in order to perform resources saving.

The studied WWTP is a conventional activated-sludge plant (design size 330,000 Population Equivalent - PE), treating domestic wastewater, that discharges in a sensitive area. The process scheme includes fine screen, grit chamber, pre-denitrification, oxidation-nitrification, secondary settling, tertiary treatments for chemical phosphorus removal (coagulation, flocculation, sedimentation + sand filtration) and UV disinfection. High influent load fluctuations are commonly recorded.
because the plant is located in a tourist area, hence actual PE almost double in summer season.

First of all, two different coagulants were tested, i.e. ferric chloride and aluminium sulfate. Experimental tests were performed at full-scale with different dosages for both chemical reagents in order to find optimal treatment conditions considering both process performance and related costs. Aluminium sulfate revealed to be the best option. The same process was carried out concerning the choice of the more suitable polyelectrolyte and its dosage.

Furthermore, the optimal condition concerning the percentage of the total flowrate to be submitted to tertiary treatments was analysed: mass balance and cost calculation (pumping, coagulant and polyelectrolyte cost) were performed considering four different system configurations which allowed to comply with discharge limits both in terms of effluent phosphorus and \textit{E.coli} concentration. Results were compared to the actual scenario. The reduction of the percentage of flowrate to be treated in tertiary treatments resulted in the decrease of chemical reagents and energy consumption with a consequent reduction of the cost of about 30,000 €/y, while preserving process performance.

In the examined WWTP, biological phosphorus removal occurs, as proved also by the presence of Phosphorus Accumulating Organisms (PAOs), identified by microbiological analyses. For this reason, some experimental campaigns were carried out to find optimal dissolved oxygen (DO) and oxidation-reduction potential (ORP) conditions to be maintained within biological reactors and secondary settlers. With the enhancement of biological phosphorus removal process performance, the application of chemical phosphorus abatement can be reduced, thus decreasing chemical reagents consumption (and cost) and performing resources saving. From the techno-economic evaluation of the processes, a cost saving of about 50,000 €/y was estimated.

REFERENCES


Mainstream SCEPPHAR configuration for integrating P and PHA recovery in the water line of WWTPs

Oriol Larriba, Borja Solís, Zivko Juznic-Zonta, Albert Guisasola, Juan A. Baeza
GENOCOV, Departament d'Enginyeria Química Biológica i Ambiental, Escola d'Enginyeria, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, 08193 Barcelona, Spain (Oriol.Larriba@uab.cat, Borja.Solis@uab.cat, Zivko.JuznicZonta@uab.cat, Albert.Guisasola@uab.cat, JuanAntonio.Baeza@uab.cat)

Abstract: This work presents a novel pilot-scale configuration, mainstream SCHEPPPAR (Short-Cut Enhanced Phosphorus and PolyHydroxyAlkanoate Recovery), within the framework of resource recovery. This configuration is designed to: i) efficiently remove C, N and P, ii) recover up to 50% of incoming phosphorus in struvite form, iii) reduce aeration requirements up to 25%, and iv) recover about 9% of influent organic matter as PHA.

Keywords: SCEPPHAR, mainstream, nutrient recovery, struvite; PHA; EBPR

The new paradigm of circular economy requires new technologies for resource recovery during urban wastewater (WW) treatment. This work presents a novel configuration named mainstream SCEPPHAR (Short-Cut Enhanced Phosphorus and PHA Recovery) which is one of the novel technologies tested in the SMART-Plant project (Scale-up of low-carbon footprint Material Recovery Techniques, EUH2020, grant agreement 690323). The SMART-Plant project aims to prove the feasibility of novel WW treatment technologies at pilot-scale towards a circular economy scenario with nutrient recovery, and reduction of energy consumption and carbon footprint.

Mainstream SCEPPHAR aims not only at treating urban WW, but also at recovering P and N as struvite and part of the inlet organic matter as PHA. This configuration is an evolution of the two-sludge system proposed by Marcelino et al. (2011) including resource recovery. The system is based on two sequential biological reactors (SBRs): the HET-SBR performs EBPR by alternating anaerobic/anoxic/aerobic conditions while the AUT-SBR is in charge of nitrification (or partial nitrification process up to nitrite). Regarding P-recovery, this combines EBPR and struvite precipitation from the main water line profiting from the high P concentrations in the anaerobic stage (Acevedo et al., 2015; Baeza et al., 2017; Guisasola et al., 2019). Thus, part of the supernatant rich in P and ammonia is diverted to a precipitation reactor, where pH is increased and MgCl₂ is added in order to produce struvite. EBPR performance is constrained by a low concentration of organic matter. Hence, its integration with nitrogen removal via nitrite would decrease the organic matter needs for simultaneous biological removal of N and P (Marcelino et al., 2011).

In a conventional EBPR process, P is removed by purging biomass at the end of the aerobic phase (i.e. where biomass has the maximum internal P-content). This leads to undesired and uncontrolled struvite precipitation in the subsequent anaerobic digestion of this sludge. SCEPPHAR implements a purge at the end of the anaerobic
phase, when biomass has the lowest internal P-content, thus decreasing the problems of undesired precipitation. Moreover, the biomass of the purge contains a high fraction of PHA, which is highly beneficial since i) PHA can be used as a precursor for bioplastics production and ii) anaerobic digestion of this sludge produces higher methane yield. The new configuration recovers up to 50% of the inlet P, while aeration savings up to 25% are obtained due to the nitrite short-cut implemented in AUT-SBR and some ammonia removal by struvite precipitation.

The pilot plant started its operation during June 2017. The full presentation will give all the experimental data from two years of continuous operation of mainstream SCEPPHAR including N₂O emissions (e.g. Figure 1 and Figure 2). We will detail successes and hurdles found through this experimental period and give guidelines for a future implementation of this technology at full-scale.

Figure 1 Results of removal during the start-up of the mainstream SCEPPHAR pilot plant. Ammonium at the influent (▲), ammonium at the effluent (∆), phosphate at the influent (●), phosphate at the effluent (○).

Figure 2 Example of full cycle monitoring of the mainstream SCEPPHAR pilot plant with complete P and N removal. HET-SBR (left) and AUT-SBR (right). Ammonium (△), nitrite (▼), nitrate (▲), phosphate (●).

REFERENCES
Boosting the P Extraction from the Sludge by Rearranging the Sludge Line in a WWTP


*CALAGUA – Unidad Mixta UV-UPV, Institut Universitari d'Enginyeria de l'Aigua i Medi Ambient-IIAMA, Universitat Politècnica de València. Camí de Vera s/n, 46022 València, Spain. mirolal@iiama.upv.es; jferrer@hma.upv.es; rababa@dihma.upv.es
**CALAGUA – Unidad Mixta UV-UPV, Departament d’Enginyeria Química, Universitat de València. Avinguda de la Universitat s/n, 46100 Burjassot, Valencia, Spain. nuria.marti@uv.es
***EMUASA, Plaza Circular, 9. 30008 Murcia, Spain. fnavarrosan@emuasa.es
****CETAqua Galicia, Edificio Emprendia s/n, Campus Vida. 15782 Santiago de Compostela, La Coruña, Spain. teresa.alvarino@cetaqua.com

Abstract: Currently, it is essential the application of new P management strategies to enhance its recovery in the Waste Water Treatment Plants (WWTP). This paper shows a comparative assessment by simulation of two different sludge line configurations aiming to maximize the P extraction and so its final recovery. For this purpose, it was selected the Murcia-Este WWTP as the site where both alternatives were evaluated. Alternative 1 was based in the P separation through the sludge elutriation over the primary thickeners and Alternative 2 was based in the WASSTRIP® process. Both alternatives were able to achieve similar results for the P extraction (between 43.1% and 48.3% of P extracted over the influent P). However, the CAPEX and OPEX were significantly higher for the Alternative 2, making more attractive the sludge line configuration based on the elutriation scheme.

Keywords: Phosphorus recovery, extraction, elutriation, sludge management, mathematical modelling

INTRODUCTION
There are two major issues that trigger the research in P-recovery from wastewaters: i) achieving a sustainable P-cycle with reduced losses, mitigating its scarcity and ii) reducing the precipitation of struvite and other phosphate compounds on the walls of pipelines, reactors and other equipment that hamper the operation of WWTP and increase its cost. In full-scale WWTP, the currently most spread P-recovery techniques take place downstream the anaerobic digestion and their recovery yields are reduced as these processes takes place after the uncontrolled P-precipitation.

In this work are compared the implementation by simulation of two sludge management strategies to extract the P from the sludge before the anaerobic digestion in the Murcia Este WWTP: one based on the separation of a PO₄-enriched stream via the sludge elutriation process and the other one by dewatering the sludge mechanically, based on the WASSTRIP® process, which is already full-scale implemented in different countries. The leitmotiv of the implementation of both schemes was the utilization of the currently built elements, minimizing the costs associated to the acquisition of the required equipment and the rearrangement of the pipelines, pumps, etc.

MATERIAL AND METHODS Murcia-Este WWTP was characterized in three analytical campaigns (measuring all the sludge and water lines) to afterwards calibrate the model BNRM2 (Barat et al., 2013). The calibrated Murcia-Este model was
employed to optimize the sludge line configurations for both alternatives using the software DESASS 7.1.

In Figure 1.1 and Figure 1.2 are depicted the schemes of the current sludge line and the Alternatives 1 (A1) and 2 (A2). A1 was based in the release of the stored poly-P in the P-release tank (volume equivalent to the volume of the current mixing chamber and the non-used secondary thickener). Afterwards, the P-recovery stream was separated in the primary thickener by the elutriation of the mixed sludge over the primary thickeners.

A2 was based in the addition of a VFA-enriched stream, obtained in the primary thickeners, to the secondary sludge in the P-release tank (volume equivalent to the current two secondary thickeners). The separation of the P-recovery stream was carried out after sludge dewatering in dynamic thickeners.

RESULTS AND CONCLUSIONS The model was accurately calibrated. The simulations of each alternative were performed assuming a P removal efficiency in the water line around the 90%. In A1 the 43.1% of the influent P was extracted in the P-recovery stream as PO₄, whereas in A2 it was extracted the 48.3%. The uncontrolled P-precipitation, estimated according to Martí et al. (2008), was reduced a 52.7% (in the A1) and a 59.8% (in the A2) under optimal operating conditions. The main drawback of implementing A2, despite the higher PO₄ extraction, was the high CAPEX and OPEX, due to the pumping requirements and the dynamic thickeners required to obtain the P-recovery stream (including its energy and chemical consumptions). The total annualized equivalent cost per Tm of P extracted was between 30-40% higher in A2 than in A1.

This study has shown the feasibility of implementing several P-management strategies to carry out the recovery before the anaerobic digestion in the Murcia-Este WWTP, achieving similar efficiencies, increasing the sustainability of the P-cycle and reducing the uncontrolled precipitation in the sludge line. However, the CAPEX and OPEX are significantly higher for the A2, making more attractive the sludge line configuration based on the elutriation scheme (A1).

REFERENCES

Phosphorus Recovery and Management in Alto Trevigiano Servizi: From Pioneer Struvite Recovery to Current Regional Strategies


Abstract: Alto Trevigiano Servizi is a public-owned water utility that manages urban water cycle services of 52 municipalities in Veneto region, North-East of Italy. Innovative technological solutions and strategies during the years have permitted to developed and realize an integrated approach in the management and recovery of phosphorus. Treviso wastewater treatment plant developed one of the first demonstrative area to recovery struvite from urban wastewater. Moreover, the Short Cut Enhanced Phosphorus and PHA Recovery, integrated in Carbonera, is actually permitting the integration of conventional biogas recovery from cellulosic primary sludge with the energy-efficient nitrogen removal via-nitrite from sludge reject water and the recovery of PHA and struvite. Finally, a future upgrade of Castelfranco Salvatroda plant, focused on centralized and smart management of wastewater sludge, will permit to innovate and valorise circular economy in the territorial scenario.
Monday, 9th September 2019

Session 6

ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY ASSESSMENT
Life Cycle Assessment of Material Recovery from Municipal Wastewater: Circular Economy with Environmental Benefits


*Berlin Centre of Competence for Water, Cicerostr 24, 10709 Berlin, Germany, christian.remy@kompetenz-wasser.de
**Cirtec B.V., Nijverheidsweg 10, 1442 LD Purmerend, The Netherlands
*** Universitat Autonoma de Barcelona, 08193 Bellaterra, Spain
**** Universita di Verona, Via dell’Artiglierie 8, 37129 Verona, Italy
***** Biotrend S.A., Biocant Park, Nucleo 04 – Lote 2, 3060-197 Cantanhede, Portugal
****** Universitat de Vic, Sagrada Familia, 7, 08500 Vic, Spain
******* Special Building Products Ltd, Unit 13, Abendury Way, Wrexham LL139UZ, UK

Abstract: Recovery of valuable materials from municipal wastewater is one approach to realize circular economy in the wastewater sector. Different technologies have been tested and applied to recover products such as cellulose, bioplastics, or struvite within a wastewater treatment plant (WWTP). However, material recovery also introduces new process steps into the treatment scheme, which require additional energy or chemicals and related greenhouse gas emissions. From an environmental perspective, Life Cycle Assessment (LCA) is a suitable tool to analyse the entire system of material recovery from WWTPs, including the potential value chains for product valorisation. The present paper investigates different technologies for material recovery with LCA based on data of industrial-scale demonstration trials and shows that material recovery can be realized with distinct environmental benefits, also due to positive side effects on the overall treatment scheme of the WWTP.

Keywords: Life Cycle Assessment, material recovery, municipal wastewater

Material recovery from municipal wastewater is one element of circular economy which can be applied in the wastewater sector. Raw wastewater contains a range of valuable substances such as cellulose fibres, organic carbon, and plant nutrients nitrogen and phosphorus. Innovative processes have been developed and demonstrated to recover these substances in wastewater treatment plants (WWTPs) and harvest valuable products, e.g. cellulose as structural material or biofuel, bioplastics such as polyhydroxyalkanoate (PHA) or struvite as phosphorus fertilizer.

However, material recovery also introduces new technologies and processes into the wastewater treatment scheme, which will need additional energy and chemicals and cause related environmental effects. From an environmental and policy perspective, it is interesting to analyse if material recovery will lead to an overall environmental benefit for the wastewater sector, or if additional efforts fully offset the benefits of product recovery and lead to a net increase in energy demand and related greenhouse gas emissions.
Life Cycle Assessment (LCA) as defined in ISO [ISO 14040 2006] is a suitable tool to analyse the environmental impacts of complex product systems and compare different scenarios in their energy demand and greenhouse gas emissions. LCA takes into account direct and indirect effects, i.e. emissions at the WWTP and also emissions related to the production of electricity, chemicals or materials. In addition, the complete value chain of material recovery can also be included to consider the environmental benefit coming from the substitution of primary materials by WWTP-derived products.

The present study analyses three different products (cellulose, PHA, and struvite) originating from municipal WWTPs and their corresponding value chains with LCA (Table 1.1). Data for recovery processes and value chains have been collected from industrial-scale demonstration units during long-term trials at specific WWTPs in the H2020 innovation action SMART-PLANT (Grant No. 690323), while remaining data gaps have been closed in cooperation with process providers and research partners.

<table>
<thead>
<tr>
<th>Product</th>
<th>Test location</th>
<th>Recovery process</th>
<th>Value chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose</td>
<td>WWTP Geest-merambacht (NL)</td>
<td>Fine sieve</td>
<td>Biodrying → biofuel</td>
</tr>
<tr>
<td>Cellulose</td>
<td>WWTP Geest-merambacht (NL)</td>
<td>Fine sieve</td>
<td>Pelleting → sludge plastic composite</td>
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<td>PHA</td>
<td>WWTP Manresa (ES)</td>
<td>SCEPPHAR in mainstream</td>
<td>PHA extraction → sludge plastic composite</td>
</tr>
<tr>
<td>PHA</td>
<td>WWTP Carbonera (IT)</td>
<td>SCEPPHAR in sidestream</td>
<td>PHA extraction → sludge plastic composite</td>
</tr>
<tr>
<td>Struvite</td>
<td>WWTP Carbonera (IT)</td>
<td>SCEPPHAR sidestream</td>
<td>Fertilizer</td>
</tr>
</tbody>
</table>

Value chains for the recovered products include bio-drying to obtain a bio-fuel from cellulosic sludge, the production of sludge plastic composite from cellulose fibres and PHA which has been extracted from PHA-rich biomass of the SCEPPHAR process [Frison et al 2015], and use as agricultural fertilizer of recovered struvite.

Overall, preliminary results show that environmental benefits of material recovery from municipal WWTPs originate not only from substituting primary materials in the value chain, but to a major part from positive side effects such as energy savings or emission reduction (e.g. \( \text{N}_2\text{O} \)) for the WWTP process. Materials recovered from WWTPs which may not be able to directly compete with primary products in their environmental profile could be favourable in a holistic life-cycle perspective due to e.g. savings in aeration or sludge disposal. Finally, circular economy approaches in WWTPs should also target to improve the wastewater treatment process itself, which can then lead to win-win situations of WWTPs with lower environmental footprint and integrated recovery of valuable materials.

REFERENCES


Environmental and Economic Assessment of Solar-Assisted Thermal Energy Recovery from Wastewater

I. Muñoz*, F. Portillo**,***, S. Rosiek**,***, F. J. Batlles**,***, J. Martínez-Del-Río****, I. Acasuso*****, V. Piergrossi******, M. De Sanctis ******, S. Chimienti*******, C. Di Iaconi******

* 2.-0 LCA consultants, Rendsburggade 14, room 2.345, 9000, Aalborg, Denmark (e-mail: ivan.munoz@lca-net.com)
** Department of Chemistry and Physics, University of Almería, 04120 Almería, Spain
*** CIESOL, Joint Centre of the University of Almería -CIEMAT, 04120 Almería, Spain
**** Department of Economics and Business, University of Almería, 04120 Almería, Spain
***** Hedera helix I&B, Avda. Putxeta 1, Abanto y Zierbena, 48540, Bizkaia, Spain
****** CNR – Water Research Institute, Via F. De Blasio 5, 70132 Bari, Italy

Abstract: The integration of an off-grid solar-assisted heat pump (SHP) and a sequencing batch biofilter granular reactor (SBBGR) for thermal energy recovery from wastewater was assessed by means of life cycle assessment (LCA) and life cycle costing (LCC). This integrated system was compared to a reference situation where wastewater is treated in a conventional WWTP. The results show clear environmental and economic benefits, such as a 42% reduction in greenhouse-gas emissions and a cost reduction of 53%.

Keywords: wastewater-source heat pump; sequencing batch biofilter granular reactor (SBBGR)

Urban wastewater constitutes a promising low-grade source of thermal energy, as it is produced steadily, in high volumes and with small temperature variations, making it suitable for heating and cooling purposes through heat pump systems. A limitation to the widespread tapping of this energy source is biofouling of heat exchangers in contact with untreated wastewater. The novel sequencing batch biofilter granular reactor (SBBGR) constitutes a potential solution to this problem. The SBBGR is an attached-biomass system operating with a complete separation of the biomass from the liquid phase, thus allowing for a reactor zone free of suspended solids where a heat exchanger can be placed. Coupling of a SBBGR with a solar-assisted heat pump (SHP) has been recently demonstrated at pilot-scale in Bari, Italy, in the context of the EU project THERBIOR (http://www2.ual.es/therbior/). We conducted a prospective life cycle assessment (LCA) and life cycle costing (LCC) to the integration of these two systems for air-conditioning purposes in a Mediterranean context.

The basis for the assessment is a pilot plant installed in Bari, where an existing SBBGR unit was upgraded with a SHP (figure 1.1, left) as described in Piergrossi et al. (2018). The LCA and LCC studies were applied to a theoretical scale-up of this pilot installation to a plant designed for 5,000 person-equivalents. This was compared to a reference scenario where wastewater is treated in a conventional WWTP applying activated sludge. The life cycle stages included for the THERBIOR plant are shown in figure 1.1 (right). As it can be seen the recovery of energy from wastewater leads to a
service of heating/cooling that is assumed to substitute the same amount of energy from a grid power-driven air-source heat pump.

Table 1.1 below shows some of the results for the LCA, as well as the results for the LCC. The basis for the comparison is the treatment of 1 m³ urban wastewater with the local composition in the area of Bari. It can be seen that greenhouse-gas emissions per m³ are reduced by 42% in the THERBIOR scenario, mainly due to the substituted heat pump and lower sludge disposal impacts (incineration with energy recovery). A similar pattern was seen in other environmental impacts included in the LCA.

The LCC results also show a substantial cost reduction in the THERBIOR scenario, of 0.74 €/m³. In this case this reduction is not so much related to the energy recovery by the SHP: the sum of its life cycle costs and benefits barely breaks even. On the other hand, the WWTP based on the SBBGR concept achieves substantial cost reduction, especially in terms of sludge disposal.

REFERENCES

Life Cycle Assessment of Nutrient Recovery from Wastewater – Current Practices and Insights


*Department of Water Management, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, the Netherlands. Email: k.l.lam@tudelft.nl
** Amsterdam Institute for Advanced Metropolitan Solutions, Kattenburgerstraat 5, 1018 JA, Amsterdam, The Netherlands
*** Waternet, Korte Ouderkerkerdijk 7, 1096 AC, Amsterdam, The Netherlands.

Abstract: Life cycle assessment (LCA) is an established methodology to assess the potential environmental impacts of products and processes. We reviewed 49 recent LCA studies (2010-2019) related to nutrient recovery from wastewater to synthesise some current practices and insights. Their scopes, general results, variations, limitations and uncertainty management are discussed. Most studies are either comparing the environmental impacts of having recovery versus without recovery or comparing the environmental impacts of different recovery alternatives. Most studies reported an overall positive environmental performance for nutrient recovery from wastewater, especially when combining with source separation of human excreta. There are many opportunities to improve the LCA practice such as improving methodological consistency, ensuring transparency of inventory and methods, considering result uncertainty, and connecting the recovered nutrient products to local factors.

Keywords: Life cycle assessment; nutrient recovery; review

Many technologies exist for recovering nutrients such as phosphorus and nitrogen from wastewater. The challenge of transitioning to resource-efficient urban water systems is often not the availability of technology for resource recovery, but the lack of planning and design methodology to identify and deploy the most sustainable solution in a given context (Guest et al., 2009). Life cycle assessment (LCA) provides a methodology to quantify potential environmental impacts (benefits or burdens) from implementing nutrient recovery strategies and in some cases, provide insights of potential trade-offs between different environmental impacts and/or economic performance (when evaluating with cost assessment).

This study reviewed 49 peer-reviewed LCA studies (2010-2019) related to nutrient recovery from wastewater (Figure 1.1). The objective is to provide an overview of the current practices and insights from these LCA studies across different countries and scales. This can contribute to global perspectives for planning and implementation of next-generation resource recovery, wastewater treatment and sanitation infrastructure.

Most of these LCA studies are either i) comparing a system with nutrient recovery approach(es) (in some cases, also integrated with other resource recovery approaches) to a reference system without recovery, or ii) comparing multiple recovery alternatives for a given system. Most studies evaluated i) sewage sludge management strategies for nutrient recovery, ii) recovery through struvite precipitation, or iii) urine source separation integrated with nutrient recovery. A range of environmental impact
categories were assessed, with the most-evaluated categories being global warming potential (44), eutrophication potential (36), acidification potential (33), ecotoxicity (27) and human toxicity (26) and photochemical ozone formation (24).

Most studies reported a positive environmental performance for nutrient recovery from wastewater, especially when combining with source separation of human excreta. One prominent benefit is the reduction of greenhouse gas emissions mostly from substituting synthetic fertiliser, despite potential burdens of ecotoxicity and human toxicity. Minimising chemical inputs in nutrient recovery processes is an important factor to enhance the environmental performance of recovery processes.

How to account for the environmental benefits from the recovered nitrogen and phosphorus differs considerably among these studies (e.g., type of synthetic fertiliser being substituted, bioavailability of recovered material). In some cases, the underlying assumptions for fertiliser offset are neither documented nor well-justified.

Assessing only a few of the environmental impact categories and/or with a limited system boundary may be insufficient to make informed decisions for implementing nutrient recovery strategies. For instance, some studies only looked at the carbon footprint of nutrient recovery without acknowledging the potential negative impacts from for example, ecotoxicity, human toxicity or emissions from storage.

Like any model-based analysis, uncertainty presents in LCA. While studies increasingly used Monte Carlo simulation to examine uncertainty propagation, the practice remains limited. Sensitivity analysis is commonly conducted to identify key influencing parameters on LCA results. This is particularly important where the technology evaluated is still in its early stage of development. Sensitivity analysis can highlight areas for further research to address the more important factors.

![Figure 1.1 Scope of 32 nutrient recovery LCA studies reviewed in terms of i) system scale, ii) number of impact categories evaluated, iii) number of resource recovery strategies compared in each study, and iv) studied regions. Each circle is a study, and its size corresponds to the number of strategies compared in that study (from 1 to 18 resource recovery strategies). 17 studies are not shown in this figure because system sizes were not specified.](image)

REFERENCES

The Economics behind the Combination of AnMBR and FO Technologies for Municipal Wastewater Treatment

S. Vinardell*, S. Astals*, J. Mata-Álvarez*, J. Dosta*

* Department of Chemical Engineering and Analytical Chemistry, University of Barcelona, 08028 Barcelona, Spain (svinardell@ub.edu)

Abstract: Anaerobic membrane bioreactor (AnMBR) technology is drawing attention for municipal wastewater treatment and resource recovery. However, the low concentration of organics in sewage compromises the economic and technical feasibility of this application. Forward osmosis (FO) stands as an excellent platform to pre-concentrate sewage and overcome these limitations. This techno-economic study evaluates 7 different scenarios for municipal wastewater treatment, including 6 scenarios where AnMBR and FO are combined. The results of this study show that the costs of integrating FO with AnMBR are driven by FO recovery. Although an integrated facility where FO is used for pre-concentration and AnMBR for sewage treatment may be a feasible approach, FO flux improvements are still required to boost the competitiveness of the technology.

Keywords: AnMBR; forward osmosis; municipal wastewater

INTRODUCTION Anaerobic membrane bioreactor (AnMBR) technology is gaining interests for municipal wastewater treatment (Lin et al., 2013). Although this configuration is a step forward towards the application of anaerobic digestion at psychrophilic temperatures, the diluted origin of municipal wastewater is still a challenging issue to be tackled. Forward osmosis (FO) pre-treatment has recently been proposed as a promising platform to pre-concentrate municipal wastewater. However, further studies are necessary to assess the reliability of this technology, since FO membranes play a key role in the economy of the process. This study is aimed at gaining a first insight into the economic and technical feasibility of joining AnMBR with FO technology by comparing different scenarios of FO.

METHODOLOGY A baseline scenario 1 without FO pre-treatment (Figure 1.1a) and three different AnMBR scenarios are proposed in function of the FO recovery (i.e., 50, 80 or 90% of recovery corresponding to scenarios 2, 3 and 4, respectively) (Figure 1.1b). For FO treatment, two options are evaluated for each scenario: (i) seawater is used as a draw solution in an opened-loop scheme, thus simulating a seawater desalination process with maximisation of water recovery (scenario A), and (ii) a synthetic draw solution is used in a closed-loop scheme, in the case of lacking availability of seawater (scenario B) (Figure 1.1c). In all options, reverse osmosis (RO) is employed as a draw solution treatment. The design is carried out considering a medium-sized population of 30000 PE. The life-cycle analysis will be based on capital expenditure (CAPEX) and operating expenses (OPEX).
RESULTS AND DISCUSSION The results indicate a clear trend regarding AnMBR system, namely, the higher the FO recovery, the lower the reactor volume and the UF membrane surface (Table 1.1). From this point, CAPEX of the AnMBR will sharply decrease as the FO recovery increases. Although this may be an important factor governing the economics of joining AnMBR with FO, other considerations must be taken into account. OPEX costs related to AnMBR treatment, which are mainly influenced by gas sparging rate and recirculation flow to the membrane tank, may have a different behaviour in comparison to AnMBR CAPEX, due to the higher recirculation flow that is required in scenario 3 (MLSS in the membrane tank was limited to 18 g L⁻¹ based on previous literature). Concerning FO-RO pre-concentration step, the higher the FO recovery, the larger the membrane surface. Consequently, overall CAPEX and OPEX costs are clearly influenced by the FO-RO system, especially when the low fluxes and high costs of FO modules are considered.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>AnMBR Volume (m³)</th>
<th>UF membrane surface (m²)</th>
<th>Q gas sparging (Nm³/h)</th>
<th>Recirculation flow (m³/day)</th>
<th>Methane recovery (Nm³/day)</th>
<th>FO membrane surface (m²)</th>
<th>RO membrane surface (m²)</th>
<th>Water production (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sce. 1</td>
<td>5106</td>
<td>18192</td>
<td>4184</td>
<td>5425</td>
<td>323</td>
<td>11767</td>
<td>11778</td>
<td>4240</td>
</tr>
<tr>
<td>Sce. 2A</td>
<td>2553</td>
<td>9096</td>
<td>2092</td>
<td>3492</td>
<td>406</td>
<td>6167</td>
<td>6167</td>
<td>2220</td>
</tr>
<tr>
<td>Sce. 2B</td>
<td></td>
<td>3638</td>
<td>837</td>
<td>11008</td>
<td>456</td>
<td>15478</td>
<td>15478</td>
<td>5572</td>
</tr>
<tr>
<td>Sce. 3A</td>
<td></td>
<td>1810</td>
<td>416</td>
<td>5418</td>
<td>473</td>
<td>25079</td>
<td>25079</td>
<td>3552</td>
</tr>
<tr>
<td>Sce. 3B</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>41776</td>
<td>41776</td>
<td>6016</td>
</tr>
<tr>
<td>Sce. 4A</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>11100</td>
<td>11100</td>
<td>3996</td>
</tr>
<tr>
<td>Sce. 4B</td>
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</table>

From this techno-economic analysis, it can be concluded that the combination of AnMBR and FO has potential for municipal wastewater treatment, although further improvements on FO flux are still required to improve the competitiveness of the technology.

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REFERENCES

Circular Economy in Water Sector and Italian Regulation Activities

A. Guerrini*
*aguerrini@arera.it

Abstract: In the circular economy system, the water sector is increasingly becoming a field of concrete experimentation and application on an industrial scale of techniques aimed at saving and producing energy, and at the production of materials from water treatment cycles. The water cycle itself represents a "circular economy system" connected to the use of water resources and to the processes of recovery of "secondary" resources, such as energy and materials. This presentation aims to identify the measures that can be taken by the institutions responsible for regulating the sector in order to encourage operators to invest in the circular economy and to develop corporate policies based on environmental sustainability and efficiency. It describes: the main actions for the recovery of energy and matter from the management of the water cycle; the current configuration of the regulatory measures adopted in Italy by ARERA; some future developments in regulation policies.

Keywords: Energy recovery; water cycle and circular economy; water reuse

The presentation focuses on the main actions for the recovery of energy and matter from the management of the water cycle, the related technical solutions, and the degree of diffusion among companies in the sector; the current configuration of the regulatory measures adopted in Italy to encourage investment in the circular economy, with particular reference to the case of the Energy, Networks and Environment Authority (ARERA), with expertise in the water service since 2011; some future developments that regulatory action could follow to offer more effective incentives to companies, in light of the risks to which investments in new business segments of the circular economy are subject, and the positive effects that these same investments can produce in terms of lower environmental impact (eg: CO2), reduction of business costs and/or new revenue opportunities.

Figure 1.1 The water cycle and the related circular economy system.

Among the energy-saving interventions, a peculiarity of the water service is the control of leaks. On the aqueduct system, the search for leaks is certainly a first step to reduce electricity consumption. Other measures can also be implemented in drinking water and wastewater treatment plants. The water service operators can also choose to produce electricity, exploiting the potential energy by the "jumps" of the path along which the pipelines run. In the wastewater treatment management, the wastewater treatment plant
can be operated as a factory of renewable resources. At an international level, experiences of reuse for industrial and irrigation purposes are becoming increasingly widespread on the purification front. However, both fronts of intervention on the circular economy system in the water cycle - energy-saving and social and environmental sustainability - have not yet benefited from special incentives from the national regulator, if not indirectly. With reference to the costs for the purchase of electricity, the tariff method does not currently provide, therefore, for measures to encourage energy-saving.

The possible impacts of the incentive mechanisms in the technical quality control model on the energy efficiency of operators may be indirectly visible. In fact, even though it is an output-based model, characterized by the technological neutrality of the regulator, many of the interventions and management activities planned by the operators to ensure the achievement of the targets identified (e.g. the containment of water leaks and the reduction of sewage flooding) may also be functional to energy saving and efficiency in the networks. Similarly, from the point of view of environmental sustainability, the objectives set for the purification activity, in particular that of minimising the need to dispose of sewage sludge in landfills, are requiring operators to make an effort with a view to pursuing alternative strategies for the recovery of material or the reuse of the total quantity of sludge produced, for example in agriculture, by direct spreading or by composting and producing soil improvers, or energy recovery by means of waste-to-energy plants. In Italy, the most advanced operators have experimental projects of production of biomethane from biogas obtained from the anaerobic digestion of sewage sludge. The direct benefits for the users deriving from such applications can be quantified in terms of reduction of the costs of electric energy and of fuel purchase, to which should be added the eventual revenue obtained from obtaining the public contribution and from the sale to third parties. Also with regard to electricity produced from renewable sources, the legislator has taken measures aimed at their dissemination, providing economic support (i.e. the mechanism of white certificates or energy efficiency certificates and the FER1 mechanism).

In the definitions of the water sector perimeter provided by the Italian regulator the activities of installing and managing 'water houses' or "high quality fountains" and 'reusing waste water' were included among the other water activities, i.e. 'other activities relating to water services'. These installations can therefore be of a tariff nature, or can take the form of a public contribution (generally municipal or regional funds). The water reuse in agriculture should be encouraged at European and Member State level. Supporting the development of circular economies (functional to the "closure" of the water cycle), through the pursuit of sustainability and energy saving objectives, can constitute a new phase in the regulatory process. The possibility of extending the regulatory instruments hitherto aimed at investment development, cost efficiency and quality of water services, including energy efficiency and environmental sustainability objectives, as a prerequisite for circular economy measures. The development of circular regulation of the economy within the integrated water service must also ensure the correct application of the european principle of full cost recovery of the service.

REFERENCES

AA.VV., Linee guida per la gestione delle perdite idriche nelle reti, disponibile sul web: http://www.madchild.it/ingciv/images/appunti/Crostruzionidralicic/WP3-IT.pdf


Novel Financing Strategies to Simultaneously Advance Sanitation and Agriculture Through Nutrient Recovery


*University of Illinois, 205 N Mathews Ave, Urbana, Illinois 61801, USA, hlohman2@illinois.edu, jtrimme@illinois.edu, rcusick@illinois.edu, jsguest@illinois.edu
**Community Integrated Development Initiatives, Zzimwe Rd, Kampala, Uganda, kinyumud@gmail.com, muwongemubasira@yahoo.com, nagirinymaria@gmail.com, frednserekom@gmail.com
***Makerere University, P.O. Box 7062, Kampala, Uganda, banadda@caes.mak.ac.ug

Abstract: Although access to safely managed sanitation is improving, over two billion people still do not have basic sanitation globally. The sixth Sustainable Development Goal seeks to achieve universal sanitation access; however, limitations in financial resources demand innovative approaches to meet this goal. Resource recovery may serve as a mechanism to improve access to agricultural nutrients, thereby creating income streams that could help offset sanitation costs. The objective of this work was to determine if resource recovery sanitation can enable profitable bodily waste management through the sale of recovered nutrients. A techno-economic analysis was used to assess the profitability of business models for use in Uganda. Results show that profitability can be achieved at a nutrient selling price at or below fertilizer market value in Uganda. This research makes a case to support innovative sanitation strategies and recovered nutrient markets in areas with poor fertilizer and sanitation access.

Keywords: Urine; struvite; ion-exchange

Globally, about 2.3 billion people lacked basic sanitation at the completion of the Millennium Development Goal era (UN, 2018). Although sanitation access is improving, the growth of more urbanized areas continues to put pressure on finances and urban infrastructure such as sanitation facilities (Nansubuga et al., 2016). In lower income countries, centralized sanitation systems often serve affluent parts of cities, while remaining areas rely on onsite facilities (Nansubuga et al., 2016). Wastewater collection and treatment is not affordable for many households, and in Uganda specifically, many households release the contents of sanitation facilities into drainage channels to avoid operation and maintenance costs (Banadda et al., 2009).

With over 80% of countries reporting insufficient funds to meet national water, sanitation, and hygiene targets, limitations in financial resources push us to consider innovation to meet multiple Sustainable Development Goals simultaneously (UN, 2018). Resource recovery sanitation is an opportunity to change the economics of wastewater by considering human waste as a valuable and revenue-generating resource (through water, energy, N, P, and K recovery). Global cost estimates to achieve universal sanitation coverage have been conducted but have been limited to conventional management systems and thus continue to constrain innovative thinking. Likewise, individual cost analyses of selected innovations often do not consider
financing strategies to link multiple goals. To bridge this existing gap in understanding, the overarching goal of this work was to determine if resource recovery sanitation can be a profitable business opportunity through selling recovered nutrients (N, P, K).

A techno-economic analysis framework was used to assess the economic viability of a proposed resource recovery scheme in Uganda by incorporating a discounted cash flow analysis to track life cycle costs and income (informed by local data collection in Uganda). The process includes urine collection from urine diversion dry toilets and centralized nutrient recovery of P through struvite precipitation, N through ion exchange, and K in the remaining waste stream. The study considers different financing scenarios to assess the profitability of the proposed recovery processes. The recovered nutrient selling price (USD per kg total nutrients (N+P+K)) was varied to determine the breakeven point of the business model and to compare to the typical market value of fertilizers in Uganda (Figure 1.1). Results show that multiple scenarios are profitable at a nutrient selling price at or below a fertilizer market value.

![Figure 1.1 Resource recovery sanitation eight-year profit potential. Nutrients recovered (N, P, K) are sold at a varying price point (USD∙kg⁻¹ total nutrients). Dark solid lines indicate the median value and shaded zones indicate 5th, 25th, 75th, and 95th percentiles. Profit can be achieved at or below the local fertilizer market value in Uganda.](image)

This work is an important piece to the overall conference theme of Resource Recovery because it shows under which scenarios nutrient recovery sanitation can be a profitable business opportunity, and it makes the case for a nutrient market that supports businesses specializing in product recovery and sale. Nutrient recovery from sanitation is not intended to undercut existing local businesses but serves as an additional source of nutrients in resource-limited locations.

REFERENCES


Integration of Statistical Monitoring and Life Cycle Assessment to Evaluate the Sustainability Behaviour of WWTPS

P. Stanchev*, V. Vasilaki Name**, E. Katsou ***

* Brunel University London, Kingston Lane, Uxbridge UB8 3PH, peyo.stanchev@brunel.ac.uk
** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, vasileia.vasilaki2@brunel.ac.uk
*** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, evina.katsou@brunel.ac.uk

Abstract: This paper presents an innovative approach of coupling statistical methods and life cycle analysis to evaluate the static and dynamic sustainability performance of wastewater treatment plants (WWTP) with activated sludge process. Statistical analysis has been performed including: screening stage to improve data quality, detection and diagnosis of abnormal events and faults, identification of operational states and data clustering. For the identified periods and operational states, static and dynamic Life Cycle Assessment (LCA) analysis has been performed following the ReCiPe Midpoint (H) method to evaluate the environmental impact of the WWTPs. Moreover, the trade-offs between direct and indirect emissions in each impact category and between the selected impact categories have been analysed in relation to the different WWTP operational states and environmental conditions. On this basis, comprehensive correlation and regression analysis have been conducted to reveal the statistical correlation between the WWTP inflow, operational, effluent parameters and the environmental performance. The approach has been tested using two-year operational data and dedicated direct GHG monitoring campaigns from a full-scale WWTP, located in UK. This study provides a methodological framework to analyse the sustainability performance of wastewater treatment processes and a step towards model predictive control of WWTPs including environmental aspects.

Keywords: Statistical based monitoring, data analytics, WWTP, dynamic LCA, sustainability performance

Figure 1.1 Graphical abstract of the concept
INTRODUCTION The wastewater treatment processes generate both direct and indirect emissions during biological processes (mainly CO2, CH4 and N2O) and indirect emissions associated with the energy, chemical consumption and transportation (Mannina et al., 2019). The mechanisms involved in the generation of the environmental impact have distinct dynamic behaviours determining a specific temporal occurrence. However, the current LCA methods consider mainly fixed time horizons or steady state conditions (Zang et al., 2015). To achieve efficient operation of the wastewater treatment processes some key variables involved in the process, such as dissolved oxygen, nitrogen, phosphorus, and pH, need to be accurately monitored and controlled (Harrou et al., 2018). Studies have applied historical data from WWTPs to develop statistical methods that predict profile of target process variables or key performance indicators that are difficult or cannot be monitored online. Data-driven techniques have been used to identify non-linearities and complex structures of wastewater treatment processes for process optimization, monitoring and control. However, the dynamic behaviour of the WWTPs is complex and uncertain due to the wide variations of influent composition, flow rate, variations in the physical properties and environmental conditions, dependencies between the process variables. These factors increase the difficulty of monitoring and control of the wastewater treatment process and challenge the conversion of the generated data into valuable information (Harrou et al., 2018). The main aim of this study is to combine statistical monitoring and environmental impact assessment techniques in order to analyse the dependencies between the WWTP inflow, operational, effluent parameters and the generated environmental impact in order to model the sustainability behaviour of the WWTP processes.

MATERIALS AND METHODS The proposed methodology includes statistical methods that convert the online and offline monitoring data from WWTP into information. Linear and multiple regression analysis have been applied to model the relationship between the inflow parameters (flow rate, precipitation, NH4, PO4, BOD, COD), operational parameters (DO, airflow, MLSS concentration, energy consumption), effluent parameters (NH4, PO4, BOD, COD) and the generated direct and indirect emissions. The LCA framework has been applied to calculate the environmental impact of the WWTP following the ReCiPe Midpoint (H) method.

CASE STUDY The approach has been demonstrated in a full scale WWTP with activated sludge process located in UK serving around 85,000 population. Two years of online and offline operational monitoring data have been collected for the purposes of the statistical analysis. Concerning the LCA analysis, measurements of the direct GHG emissions have been acquired from an installed online gas analyser coupled with a floating sampling gas chamber installed in the activated sludge reactor.

RESULTS AND DISCUSSION The statistical monitoring techniques enabled to identify and explain abnormal events occurring in the plant and select different periods of operation without any significant disturbances. Regression analysis revealed the relationship between key parameters. Figure 2 shows the relationship between the direct N2O emissions, ammonia and DO parameters within the different lanes of the activated sludge unit and the results from the regression analysis on the right side. The overall results from the carbon footprint analysis are shown in figure impact assessment analysis.
CONCLUSION This study demonstrates an innovative approach of coupling statistical monitoring and LCA concepts, which revealed the link between the temporal variations of the wastewater treatment processes operation induced by different internal and external factors and the environmental performance of WWTPs. The developed data-driven LCA framework has been applied both for static and dynamic benchmarking of the wastewater treatment processes to provide recommendations for the optimisation of the process operations under specific influent and environmental conditions. The latter enabled to better understand the sustainability performance of WWTPs and is a step towards model predictive control, including sustainability aspects, of WWTPs.

REFERENCES


Evaluation and Cost-Efficiency of On-Site Wastewater Reuse Systems


*University of Ljubljana, Faculty of Health Sciences, darja.istenic@zf.uni-lj.si
**University of Ljubljana, Faculty of Civil and Geodetic Engineering

Abstract:
Green technologies can offer various benefits due to their nature-based solution approach focusing on producing valuable products while treating wastewater (WW). The composition of WW corresponds to the willows’ and algae’s nutrient needs which enables efficient water treatment and biomass production. The results on pilot evapotranspirative willow system (EWS) and algae-based technology (ABT) showed that for the treatment of WW produced by 1 person, 42 would be needed for EWS and 5-10 m² for ABT, while producing 140-170 kg of wood biomass and 73-146 kg of algae biomass per PE/year. The study lays the foundation for future research on the WW treatment with EWS and ABT with the aim to close nutrient cycles and produce environmentally-friendly fertilizers in the form of treated effluent and wooden or algae biomass.

Keywords: natural-based system; zero-discharge; algae system

Green technologies (GreenT) are one of the means for resource recovery from municipal wastewater (WW). They can recover nutrients via biomass production and produce treated water for reuse; however, most GreenT still need improvements of performance and economic feasibility. Two GreenT were established in Ajdovščina, Slovenia, namely algae-based technology (ABT) with the production of algae biomass and treated water for irrigation, and evapotranspirative willow system (EWS) with zero outflow for wood biomass production. The aim is to optimize and evaluate EWS and ABT on real-case for optimal production and reuse of resources. The algae biomass can be used for fertilizers, and other bio products (Delgadillo and Sims, 2011), while the wood biomass from EWS can be used for energy or composting matrix. Furthermore, the composition of WW corresponds to the willows’ and algae’s nutrient needs which thus enables efficient reduction of nutrients, BOD, heavy metals and pathogens in WW, while increasing the yield and profit (Gouveia et al., 2016; Gregersen and Brix, 2001). However, the treatment efficiency of ABT depends on light availability for algae growth, pollution load, hydraulic retention times, and surface area while the performance of EWS primarily depends on evapotranspiration (ET), which all need to be addressed appropriately.

EWS have no discharge to the environment since all WW is used for ET. EWS consists of a waterproof bed filled with soil and planted with willows. The pilot EWS consisted of 9 beds (each 3 m long, 1 m wide and 1.8 m deep and planted with 3 willow trees). The beds were positioned one by another to form one uniform stand. We have tested biomass production of 3 white willow clones, namely the autochthonous white
willow ‘V 160’ (*Salix alba*) and two of its hybrids ‘V 052’ (*S. alba var. calva* x *S. alba*) and ‘V 093’ (*S. alba* x *S. alba var. vitellina*) x *S. alba*). The beds were filled with mechanically pre-treated WW according to the willows’ water needs. The EWS was established in 2015 and monitored for 3 years.

Aside from the pilot EWS, ABT of 3 m³ was constructed in 2018 and put in operation in 2019. The media was established from mechanically pre-treated WW to which a pure culture of *Chlorella vulgaris* was added. Since the pond is open-system, other algae species were also introduced. The media is constantly stirred with a paddle wheel at speed 0.2–0.3 m/s. The initial inflow of 150 L/day is expected to be increased to 300 and finally to 600 L/day. The system was dimensioned, and algae biomass production was calculated according to the operation parameters of an ABT for treatment of digestate from a biogas production plant and black water (Griessler Bulc et al., 2017).

The results showed that for the treatment of WW produced by 1 person, 42 would be needed for EWS and 5-10 m² for ABT. EWS produced 140-170 kg of wood biomass (Istenič et al., 2018) and ABT is estimated to produce 73-146 kg of algae biomass per PE/year (i.e. 3.2-3.9 kg of wood or 1.67-2.34 kg of algae biomass from 1 m³ WW). For a household with 4 people this means 561 do 683 kg of wood biomass per year. The price of woodchip in Slovenia is 0.05 €/kg which means that annual savings of the household due to produced biomass are 28-34 €. In case of household level ABT would produce 292-384 kg of algae biomass. The monetary value of so produced algae biomass is difficult to estimate since the algae can be used for various purposes; however, at the household level the most cost-effective reuse is as a fertilizer for lawns, namely P:N ratio of algae biomass 1:4.7 is close to the ratio needed for grass (1:3). The TP in dry algae biomass is 14 gP/kg and the TN is 66 gN/kg (Masi et al., 2017). Considering that grass demands at least 15 gN/m²/year, the produced biomass enables fertilization of 4.4 - 8.8 m² of grass.

EWS and ABT can be an appropriate solution for WW treatment, nutrient recovery and biomass production. Major drawbacks are high areal footprint and seasonal dynamics which can be managed by precise modelling of related parameters, which will be further evaluated.

REFERENCES


Life Cycle Assessment and Cost-Benefit Analysis of a Multi-Step Process of Olive Mill Wastewater Valorization through Polyphenol Adsorption and Anaerobic Digestion

D. Frascari*, T. Wardenaar**, E. Oertlé***, A. Jaouani****, D. Pinelli*
*Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Italy, dario.frascari@unibo.it
**PNO Consultants BV, Rijswijk, The Netherlands, Tjerk.Wardenaar@pnoconsultants.com
***Institute for Ecopreneurship, University of Applied Sciences and Arts Northwestern Switzerland, Muttenz, Switzerland, emmanuel.oertle@fhnw.ch
****Institut Supérieur des Sciences Biologiques Appliquées de Tunis, Université de Tunis El Manar, Tunisia, ajaouani@yahoo.fr

Abstract: Olive mill wastewaters (OMWs) represent a major environmental concern due to their high organic load and phytotoxic activity. The selective recovery of phenolic compounds (PCs) from OMW is promising, thanks to the antioxidant and antimicrobial properties of PCs. The goal of this work was to perform the life cycle assessment (LCA) and cost-benefit analysis (CBA) of a full-scale process of PC adsorption/desorption on resin Amberlite XAD16N designed on the basis of laboratory tests aimed at performing a preliminary process optimization. The results indicate that the proposed technology, if integrated with an anaerobic digestion step, represents a promising solution for the treatment and valorisation of OMW, a major agro-industrial waste in Mediterranean countries.

Keywords: Olive mill wastewater; antioxidants; anaerobic digestion; life cycle assessment; cost-benefit analysis

MAIN RESULTS Adsorption tests were conducted at different velocities in a 1.8-m column packed with XAD16N. The optimal superficial velocity and retention time (2.78 m/h and 0.56 h) allowed the attainment of satisfactory performances in terms of resin operating capacity (0.46), PC adsorption yield (0.92), PC mass fraction in the sorbed product (0.50 gPC/gVS) and specific antioxidant activity (3-6 gascorbic acid/gPC). In order to perform an LCA and CBA of the proposed technology for PC recovery, a scale-up of the adsorption / desorption process was performed. The LCA and CBA were referred to 1 season of olive oil and OMW production. The total OMW volume to be treated during the season was set to 10000 m3, a typical value for a large size olive mill. The OMW flow-rate fed to the plant was set to 4.17 m³/h, so as to obtain a total treatment time equal to about 4 months, a period comparable to the OMW production period. The same operating conditions of the best performing lab-scale test was applied as scale-up criterion. The resin bed height and the column diameter of the industrial plant resulted equal to 1.82 and 1.38 m respectively. The dry mass of resin XAD16N to be loaded in the plant resulted equal to 700 kg, corresponding to 975 L of commercial resin.

Life cycle assessment The LCA of the PC recovery process was performed following the stages defined by the ISO 14040 standard. The goal of the LCA was to identify
which components of the plant and process contribute mostly to the overall environmental impact, so as to identify improvement potential. The software SimaPro 8.4.0 and the database Ecoinvent 3.3 were utilized. Five LCA methods were applied and compared. For all methods, the selected functional unit was the treatment of 1 m³ of OMW. The ILCD 2011 Midpoint+ method was selected for a more detailed analysis of the results, as it is a widely recognized and harmonized method at European level. The process shows an overall environmental burden of 4.6 mPt/m³OMW. The highest contributions result from the treatment of the residual dephenolized OMW (2.4 mPt/m³), infrastructure (0.9 mPt/m³), electricity for pumping (0.5 mPt/m³), heat for the evaporation of the solvent used in the desorption, ethanol (0.3 mPt/m³) and solid waste anaerobic digestion (0.2 mPt/m³). The overall environmental impact of the process resulted equal to about twice the impact of the benchmark process, i.e. of the treatment of raw OMW in a municipal WWTP. However, the results indicate that there is a large potential to improve the process environmental performance by adding an additional treatment step – such as anaerobic digestion – to make the treated OMW reusable for irrigation.

Cost benefit analysis The CBA was performed according to the European Union guidelines for the appraisal of investment products. The goal was to determine the minimum market price at which the recovered PC should be sold to generate a positive business case for the OMW producer. In particular, a 6% of the weighted-average cost of capital (WACC) was selected as the key threshold in order to determine a positive investment decision. The CBA was referred to a 20-year period, assuming a financial discount rate equal to 4%. The cost of the plant’s equipment (CAPEX) was determined by means of the SuperPro Designer® software. The plant’s operational and maintenance cost (OPEX) was based on the process inventory and on the application of standard unit costs for reagents, energy and labor in Europe obtained from the Eurostat database and from the quotations for the price of chemicals obtained from two major suppliers of chemicals. The industrial price of resin XAD16N was provided by the resin supplier (DOW Chemicals). An average 2% price inflation was applied to correct for price increases to the reference year. The PC market price required for the generation of a positive business case resulted reasonable (1.7-13.5 €/kgPC) and depending on the PC concentration in OMW (that was assumed to vary over the 0.5-4 g/L range). Considering that the market price of PC-rich products varies in the 250-2500 €/kgPC, even though a further refining is certainly required for the PC-rich product object of this study, the resulting price range for the generation of a positive business case is likely to be a realistic one.

CONCLUSIONS The LCA indicated that the highest environmental burdens are due to the treatment of the dephenolized OMW, to the heat required to evaporate the desorption solvent and to the need of a periodic ethanol reintegration. The overall environmental burden could be significantly reduced through the addition of an anaerobic digestion step for the production of irrigation-quality water and fertilizers from the dephenolized OMW. The cost analysis of the proposed technology indicated that the PC market price required for the generation of a positive business case (1.7-13.5 €/kgPC) is a reasonable one, and that therefore the proposed process for PC adsorption has chances to find a successful implementation in Mediterranean regions characterized by a relevant OMW production.

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Measuring the Circularity Potential of an Eco-Friendly Touristic Facility in a Mediterranean Island

C.E. Nika*, P. Stanchev**, E. Katsou***

*Brunel University London, Kingston Lane, Uxbridge UB8 3PH, eliza.nika@yahoo.gr
** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, peyo.stanchev@brunel.ac.uk
*** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, evina.katsou@brunel.ac.uk

Abstract: Green Infrastructure, Nature-based Solutions (NbS) and biomimicry can be seen as sustainable solutions tackling the problem of reduced water availability and jeopardized water quality by enabling water reuse and recycling. However, the lack of a holistic methodological framework assessing water systems (combination of centralized, decentralized and NbS) is limiting their transferability and wider implementation. The current work aims at the development and application of a circular assessment methodology of such systems, taking into consideration metabolic profiles of water, and water-related energy and nutrients, environmental impacts, socio-economic values and products valorization pathways. Performance indicators that can be used as metrics of sustainability and circularity were derived. The methodology was applied in an eco-friendly touristic facility (Eco-lodge) in Tinos Island, Greece enabling the quantification of the proposed indicators with validated data, as well as assessment of the costs and benefits of the hybrid water system.

Keywords: Sustainability and circularity assessment; nature-based solutions; water and nutrients reuse & recycling

INTRODUCTION In the Mediterranean region, the rising domestic, industrial, and agricultural water demands superimpose on the uneven distribution of water supplies causing an increased water stress (Capone et al., 2012). Climate change is furthermore considered to exacerbate water scarcity (Roson and Damania, 2017). In order to protect and enhance nature and natural processes, as well as to promote a long-term sustainability, the European Commission has invested in GI and NbS as tools that simultaneously provide environmental, economic and social benefits (Faivre et al., 2017). These solutions further enable water and nutrients reuse and recycling, highlighting the link to the concept of circular economy (Voulvoulis, 2018). Efforts have been made to evaluate the performance of such solutions focusing on their costs and benefits by either proposing indicators that have not been applied in operational environment (Calliari et al., 2019), or by assessing one specific solution (Zolch et al., 2017). The focus of the current work is on the development and application (at operational environment) of a holistic methodology to assess the sustainable and circular performance of hybrid water systems (decentralised GI, NbS and biomimicry solutions coupled to a conventional water system).

MATERIALS AND METHODS The methodological framework was based on the concepts of Urban Water Metabolism and Material Flow Analysis, LCA, Harvest to Harvest Approach, and LCC and Cost-benefit Analysis.

CASE STUDY The developed methodology was applied in an eco-friendly touristic facility (Eco-lodge) in Tinos Island, Greece. In Tinos Eco-lodge drinking water
supplied from the centralized network is used for potable uses only, whereas off-grid solutions are implemented to cover the domestic and agricultural water needs.

**RESULTS AND DISCUSSION** The coupling of the concepts mentioned in Materials and Methods section enabled the consideration of metabolic water, water-related energy and nutrients flows, environmental impacts, enhancement of ecosystem services, socio-economic values, and valorisation pathways. Circularity and sustainability indicators were derived from this assessment and they were successfully quantified with validated data of Tinos Eco-lodge. Figure 1.1 illustrates the water balances in Tinos Eco-lodge Water System.

![Figure 1.1 Basic Water flows in Eco-lodge Water System](image)

**CONCLUSIONS** A holistic methodology assessing the sustainability and circular performance of hybrid water systems was developed in order to address water scarcity. Qualitative and quantitative performance indicators were derived and validated with real data. The methodology was applied in an eco-friendly touristic facility, where centralized and off-grid solutions are used, evaluating the sustainability and circular potential of the studied water system.

**REFERENCES**


Tuesday, 10th September 2019

Session 7

URINE VALORIZATION AND WATER REUSE
Conversion of Urine-Diversion Double-Vault Toilet (UDDT) Faecal Sludge Fractions into Beneficiated Products

M. Vivian*, N.B. Ndlovu, Sudhir Pillay**, A.O. Olanrian

*Discipline of Microbiology, School of Life Sciences, Westville Campus, University of KwaZulu-Natal, Durban, South Africa  
**Water Research Commission, 4 Daventry Road, Lynnwood Bridge Office Park, Pretoria, South Africa. Email: sudhirp@wrc.org.za

Abstract: The eThekwini Municipality has around 80,000 Urine Diversion Double-Vault Toilets (UDDTs). To explore the beneficiation of source-separated waste from these toilets, the municipality has commissioned a Black Soldier Fly (BSF) larvae processing plant and a struvite processing facility for the faecal and urine fractions, respectively. A key research need identified for the continued beneficiation of waste was the microbial risks associated with struvite production from urine and optimisation of the BSF larvae growth and subsequent pathogen and sludge volume reduction capabilities. The research provided key insights to the source of contamination from struvite-derived urine and optimal conditions for digestion of UDDT faecal sludge.

Keywords: Faecal Sludge Management, Struvite, Black Soldier Fly Larvae

BACKGROUND  
The eThekwini Municipality covers an area of 2,291 km² with the city of Durban as its core. Due to the legacy of apartheid spatial planning, urbanised areas are generally characterised by sanitation provision through connection to full flush reticulated sewerage. South Africa is a water-scarce country and full flush reticulated sewerage is technically not feasible throughout the country. For this reason, the municipality implements waterless sanitation outside the sewered network.  

Indigent households outside the sewered infrastructure are serviced with Urine Diverting Double-Vault Toilets (UDDTs). Around 80,000 UDDTs have been installed in eThekwini as alternative to Ventilated Improved Pit (VIP) latrines. UDDTs, as the name suggests, physically separate the urine and faecal component at the pedestal bowl interface. The benefit of urine and faecal separation are numerous. First, a drier sludge product results from urine/faeces separation with reduced sludge volumes to be handled and disposed. Second, urine which is rich in plant nutrients, can be harvested for use in food gardens. The processing of collected urine was explored through the VUNA (Valorisation of Urine Nutrients in Africa) Project (see: https://www.eawag.ch/en/department/eng/projects/vuna/), which sought to extract phosphorus through struvite precipitation for agricultural purposes.

The urine collected from UDDTs are different from fresh urine as they contain high ammonia concentrations, a high pH value and a strong odour caused by degradation of urea and other organic substances. During the processing of collected urine, it was noted that struvite cakes may contain pathogens which is a cause for public health concern (Bischel et al., 2015). Understanding the cause of pathogen accumulation in
struvite cakes and optimising the struvite processing could potentially reduce microbial risk. This aspect is explored in this paper.

The second objective of this study was to evaluate the potential of Black Soldier Fly (BSF) (*Hermatia illucens*) larvae technology for the treatment of collected faecal fraction from UDDTs. BSF are not pests and have a limited lifecycle. The larvae feed on animal manure, fresh human faeces and municipal organic matter and able to consume a large amount of organic matter in a short period of time while reducing pathogens (Diener et al., 2011 and Bank et al., 2014). The larvae can be harvested and the lipid processed into animal feeds and oils. This objective of the study aimed at investigating the potential of BSF for the effective digestion of faecal sludge from UDDTs. The results would be used in a technical-scale BSF larvae plant commissioned in eThekwini for the processing collected UDDT sludge.

**MATERIAL AND METHODS** Urine was collected from collection tanks serving households in a peripheral informal settlement in Durban. The urine was collected and transported to the Newlands Mashu field test facility by municipal workers for immediate sampling and analysis. The collection was conducted in triplicate and samples for microbiological analysis were collected in sterile 50mL centrifuge tubes. The samples were taken to the laboratories at the University of KwaZulu-Natal (Westville Campus) for analysis. A manual 320L struvite reactor was used to produce struvite from fresh urine at the EWS Newlands Mashu facility (100g of struvite from 160L of urine). Details of the system will be provided in presentation and paper submission.

UDDT sludge and food waste were collected from the Isipingo BSF larvae treatment plant. Bagasse was collected from Eston sugarcane mill, while poultry feed was bought from a local pets and aquarium store. Two-day old BSF larvae were obtained from AgriProtein in Cape Town. Different substrates (food waste, bagasse and poultry feed) and different UDTT sludge to substrates ratio were tested to optimise the growth of BSFL while digesting the UDDT sludge. Further in-depth details will be provided in the presentation and paper submission.

**MAIN FINDINGS AND CONCLUSIONS** Both bacteriophages (MS2, Phi174x) and somatic coliphage (*E. coli* 13706) used in this study were found in the struvite produced from collected urine (1000’s PFU/g – results not shown). The results indicate that cross contamination of urine may be occurring. It is hypothesised that this could be through incorrect UDDT usage with faeces entering the urine collection receptacle. It is recommended that municipality re-start their community education programme on the use of UDDTs. Different processing temperatures were tested to reduce the pathogen load detected in struvite cakes. A minimum of 12h was required to reduce pathogen load with Salmonella species showing greater resistance to heat processing (Fig.1.1).

Research was also undertaken to increase struvite processing capability through optimization of parameters affecting P & N recovery from urine (results not shown). Guidelines for the processing conditions of urine and applications of the urine-derived struvite were developed from the research.
BSF larvae growth was accessed under various substrate conditions is shown in Table 1.1.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment 1</td>
<td>Urine Diversion (UD) Faecal Sludge + 80ml distilled water</td>
</tr>
<tr>
<td>Treatment 2</td>
<td>75UD + 25 Food Waste (FW) + 40ml distilled water</td>
</tr>
<tr>
<td>Treatment 3</td>
<td>50UD + 50FW + 80ml distilled water</td>
</tr>
<tr>
<td>Treatment 4</td>
<td>75UD + 25PF + 120ml distilled water</td>
</tr>
<tr>
<td>Treatment 5</td>
<td>50UD + 50PF + 320ml distilled water</td>
</tr>
<tr>
<td>Treatment 6</td>
<td>75UD + 25Bagase (B) + 40ml distilled water</td>
</tr>
<tr>
<td>Treatment 7</td>
<td>50UD + 50B +80ml distilled water</td>
</tr>
</tbody>
</table>

The experiments revealed that the faecal sludge (with or without substrate amendment) was supportive of the growth of the BSFL (data will be shown during presentation). The faecal sludge was also properly digested by the BSFL, resulting in a very significant reduction in bacterial pathogens tested. An increase in nutritional content of the faecal sludge, notably phosphate and potassium, was also noted after the digestion process. The pH of the digested sludge ranged between 6.5 and 8.8, which is indicative of the possible land application of the sludge. The lipid and protein analysis of the BSFL suggest their possible biotechnological use.

REFERENCES
Achieving Nutrient Resource Efficiency through Urine Separation, Processing and Reuse: A Comprehensive Study


*University of Michigan, Ann Arbor, MI USA. nglove, jlarvai, gdaigger, rdhardin, sphilton, gregak, llucinda, njlowe, ered, skerlos, kwigg, all “@umich.edu”

**Rich Earth Institute, Brattleboro, VT USA. abe, arthur, kim, all “@richearthinstitute.org”, tatianas@sover.net

***University of Buffalo, Buffalo NY USA. dianaaga, radickma, rpetteys, all “@buffalo.edu”

****Stanford University, Palo Alto, CA USA. wtarpeh@stanford.edu

Abstract: Urine separation, processing and reuse introduces a way to accomplish both nitrogen and phosphorus recovery. Challenges over the scalability of this practice requires both field and model-based analyses. This presentation will convey the results of a multifaceted study that includes experimental work (collecting urine, processing it, applying it as a fertilizer, and evaluating the food crops produced), emerging contaminant assessment, life cycle assessment modeling, user behavior assessment, and demonstration of a building-scale “smart” urine separation and processing system.

Keywords: Urine; peecycling; nitrogen; phosphorus

Nitrogen (N) and phosphorus (P) are both critical elements that support food production yet negatively impact water quality if poorly managed. P recovery is well established in centralized wastewater treatment systems; however, recovering P in highly diluted waste streams–albeit commonly applied–is highly inefficient compared to doing so with concentrated waste streams. N recovery methods are not as well developed and, again, are more efficient from concentrated waste streams. Human urine contains the majority of N (~85%) and P (~60%) in human waste and, therefore, is a viable target for nutrient recovery from domestic wastewater systems (whether centralized or decentralized). Our presentation will convey the results from a comprehensive study that is evaluating urine separation, processing and reuse as a strategy for nutrient recovery. Our study includes multiple components: (i) a life cycle assessment (LCA), (ii) urine processing technology development and demonstration, (iii) field trials with food crops, (iv) monitoring of chemical (pharmaceuticals) and microbiological (bacteria and virus) fate from fertilizer to crop, (v) crop quality analysis including micronutrient levels, (vi) an attitudinal assessment, and (vii) demonstration of a “smart” building-scale urine separation and processing system.

We have experimentally assessed multi-step urine processing methods that achieve nutrient concentration, odor control, and contaminant reduction. Process 1 included: activated carbon adsorption to remove pharmaceuticals, membrane or freeze/thaw concentration, and pasteurization for pathogen elimination. Process 2 included: struvite precipitation to capture phosphorus and ammonium sulfate production using ion
exchange. For each approach, we: are finalizing measurement of nutrients and pharmaceuticals; used UDFs created by each process to grow crops that we assessed for yield and pharmaceutical content; and are measuring crop micronutrient levels. Field trials were conducted in Vermont USA and included lettuce and carrots treated by Process 1 using freeze/thaw for concentration, Process 1 without activated carbon treatment, Process 2, synthetic fertilizers, or no fertilizer. Crop yield (dry mass) did not differ significantly between treatments. The average for the control treatment was about half that of the fertilized treatments; however, it was also the most variable and we cannot say that it is statistically different. This means the UDF and synthetic fertilizer yields were comparable, and fertilized treatments had much lower variability in crop yields than unfertilized controls. Pharmaceutical results are being analysed: all our methods are developed for chemical levels in water, soil and crop tissue samples, all samples have been collected, analyses are underway and results will be presented. Work on virus fate during UDF processing has been completed (Goetsch et al., 2018) as well as antibiotic resistance gene levels and fate. In all cases, we find that although DNA is detected in processed urine, it is unlikely to be infectious or transferrable. Therefore, one must look beyond DNA-based methods to assess the public health impact of emerging contaminants.

A comparable LCA analysis has been completed (Hilton et al., 2018) and a final uncertainty analysis is underway. The analysis compares centralized treatment as practiced in three regions of the U.S. that have different nutrient discharge standards (modest in the Upper Northeast, moderate in the Great Lakes region, and stringent in the Chesapeake Bay region) to UDF Process 1 (using membrane-based concentration, and adding urine acidification to prevent precipitation in plumbing and to keep nitrogen in the urea form) and Process 2. The results show that the UDF scenarios had the lowest environmental impact in all categories evaluated (global warming potential, eutrophication, cumulative energy demand, water consumption) but one (acidification). The model outcomes suggest that urine separation, processing and reuse should focus on optimizing the stabilization and collection of urine, and the electricity needed for concentration and sulfuric acid needed for ion exchange. In wastewater treatment facilities lacking strict effluent nutrient limits, urine diversion will not significantly reduce operational burdens, but will significantly decrease the amount of N and P in the effluent. In places with strict effluent limits, urine diversion will not significantly affect the amount of N and P released as effluent, but will significantly lower the impacts associated with treating wastewater.

Two other components of our study will be summarized during the presentation. First, our team is completing a nation-wide survey of user attitudes about use of foods fertilized with UDF compared to other fertilizer forms. The results are being analyzed and will be used to understand barriers to acceptance and will guide communication strategies that can help to advance acceptance towards urine diversion and use of UDF-fertilized products. Second, we developed a building-scale system for transforming urine near the point of generation into sanitized and concentrated fertilizer using Process 1 without activated carbon. The building-scale demonstration, automated for both real-time control, data collection, and remote management, will be introduced.

REFERENCES
Safe Production of Microbial Protein from Urine


* Technical University of Denmark, Department of Environmental Engineering, Building 113, DK-2800 Kgs. Lyngby, Denmark (Corresponding author: bvape@env.dtu.dk)
** Veolia Water Technologies AB, AnoxKaldnes, Klosterängsvägen 11A, SE-226 47 Lund, Sweden

Abstract: An electrochemical cell was used for ammonia extraction from urine. Extracted ammonia was free of trace elements and thus suitable for production of microbial protein. Protein quality was similar to that obtained using dAMS media for cultivation of methanotrophic bacteria.

Keywords: Single cell protein; methane oxidizing bacteria; nutrient recovery

An increasing global population is causing alarming depletion rates of many planetary resources: production of chemical fertilizers alone has increased by 500% over the last 50 years due to agricultural intensification to supply the animal and vegetable protein for human consumption. Current modes of agricultural protein production are inefficient, generate large amounts of waste, have a high land and water footprint, are energy intensive, and are ultimately unsustainable. Therefore, new and lower-footprint modes to produce protein-rich feed or food ingredients are needed. Single-cell protein (SCP) consisting of microbial biomass – grown on various resource streams – can generate nutritive proteins – with quality equal or exceeding those of traditional references like soy of fishmeal – at a lower cost than traditional protein production chains (Matassa et al., 2016). Large amounts of nutrients are excreted and conveyed into domestic sewage. Conventional wastewater management involves nutrient removal and is both energy and chemical resource intensive. As nutrients in sewage are diluted and contaminated with fecal pathogens, their safe recovery is not trivial. Yet, urine contributes 80% of all the nitrogen (N) and 50% of all the phosphorus (P) in domestic sewage in a small fraction of the total sewage volume and with minimal pathogen content. With urine separation gaining momentum a nutrient concentrated stream has become available which is suitable for recovery and upcycling (Maurer et al., 2003). The ambition of this work is to demonstrate the production of high-quality microbial protein using nutrients from urine for cultivation of methanotrophic bacteria.

A 2 chamber (200 cm³ each cell) electrochemical reactor was used for ammonia extraction from male urine (anode chamber), using 50 mmol sodium bicarbonate solution as electrolyte in the cathode chamber (Fig. 1.1). Chambers were separated with a strong acid cation exchange membrane. The cathodes were made of titanium alloy (anode coated with IrO₂). The applied voltage was 3.5 V. Urine was spiked with different pharmaceuticals or recalcitrant chemicals, including 1-H-benzotriazole, 5-methyl-1H-benzotriazole, carbamazepine, atrazine, ketoprofen, diclofenac, clofibric acid, bezafibrate, mecoprop and gemfibrozil. After 48 hours 42% of the ammonia
could be extracted to the cathode chamber with an efficiency of 35%. Extracted resources were free of spiked pharmaceuticals or pesticides and thus could be used for feed-grade microbial protein production. Similar experiments were run using municipal household waste and digested manure as ammonia source.

250 mL serum bottles were used for cultivating an enrichment of methanotrophic bacteria. Bottles were filled with 80ml active cultures and 18.5 ml of the headspace were replaced with methane to ensure a favourable ratio of 60:40 of oxygen to methane. Three different sets of experiments were run: i) control experiments using dAMS medium; ii) extracted ammonia with pH correction using a phosphate buffer; iii) extracted ammonia supplied with trace elements and pH corrected using a phosphate buffer. Batches without trace elements did not support the growth of methanotrophic bacteria. However, both the control and the batch with extracted ammonia showed similar performance in terms of methane yields and microbial growth. Both showed similar amino acid profile (Fig. 1.2), but lacked some essential amino acids (e.g., methionine, valine and histidine) compared with already commercialized Uniprotein® microbial protein.

**REFERENCES**


Green Walls Optimized for Treatment and Reuse of Greywater


*IRIDRA Srl, Florence, Italy, fmasi@iridra.com
**Politecnico di Torino, DIATI - Department of Environment, Land and Infrastructure Engineering, Torino, Italy
*** Centre for Hydrosystems Studies, Technical University of Lisbon, Lisbon, Portugal

Abstract: Greywater can be a valuable non-conventional water resources for uses requiring a not-potable water quality, such as WC flushing and irrigation. Greenwalls can be an interesting nature-based solution to treat and reuse on site greywater. This study wants to present results from a pilot study, which investigated different mixtures of conventional and innovative materials used as growing media. The aim is to identify the most efficient green wall configurations in terms of treatment efficiency.

Keywords: Greywater; Green walls; Nature-based solution

The sustainable management of water resources is one of the most concerning challenge to cope with water scarcity and increasing water demand. The treatment and the reuse of wastewater represents a valid and convenient solution that is progressively spreading, turning wastewater from a waste to a valuable resource for water, energy, and nutrients. Specifically, the portion of wastewater more suited for treatment and reuse is greywater, defined as household wastewater with the exception of toilet flushes and sometimes also kitchen sinks. Due to the segregation from higher contaminated blackwater, greywater are easier to be treated and one of the most promising non-conventional water resources to build a future sustainable water management in line with circular economy principles (Masi et al., 2018).

Nature-based solutions can be a valuable tool to treat and reuse greywater, due to their low operational and maintenance costs as well as the additional provided ecosystem services. For instance, constructed wetlands have proved to be suitable to this aim (Arden and Ma, 2018). On the other hands, high required land footprint can limit their application in cities. In this context, the conversion of green walls, not only for heat balance and aesthetic, but also for treatment and reuse of greywater is a promising option (Pradan et al., 2019). However, the study of this option is still at a preliminary stage and few studies are currently available (e.g. Masi et al., 2016, Prodanovic et al., 2017).

In this study, we propose an innovative green wall for treatment and reuse of grey wastewater, to be implemented in urban areas on unused surfaces of buildings. We performed experimental tests aimed to identify vegetation types and light growing media (e.g., coconut fiber, Polyacrilate, Biochar, activated carbon) suited for pollutant
removal from greywater and aesthetically pleasant. The identification of design and operational parameters has led to the construction of a green wall daily fed with synthetic greywater. The removal efficiency of the green wall was weekly monitored with regards to different pollution parameters.

Preliminary results showed good results in terms of treatment performances, indicating the suitability of the green wall for treatment of greywater. BOD5 removal higher than 90% were observed, as well as E. Coli concentration below 100 MPN/100 mL. COD removal up to 60% were observed. TN and TP removal are less evident, even if the effluent concentrations remain low (below 4 mg/L and 1.5 mg/L, respectively) due to low influent concentrations. Experiments are still running to verify differences in removal efficiency among different system configurations in terms of type of growing material and optimize the removal of some pollutant parameters (e.g. TSS and COD).

![Figure 1.1 Setup of experimental pilot green walls.](image)

**REFERENCES**


Improvement of Water Quality Through BAC Filtration in a Water Reclamation Plant


*Department of Civil and Environmental Engineering, University of Florence, Via S. Marta 3, Florence (IT), email addresses: laura.palli@dicea.unifi.it; stefanofiaschi.ski@gmail.com; claudio@dicea.unifi.it; riccardo.gori@dicea.unifi.it.
**G.I.D.A. SpA, Via Baciacavallo 36, Prato (IT), email addresses: m.allocca@gida-spa.it; v.viviani@gida-spa.it; r.camisa@gida-spa.it; d.fibbi@gida.spa.it.

Abstract: In the present work, a study on the effect of different dosage of oxygen in full scale biological activated carbon (BAC) filters has been carried out. In particular, the performance of the plant in removal of color, COD and ammonium have been evaluated. Comparing the average removal rates of these three parameters, the increase in oxygen dosage leads to an increase of 40% of ammonium removal, 10% of COD removal and 6% of color removal with respect to the low-oxygen filter. On the other hand, considering the costs for energy requirements and oxygen supply, costs for the two different dosages have been estimated to 0.033 €/m³ for filter with high oxygen and 0.009 €/m³ for filter with low oxygen. The amount of biomass in different sections of the two filters have also been carried out through respirometric tests. Results indicated that higher dosage of oxygen resulted in higher amount of biomass (about three times on average), well distributed through the depth of the filter.

Keywords: Water reclamation; biological activated carbon; biofilm

Among the resources that can be recovered from wastewater, water itself and energy are at the same time the easiest, due to the well-established technologies for their recovery, and also the more important, due to their broad use at every level in the society. On the other hand, economic sustainability of wastewater reclamation and reuse processes is essential and it is important to properly balance costs for wastewater reclamation and quality of reclaimed wastewater. Water in particular is very scarce in some areas and its recovery from wastewater should be increased. For example, Prato (Tuscany, Italy) is an important textile district which is one the more water-consuming industrial sector (Vajnhandl and Volmajer Valh, 2014). In the past, the main water supply source of the city was the local groundwater, leading to a progressive depletion of this resource. For this reason, wastewater reclamation has played a key role for the industrial district since 1990s (Caretti et al., 2011), through a refining plant managed by GIDA SpA. The plant is composed of the following sections: chemical decoloration, sand filtration, biological activated carbon (BAC) filtration and then disinfection with sodium hypochlorite and hydrogen peroxide. The most expensive section in term of operational cost is the BAC, due to the energy demand (required for the oxygen transfer) and the oxygen supply cost. Among the 5 BACs of the plant, two of them worked in parallel from 2012 until 2018, treating about 3·10⁶ m³ of water each, but one (filter A) having a doubled oxygen dosage than the other (filter B). In the present work, a study on the effect of the different dosage of oxygen on the performances of the plant has been carried out. A comparison between the filters A and B has been carried out in
terms of removal efficiency of color, \( \text{N}_\text{NH}_4^+ \) and COD, which are key-parameters for water reuse in textile wet-processes (Table 1.1). A regular decrease of performance over the time can be seen for color, which is removed mainly by adsorption. On the contrary, ammonium removal, by means of biological processes, doesn’t show any tendency with a typical high variability due to influent concentration. COD removal shows an intermediate behavior, even if a clear fall is present after \( 1.5 \times 10^6 \text{ m}^3 \). Comparing the average removal rates of these three parameters, the increase in oxygen dosage leads to an increase of 40% of ammonium removal, 10% of COD removal and 6% of color removal with respect to the low-oxygen filter. On the other hand, considering the costs for energy requirements and oxygen supply, costs for the two different dosages have been estimated to 0.033 €/m³ for filter A and 0.009 €/m³ for filter B.

Table 1.1 Removal percentages of color, COD and ammonium in Filter A and filter B at different phases of work.

<table>
<thead>
<tr>
<th>Treated volume</th>
<th>Color removal (%)</th>
<th>COD removal (%)</th>
<th>( \text{N}_\text{NH}_4^+ ) removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( A )</td>
<td>( B )</td>
<td>( A )</td>
</tr>
<tr>
<td>( 0 - 5\times10^5 \text{ m}^3 )</td>
<td>96%</td>
<td>90%</td>
<td>60%</td>
</tr>
<tr>
<td>( 5\times10^5 \text{ m}^3 ) - ( 1\times10^6 \text{ m}^3 )</td>
<td>67%</td>
<td>89%</td>
<td>55%</td>
</tr>
<tr>
<td>( 1\times10^6 \text{ m}^3 ) - ( 1.5\times10^6 \text{ m}^3 )</td>
<td>71%</td>
<td>65%</td>
<td>55%</td>
</tr>
<tr>
<td>( 1.5\times10^6 \text{ m}^3 ) - ( 2\times10^6 \text{ m}^3 )</td>
<td>71%</td>
<td>64%</td>
<td>41%</td>
</tr>
<tr>
<td>( 2\times10^6 \text{ m}^3 ) - ( 2.5\times10^6 \text{ m}^3 )</td>
<td>70%</td>
<td>49%</td>
<td>29%</td>
</tr>
<tr>
<td>( 2.5\times10^6 \text{ m}^3 ) - ( 3\times10^6 \text{ m}^3 )</td>
<td>53%</td>
<td>42%</td>
<td>28%</td>
</tr>
</tbody>
</table>

The different performances of Filter A and B could be due to different growth of biomass; in fact, the effect of increased concentrations of bacteria in BAC filters have been well-documented in literature (Liao et al., 2012; Magic-Knezev and van der Kooij, 2004). For this reason, the biomass concentration has been evaluated in filter A and B through respirometric tests. In particular, sample of BAC from the top and from the bottom of the filter have been taken, then sodium acetate has been added as rapidly biodegradable carbon source and the Oxygen Uptake Rate (OUR) have been evaluated. From this parameter, considering a \( \mu_H \) of 6d⁻¹ and a \( Y_H \) of 0.45 gSSV/gCOD, the amount of biomass, expressed as SSV, have been evaluated. Results report that biomass on Filter A is on average 0.23 mgSSV/gBAC, while in Filter B 0.06 mgSSV/gBAC. This important difference in biomass is easily explained by the different dosage of oxygen which allowed a bigger growth of biomass in Filter A. Moreover, considering the differences between the top and the bottom of the filters, it is interesting to consider that Filter A is oxygenated through all its depth and biomass is very homogeneous, being 0.24 mgSSV/gBAC on the top and 0.22 mgSSV/gBAC on the bottom. On the other hand, Filter B own 0.09 mgSSV/gBAC on the top where oxygen is higher (>10 mg/L) and 0.02 mgSSV/gBAC on the bottom where oxygen is absent.

REFERENCES


Removal of Micropollutants from Wastewater by Rapeseed Simultaneous Biosorption

I. Morosanu*, C. Teodosiu**, D. Fighir***, C. Paduraru****

Department of Environmental Engineering and Management, “Cristofor Simionescu” Faculty of Chemical Engineering and Environmental Protection, “Gheorghe Asachi” Technical University of Iasi, 73 Dr. D. Mangeron Bd., 700050, Iasi, Romania.

* irina.morosanu@tuiasi.ro (I. Morosanu)
** cteo@ch.tuiasi.ro (corresponding author: C. Teodosiu)
*** daniela.arsene@ch.tuiasi.ro (D. Fighir)
**** cpadur2005@yahoo.com (C. Paduraru)

Abstract: This study is based on the evaluation of the rapeseed waste potential for the simultaneous biosorption of toxic metals and reactive dye from aqueous systems. Batch experiments were performed at room temperature (20±4°C), by varying the initial concentration of one of the micropollutants (15 – 150 mg/L), while the initial concentration of the other pollutant was at a fixed value (50 mg/L). Kinetic measurements were done at various molar ratios of lead and Reactive blue 19. Selectivity study implied a higher preference of the biosorbent for metal rather than dye. The experimental data for metal biosorption was well explained by both Langmuir and Freundlich isotherms. The maximum biosorption capacities were of 25.13 mg/g and 11.36 mg/g for Pb(II) ions and dye, respectively. The pseudo-second order model was able to satisfactorily predict the kinetics of biosorption in both cases. XPS analysis revealed the presence of metal on the biosorbent’s surface.

Keywords: Simultaneous biosorption; reactive blue 19; toxic metals

Discharge of wastewaters containing toxic metals and dyes from chemical and textile industries have posed serious concerns at international level. Heavy metals, like lead, are among the priority pollutants, due to significant effects of toxicity, mutagenicity and carcinogenicity on humans and ecosystems. The presence of anthraquinone dyes in aqueous streams even in small concentrations (1 mg/L) has a negative impact on the aquatic ecosystems.

AIM The present work aims to investigate the simultaneous removal from aqueous solutions of two model micropollutants onto rapeseed (RS) waste in batch conditions. The biosorption of the target pollutants, inorganic (lead ions) and organic (Reactive blue 19 dye, Rb19), from single system was previously reported by Morosanu et al. (2017a,b). For the binary system, we evaluated the influence of key operating parameters, such as contact time and initial pollutant concentration, based on the experimental data and modelling approach. Selectivity of the biosorbent for each of the pollutants under study was determined. Morphology characterization was conducted by X-ray photoelectron spectroscopy (XPS).

RESULTS Kinetics investigations provides information on the rapidity of the biosorption. The equilibrium was reached in 150 min. for Pb(II) ions and in 240 min. for the anionic dye. The experimental data was analysed using the pseudo-first and
pseudo-second order kinetic models. Irrespective of the Pb:Rb19 molar ratio (6:1 or 1:1), it was observed that the pseudo-second order model is the dominant biosorption kinetics for both pollutants ($R^2 > 0.99$), suggesting a mechanism based on chemisorption.

The applicability of Langmuir and Freundlich isotherm models was investigated. In case of metal biosorption in the presence of 50 mg/L initial dye concentration, the equilibrium could be described by both isotherm models mentioned ($R^2 > 0.99$). The maximum Langmuir biosorption capacity for Pb(II) ions was 25.13 mg/g, which is close to the one obtained in the study of lead uptake from monocomponent solutions (Morosanu et al., 2017b). When the metal initial concentration was constant, the Langmuir equation fitted better the equilibrium state of dye biosorption.

Selectivity tests were conducted for Pb:Rb19 molar ratios of 1:1 and 6:1. In both cases, Rb19 selectivity was lower than unity, meaning that the biosorption of Pb(II) ions is preferred. In the case of metal selectivity over dye, a value over 1.3 was obtained for both molar ratios under consideration.

Deconvolution of O1s core level XPS spectra indicated that several photoelectron lines around 531, 532.6 and 533.5 eV appeared after simultaneous biosorption of metal and dye (Fig. 1). These peaks were identified as O-Pb, O=S and O-S, respectively.

CONCLUSIONS Simultaneous biosorption of lead ions and reactive dye was studied. The applicability of the pseudo-second order kinetic model indicated that chemical interactions are responsible for pollutants uptake. A maximum Langmuir biosorption capacity for Pb(II) ions was found to be similar to the monocomponent biosorption. A competitive effect between the pollutants was observed at higher concentrations. XPS indicated the interaction of metal and reactive dye with oxygen containing functional groups of the RS. Rapeseed meal, an agricultural waste, is a promising biosorbent towards the implementation of the circular economy model.

![Figure 1.1](image)

**Figure 1.1.** XPS spectra of RS before (a) and after (b) simultaneous biosorption of lead ions and Rb19 dye

ACKNOWLEDGEMENTS This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI-UEFISCDI, project number 26PCCDI/01.03.2018, “Integrated and sustainable processes for environmental clean-up, wastewater reuse and waste valorization” (SUSTENVPRO), within PNCDI III.

REFERENCES
Evaluation of Design Wastewater Treatment Plant Tertiary Process for Water Reuse with the Use of Modelling Tool


*barbara.biagi@aceaspa.it
**paolo.cirello@aceaspa.it

Abstract: Application of a Waste Water Treatment Plant modelling tool, to verify the predictability and to improve the plant process and the tertiary treatment design in activated sludge treatment plant. The tool selected for the simulation is the software WEST by DHI. The case study presents the results of plant performance evaluation, with particularly attention on nutrients removal, and evaluation of tertiary treatment design.

Keywords: Modelling; reuse; waste water treatment plant

The work deals with wastewater reuse in the context of sustainable development and resource recovery. Water reuse may reduce pollution loads and enhance water supply sources. Water reuse has been recognized as a sustainable urban water management strategy, and could be considered as a feature of resource recovery.

The abstract summarised the application of a Waste Water Treatment Plant modelling tool, to verify the predictability and to improve the plant process and the design of tertiary treatment in activated sludge treatment plant. The selected tool used for the simulation is the software WEST by DHI.

The mentioned plant has been object of an upgrade project with the aim to treat the effluent stream and recovery this water for irrigation purposes.

The results have permitted to check the plant performance with particularly attention to nutrients removal, to validate the design of the tertiary treatment and to verify the effects of returning backwash water on the activated sludge performance. Simulations has been performed to demonstrate the effect of extreme peak flow events on the plant. Additional simulations has been carried out to verify plant performance in case of by-passing some units to simulate maintenance operations.

Figure 1.1 Model schematic diagram of the plant.
The Waste Water Treatment Plant has an inflow of about 21,000 m$^3$/day on two separated lines, and consists of pre-treatment units (screening and grit removal), primary settling tanks (circular), biological process units (activated suspended sludge), secondary settling tanks (circular) and chlorine disinfection tank.

The first goal of the study has been to use the implemented and calibrated model of the Waste Water Treatment Plant to verify and select, if possible, the best management strategy to increase nutrients (nitrogen and phosphorus) removal to reach the expected law limits. Simulations has been carried out to evaluate the effects of variation of Sludge Retention Time, Dissolved Oxygen concentration, Mixed Liquor Suspended Solids recycled flow, Return Activated Sludge flow, Waste Activated Sludge flow to achieve the desired nutrients removal.

The designed recovery plant consists of sand filtration, UV disinfection and PAA post disinfection, treating the whole flow entering the plant. The designed Tertiary filtration consists of three deep bed sand filters, each unit with a diameter of 8.2 m, and a volume of about 100 m$^3$.

![Figure 1.2 Model schematic diagram of the tertiary filter plant.](image)

The model application on the activated sludge process has shown how through a new configuration of operational parameters is possible to achieve an increasing performance on nutrient removal. The total nitrogen removal efficiency, according to the model, could increase, from 40% to 70%, while, the phosphorus removal efficiency, could increase from 25% to 60%.

The simulations confirm that the designed tertiary treatment is able to reach the fixed goal on the effluent stream (D.M. 185/03 – water reuse standard); in addition the model permitted to define the best backwashing time duration with the aim to reduce water consumption without reducing plant performance.

A consistent advantage offered by this project is the possibility to reuse the effluent stream, destined for discharge, in a new way, generating a virtuous cycle and avoiding the use of a sensitive source as water represent.

An economic evaluation has been made to better understand the advantages and disadvantages of this goal.

REFERENCES

An Integrated Waste-Wastewater Management Approach to Increase Wastewater Reuse in Mediterranean Regions

G. Mancini*, A. Luciano**, P. Viotti***, D. Fino****

*Electric, Electronics and Computer Engineering Department, University of Catania, Viale Andrea Doria 6, 95125 Catania, Italy giuseppe.mancini@unict.it
**ENEA Italian National Agency for New Technologies Energy and Sustainable Economic Development, RC Casaccia, Via Anguillarese 301, 00123 Rome, Italy antonella.luciano@enea.it
***Department of Civil, Building and Environmental Engineering, “Sapienza” University of Rome, Via Eudossiana 18, 00184 Rome, Italy paolo.viotti@uniroma1.it
****Department of Applied Science and Technology (DISAT), Polytechnic of Turin, C.so Duca degli Abruzzi 24, 10129 Turin, Italy debora.fino@polito.it

Abstract: The choice of appropriate and sustainable wastewater treatment and reuse schemes should be based on a careful and holistic analysis of several elements, considering their potential role of guaranteeing the global financial soundness of the project, as well as the necessary environmental and sanitary requirements. The aim of this paper is to promote a shift of paradigm in the current management of both the organic fraction of urban waste, sludge management and wastewater reuse. Moreover, the work aims to show how the role of the treated-wastewater storage phase, under proper operating conditions, can significantly increase the safety of reuse and its economic sustainability.

Keywords: wastewater reuse; costs; holistic approach

Currently, most of the communities in South Mediterranean regions, including large Islands such as Sicily, Crete and Cyprus, show a common unsustainable approach in the field of waste and wastewater management which severely affect the related energy demand and impacts on the environment and tourism. A unique holistic approach to these issues is totally prevented and scarcely effective single-issue approaches are usually adopted compromising any potential planning action for a symbiotic development.

Many wastewater treatment plants in South Mediterranean regions suffer from severe complications in sludge treatment and disposal, as landfills are frequently reluctant to accept not adequately stabilized or dewatered sludge. Furthermore, the more severe approach in evaluating the potential direct or indirect disposal of sludge on land is inducing a drastic reduction in the chance of sludge direct disposal in agriculture or through composting. This condition, in turns, is affecting the water treatment of several WWTPs and the discharged water quality especially for small to medium size plants. The absence of a continuous and reliable disposal path, in fact, often force the wastewater treatment plant operators to increase the return sludge flux so to reduce the wasting (withdrawal) of the sludge from the system and the needs of disposal. This “solution” make the sludge more oxidized (through the increase of the sludge age) but also “lighter” so to significantly lower the separation efficiency of the settling phase and, consequently, the quality of the discharged water. The quality of the treated water is crucial not only for limiting the damages to the impacted waters and land, often affecting the health of the population and tourism expansion but also in preventing a
real re-use of this important alternative water resource which could be utilized, avoiding hostile public perception for the irrigation of selected energy-crops.

The main objectives of this work are:

• To show as a change is possible, in the South-European specific economic, social and cultural context, to the existing policy of organic waste management in symbiosis to the wastewater treatment process by making anaerobic digestion and bio-methane production central and symbiotic to the material recovery and renewable energy production as required by European Community.

• To switch, in Mediterranean regions, the traditional wastewaters and sludge management approach toward an energy saving, low-CO₂ emissions and total organic material recovery-based new perspective.

• To show as sterile opposition to WtE plants could be overcome by highlighting their full inclusion in circular economy through material and energy recovery and the use of the recovered energy to boosts others virtuous recovery cycles such as the anaerobic digestion of Organic waste and sludge and wastewater reuse in agriculture.

• To enhance a real wastewater reuse by proposing an active role of wastewater winter storage (WR) phase through multi-seasonal, WR-based procedure here proposed and simulated in terms of operational parameters to reduce the effects, particularly critical during the irrigation period, of the introduction of fresh effluents on the quality of stored water.
Recovery of Ammonium Nitrogen from Urine with an Open-Loop Hollow Fiber Membrane Contactor

J. Zhang*, M. Xie*, H. Yu*, D. Qu*+

*Beijing Key Laboratory for Source Control Technology of Water Pollution, Beijing Forestry University, Beijing 100083, China.
E-mail: 13021050699@163.com, 18810061213@163.com, 2454007130@qq.com, qudana@163.com

Abstract: In this study, an open-loop hollow fiber membrane contactor (HFMC) was developed to recover ammonium nitrogen (NH₄⁺-N) from source-separated urine. The ammonia capture performance at various feed flow rates (v) were investigated, experimental results showed that the capture efficiency decreased from 80.26% to 33.07% and effluent total ammonium nitrogen (TAN) concentration increased from 9.80±7.51 mmol/L to 219.44±13.42 mmol/L when v increased from 1.62×10⁻⁵ to 32.49×10⁻⁵ m/s. Furthermore, a theoretical model has been developed based on resistance in series model, the overall mass transfer coefficients calculated by the model (Kₒᵛ) and experimental data (Kₒᵛ,experimental) had a great agreement. The mass transfer coefficient in the membrane pores (kₒ) and lumen side (kₗ) kept constant and much larger than the shell side (kₛ). So, the ammonia mass transfer in the feed solution was the rate determining step during the ammonia capture process.

Keywords: Ammonia recovery; Urine; Open-loop hollow fiber membrane; Mass transfer

Urine was reported to be rich in nitrogen (N) of 8 kg/t, although emissions account for less than 1% of municipal wastewater, but contributes up to 80% of N. Technologies such as absorption, stripping, struvite precipitation, reverse osmosis were reported for NH₄⁺-N recovery from urine. By contrast, HFMC provides a larger interfacial area which enables a rapid ammonia recovering rate. In addition, an independent control of the feed and stripping solution flow result in less flooding or foaming. So HFMC represent a credible solution to the problem of recovering NH₄⁺-N from urine. Until now, the close-loop HFMC were investigated a lot, while few studies were about open-loop HFMC configurations. In this study, the performance of an open-loop HFMC for NH₄⁺-N recovery from urine was investigated.

The developed open-loop hollow fiber membrane contactor was shown in Figure 1. Hydrophobic polypropylene membranes (Accurel Q3/2, Membrana, Germany) were used. The feed synthetic urine (pH=12, TAN≈333.33 mmol/L) was pumped to the shell side while the stripping solution (0.5M sulfuric acid) was circulated in the lumen side of the module.

As seen in Figure 2 and Figure 3, the feed flow rate played an important role in ammonia recovery. Effluent TAN concentration fluctuated and affected by feed flow rate. The effluent TAN concentration increased from 9.80±7.51 mmol/L to 219.44±13.42 mmol/L when the feed flow rate increased from 1.62×10⁻⁵ to 32.49×10⁻⁵ m/s. In contrast, ammonia capture amount in stripping solution increased in a stable liner manner with time. Capture rates (slopes of the liner regression) at v =1.62×10⁻⁵
5~32.49×10⁻⁵ m/s were 19.83 mmol/h, 8.97 mmol/h, 3.77 mmol/h, 2.42 mmol/h, respectively. Mass balance calculation showed that 80.26%, 77.73%, 65.40%, 45.43%, 33.07% of feed TAN was recovered in the stripping solution, 16.87%~1.57% escaped into air, and residual 2.87%~65.36% remained in the effluent at \( v = 1.62 \times 10^{-5} \)~\( 32.49 \times 10^{-5} \) m/s, respectively. Other ions such as Ca²⁺, Mg²⁺, Na⁺, K⁺, Cl⁻, PO₄³⁻, SO₄²⁻ were rejected in the feed solution.

Ammonia transmembrane flux \( (J) \) and mass transfer coefficients in the open-loop HFMC was summarized in Table 1. The increase of \( v \) resulted in great enhancement of \( J, k_s, K_{ov, experimental} \) and \( K_{ov} \). \( J \) increased from 71.68 to 585.25 mmol/m²·h, while \( K_{ov, experimental} \) increased from 2.48×10⁻⁷ to 6.73×10⁻⁷ m/s when \( v \) increased from 1.62×10⁻⁵ m/s to 32.49×10⁻⁵ m/s. \( K_{ov, experimental} \) fitted well with \( K_{ov} \), \( k_m \) and \( k_l \) kept constant and much larger than \( k_s \), so the mass transfer resistance of lumen side and membrane can be ignored, and the ammonia mass transfer was the rate determining step during the ammonia capture process.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>( v ) (m/s)</th>
<th>( J ) (g/m²·h)</th>
<th>( K_{ov, experimental} ) (m/s)</th>
<th>( k_s ) (m/s)</th>
<th>( k_m ) (m/s)</th>
<th>( k_l ) (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.62×10⁻⁵</td>
<td>71.68</td>
<td>2.48×10⁻⁷</td>
<td>5.21×10⁻⁸</td>
<td>5.24×10⁻⁸</td>
<td>3.27×10⁻²</td>
</tr>
<tr>
<td>2</td>
<td>2.71×10⁻⁵</td>
<td>111.54</td>
<td>2.65×10⁻⁷</td>
<td>7.09×10⁻⁸</td>
<td>7.13×10⁻⁸</td>
<td>3.27×10⁻²</td>
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<tr>
<td>3</td>
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<td>182.54</td>
<td>2.95×10⁻⁷</td>
<td>1.01×10⁻⁷</td>
<td>1.01×10⁻⁷</td>
<td>3.27×10⁻²</td>
</tr>
<tr>
<td>4</td>
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<td>265.38</td>
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</tr>
<tr>
<td>5</td>
<td>32.49×10⁻⁵</td>
<td>585.25</td>
<td>6.73×10⁻⁷</td>
<td>3.08×10⁻⁷</td>
<td>3.17×10⁻⁷</td>
<td>3.27×10⁻²</td>
</tr>
</tbody>
</table>

REFERENCES
Application of Membrane Distillation for Optimal Fertilizer Recovery from Human Urine


*Department of Construction Environment Engineering, University of Science & Technology, (34113) 217, Gajeong-ro, Yuseong-gu, Daegon, Republic of Korea, Email: mekdim@kict.re.kr

**Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology, Sydney (UTS), P.O. Box 123, Broadway, NSW 2007, Australia

***Department of Land, Water and Environment Research, Korea Institute of Civil Engineering and Building Technology, (Daehwa-Dong) 283, Goyang-Si, Gyeonggi-Do,10223, Republic of Korea

Abstract: Membrane distillation (MD) process can be applied in wastewater resources recovery owing to its outstanding performance in extracting volatile molecules. The orthogonal quadratic central composite model has been employed to optimize MD parameters for maximum and economical ammonia recovery from human urine. The feed urine pH, the permeate side acid concentration, feed flow rate, and feed temperature has been considered as an independent variable and kg of fertilizer (NH4)2SO4 per unit $ /m3 of urine has been considered as a response. Accordingly, high-grade ammonium sulfate fertilizer has been produced and its economic viability has been compared with conventional production system which reveals that hollow fiber MD is a viable and economical alternative technology for fertilizer production from human urine. The study also modeled ammonia mass transfer process through MD membrane.

Keywords: Ammonia recovery; fertilizer production; human urine; membrane distillation;

Nitrogen is one of the most essential nutrients required for plant growth and its mainly obtained from commercial ammonium-based fertilizers. However, the current fertilizer production process is costly for its energy (e.g. > 2% of global energy) and catalyst requirement and leaves a high carbon footprint. In this research, human urine has been utilized as the main source to extract ammonia for fertilizer production. This is mainly for three major reasons; primarily because urine is easily available and cheap, urine has the highest amount of nitrogen, and urine is the major pollutant in domestic wastewater which is expensive to treat in the tertiary treatment unit (nutrient removal)(Simha & Ganesapillai, 2017). There are reasons for utilizing membrane distillation to extract ammonia from human urine. These are; MD require less temperature and no aeration, ammonia is highly volatile, MD has the highest packing density and larger active surface area, MD is less chemical-intensive, environmentally friendly, less footprint. The specific objectives of this study is, therefore: to identify the most sensitive MD parameters influencing the NH3 extraction performance and show the interaction b/n different MD parameters; setting the optimum and economical operating conditions toward maximum ammonium-based fertilizer extraction (higher NH3:H2O ratio); and to numerically model ammonia mass transfer system in MD.
RESULTS

Figure 1.1 Response of ammonium fertilizer production amount under varying different operating conditions. Note: C2_eco = Amount of ammonium fertilizer produced per 1 dollar per 1 m³ of human urine. Tf= feed temp.; M= permeate acid concentration in molarity; q=feed/permeate flow rate (rpm); pH= feed urine pH

Equation 1.1 Empirical equation to estimate amount of ammonium from urine in MD process. Where pH,Tf,q, and M refers to the feed urine pH, feed temperature, feed flow rate, and permeate acid strength

Equation 1.2 Ammonia gas flux and permeate water flux from real human urine in hollow-fiber MD process

CONCLUSION Higher temperature, pH, permeate acid concentration and flow rate didn't necessarily recover maximum NH₃. There is always an optimal point. pH is the most significant parameter. Short time operation of MD is highly economical. Permeate chemistry significantly affects NH₃ mass transfer rate. Over 98% of nitrogen of urine can be recovered using MD.

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REFERENCES
Urine Dehydration Technology for Recycling Nutrients in a Public Dry Sanitation System


* Swedish University of Agricultural Sciences, Department of Energy and Technology, Box 7032, 750 07, UPPSALA, prithvi.simha@slu.se
** Swedish University of Agricultural Sciences, Department of Energy and Technology, Box 7032, 750 07, UPPSALA, jenna.senecal@slu.se

Abstract: Urine is the main contributor of plant nutrients from the households and therefore holds great potential for recycling. The objective of this study was to scale-up a laboratory system that stabilizes and dehydrates urine to be then used as a fertilizer. A full-scale drying unit was installed in a public toilet with over 100 daily users. Methods: The unit was installed in a mobile structure and equipped with dehydrating medium having a pH >12 and operated for 3 months (March to May, 2019). Data collection included: user frequency, airflow, air moisture, temperature, change in mass of the drying containers, energy consumption, NPK concentration of the dehydration medium and pH. The study is ongoing and the results (such as user frequency, mass flows of water, N, P, K and energy consumption of the system) will be included in the paper presented at the conference. The discussion will consider the function of the system, the global potential and further development for full-scale implementation.

Keywords: Urine, nutrient recycling, sanitation

Most dry sanitation systems simply aim to collect and contain the excreta until final disposal; but there is potential to do more. Urine, the main contributor of plant nutrients from the households, holds great potential for recycling. In a dry system, the P and K excreted in the urine are easily contained during collection and storage, however the N may volatilize. When excreting urine, N is mainly (>90%) in the form of urea (CO(NH2)2), but during collection and storage, the urea is converted by urease enzymes into carbonate and volatile ammonia (Krajewska, 2009). These urease enzymes are prolific and found on faecal bacteria and biofilms. One approach to conserving the N in urine is to chemically blocking the urease enzymes by elevating the pH (Randall et al., 2016; Senecal & Vinnerås, 2017). Diverting the urine into a separate container (urine-diversion) and stabilizing it directly by increasing the pH, opens opportunity to effectively concentrate the urine. The urine, a very liquid solution containing less than one per-cent N, can be dehydrated into a solid fertiliser with a NPK composition of 10:1:3 with a potential N loss of < 20% (Senecal & Vinnerås, 2017; Simha et al., 2019; Simha et al., 2018). The objective of this work was to bring the laboratory system of the urine stabilization and dehydration to a full-scale unit in a public toilet with over 100 daily users. Sub-objectives were to produce a high quality concentrated fertiliser and decrease the energy usage within the system.

MATERIAL AND METHODS The system was installed into a standard mobile toilet cubicle containing one urinal and one urine-diverting toilet. The collection system was placed in close proximity to both toilets (<1 m pipe). The drying unit consist of three...
containers (total 0.75 m² surface area) that collect and dehydrate the urine with heating fans. In each container, eight kilograms of dehydrating medium with a pH >12 was added. Data collection included: user frequency, airflow, air moisture, temperature (in & out, 5 min interval), change in mass of the containers, energy consumption, NPK concentration of the dehydration medium and pH. The toilet cubicle was located outdoor near Säkylä in Finland for 3 months (March to May, 2019).

EXPECTED RESULTS The study is ongoing and the results will be included in the paper presented at the conference. We will present: User frequency, mass flows of water, N, P, K and energy consumption of the system. The discussion will consider the system functionality, global potential and further development for full-scale implementation. Urine contains majority of the plant nutrients found in household wastewater and is the main culprit of eutrophication as there are over four billion people discharging untreated human excreta into the environment. This technology demonstrates that urine can be collected separately and dehydrated to produce a nutrient-rich fertiliser that fulfils WHO guidelines for unrestricted use (Senecal et al., 2018).

Figure 1.1 The toilet cubicle containing the urine dehydration technology installed at the test site in Säkylä, Finland

REFERENCES


Enabling Resource Recovery by In-Sewer Treatment and Microbial Ecology-Based Engineering: Water Reuse Starts Now in the Sewer

N. Klaï*, L. Guo**, D. Santoro***, D. Frigon*

*McGill University, 845 Rue Sherbrooke Ouest, Montréal, QC H3A 0G4
**Ryerson University, 350 Victoria St, Toronto, ON M5B 2K3
***Trojan Technologies, 3020 Gore Rd, London, ON N5V 4T7

Abstract: The ability to control wastewater influent characteristics is an essential step in enabling the paradigm shift from conventional wastewater treatment plants to water resource recovery facilities, as well as to enable the recovery the most important resource: water. As a matter of fact, advanced control of wastewater influent characteristics not only guarantees an overall better effluent quality (in view of water recovery and reuse), but also enables two emerging resource recovery platforms such as “low energy mainline” (LEM) and the “partition, release and recover” (PRR) via specialized biomasses Anammox (for LEM, due to lower oxygenation requirement) and purple phototropic bacteria (for PRR, due to total nutrient assimilation). In this paper, we report the outcome of a full-scale genomic experimental study, supported by integrated modelling, carried out on a sewer connected to a wastewater treatment plant in Southern California, USA. In-sewer treatment by nitrate was carried out to achieve multiple treatment objectives, namely carbon reduction (by denitrification) and odour control (by sulfide removal). Genomic and modelling tools were used to probe, confirm and predict how the microbial community biochemical pathways would shift in presence of 70 mg/L nitrate dosing.

Keywords: Integrated studies, microbial communities, modeling, sewer, resource recovery, nitrate

INTRODUCTION

Recent studies have conclusively demonstrated how the performance of sewer networks could be considered not only against their basic function of ensuring wastewater transport, but also for their ability of profoundly modifying water quality characteristics, therefore exerting a crucial role as process interface between sewer and wastewater infrastructure (Hvitved-Jacobsen et al., 2002). Several situations can be envisaged to highlight the importance of controlling in-sewer microbial processes. Among these, the impact of odours emission via sulfide production under anaerobic conditions is a well-known one. Other examples include controlling influent characteristics to enable emerging resource recovery platforms from municipal wastewater, such as such as “low energy mainline” (LEM) and the “partition, release and recover” (PRR) via their specialized biomasses Anammox (LEM) and purple phototropic bacteria (PRR). Similarly, biological phosphorus removal could benefit for in-sewer fermentation processes to maximize VFAs content in the wastewater influent (Hvitved-Jacobsen et al., 1998). In this paper, we report the outcome of a full-scale genomic experimental study, supported by integrated modelling, carried out on a sewer connected to a water resource recovery facility in Southern California, USA. In-sewer treatment by nitrate was carried out to achieve multiple treatment objectives, namely carbon reduction (by denitrification) and odour
control (by sulfide removal). Genomic and modelling tools have been used to probe, confirm and predict how the biochemical pathways and the microbial community would shift in presence of 70 mg-NO$_3^-$/L in-sewer dosing.

**MATERIALS AND METHODS** Genomic tools have been used to probe and confirm the biochemical pathways and the microbial community shifts induced upon addition of 70 mg/L nitrate, as well as to confirm biochemical pathways used during integrated model-based analysis to predict post-sewer wastewater influent characteristics and downstream treatment processes and final effluent water quality. To simultaneously control excessive rbCOD (due to industrial discharges from food processing industries), odour control (via sulfide management) and plant effluent quality (in view of water reuse), the use of nitrate as in-sewer treatment strategy to control microbial community was hypothesized. Nitrate would promote the growth of naturally present microbial in-sewer communities (i.e., denitrifiers), which would then compete with sulfate reducing (i.e., sulfide producers) and fermentative (i.e., VFA producers) organisms by consuming organics (rbCOD) according to the mechanisms shown in Figure 1.1.

![Figure 1.1 Hypothesized biochemical pathways triggered by in-sewer nitrate dosing](image)

To prove this hypothesis, two sampling campaigns of two weeks each were carried out on a full-scale sewer line connected to a wastewater treatment plant located in Southern California, USA. The process involved in the facility are summarize in Figure 3.3. The first campaign aimed at establishing the baseline behaviour of the sewer line in absence of nitrate dosing, while during the second the sewer system was sampled to characterize its response to the addition of 70 mg-NO$_3^-$/L. The point of nitrate addition corresponded to an upstream location located at a pump station 10 km away from the headwork of the wastewater treatment plant. In each sampling campaign, 40 samples were collected from both the pump station and the headwork of wastewater treatment plant. Samples were stored at $-20^\circ$C before DNA extraction. Total DNA was extracted from biomass samples using DNeasy PowerSoil Kit following the manufacturer’s instructions. PCR was performed using 515 forward and 806 reverse primers targeting the V4 region of 16S rRNA genes. Amplicons were sent for sequencing on Illumina Miseq PE250 platform at McGill University and Génome Québec Innovation Centre (Montréal, QC, Canada). The raw sequences were quality-filtered using DADA2 (Callahan et al. 2016) at 100% sequence similarity in Qiime2 pipelines (Caporaso et al. 2010). Taxonomy was assigned using 99% similarity Greengenes reference database (McDonald et al. 2012) and tabulated at genus level. Microbial community diversity was analysed using R “vegan” package (Jari Oksanen et al. 2017).

**RESULTS** Principal component analysis (PCoA) was used to show similarities (i.e., proximity of points) in composition of the microbial communities identified at the pump station (i.e., arriving from a partially aerobic gravity sewer) and the wastewater treatment plant headwork (i.e., after having resided in anaerobic conditions in a
pressurize pipe). As can be seen in Figure 2.1, upon the nitrate dosing at 70 mg/L, a quantifiable shift in community composition was observed, thus confirming the effect of nitrate dosing in inducing ad-hoc biochemical pathways in the sewer line.

![Figure 2.1 Principal component analysis using Bray-Curtis distance of the microbial community at genus level. Samples were taken from pump station at baseline (PS-B), headwork at baseline (HW-B), pump station under nitrate dosing (PS-N) and headwork under nitrate dosing (HW-N). Each point is a different sample obtained from the two locations at regular time intervals.](image)

A key question is whether or not the treatment with nitrate is enabled by changes in metabolic functions (of the same microbial community), or else enables changes in the microbial community. In Figure 2.2, the changes induced in three bacteria sub-populations are shown. Specifically, we can observe how sulphur reducing bacteria are less abundant after nitrate dosing, while the opposite is true for both fermentative and nitrate reducing bacteria. This confirms that denitrification processes are supported not only by the availability of rbCOD, but also by the fermentation mechanisms producing VFA from hydrolysable carbon substrates. A sewer-WWTP integrated model, based on the mechanisms revealed by genomic analysis, was run under three scenarios: baseline, iron dosing and NO3 dosing. In this case, the baseline scenario means that no chemical was dosed in collection system or WWTP.

![Figure 2.2 Relative abundance of: a) Sulphur Reducing Bacteria (SBR), b) Fermentative bacteria and c) Nitrate Reducing Bacteria (NRB), at various locations (pump station and headwork) for baseline conditions (no nitrate) and after nitrate addition (at 70 mg/L).](image)
The integrated modelling results, reported in details in Guo et al. (2018), show that iron dosing is the most effective solution for H2S removal in the collection system. It also enhances phosphate removal in both collection system and WRRF. While nitrate dosing decreases sulfide concentration in the sewer, it also reduces VFA and sCOD loads to the WWTP by in-sewer denitrification as confirmed by both experimental and numerical findings (Figure 2.4).

In conclusion, the knowledge gained in this study was crucial in expanding the concept of “sewer as hydraulic infrastructure” towards the more holistic one of “sewer as bioreactor”. This was accomplished by demonstrating how microbial-ecology-based engineering and integrated modelling could be deployed in various stages of the investigation to support process design to plant optimization, and management.

REFERENCES


Tuesday, 10\textsuperscript{th} September 2019

Session 8

ENHANCED ANAEROBIC TREATMENT
Enhanced Anaerobic Treatment as Core of the WRRFs: Pilot and Full Scale Experiences

B. Jefferson*

* Cranfield University (UK)

Abstract: Transformation of sewage works from wastewater treatment facilities to resource factories that enable effective resource recovery require reconsideration of how we utilise biological processes. Specifically, a shift away from the aerobic biological technologies towards anaerobic alternative appears increasingly critical. The switch preserves the nutrient load within the wastewater for recovery, generates valuable products (methane), limits greenhouse gas emission whilst preserving, and perhaps enhancing, the potential for water reuse. In particular, the use of anaerobic membrane bioreactors (anMBRs) has gained attention as a core technology in the transformation towards resource recovery. The inclusion of the membrane helps enhance bioreactor resilience and produces an effluent stream free from solids and pathogens, and rich in nutrients. The development of flowsheets centred around anMBRs remains in its infancy with a limited number of demonstration and full scale sites. Key lessons can be learnt from these early developments that can enrich future endeavour and increase the potential to embrace resource recovery in future developments.
Efficient Utilization of Regional Biomass with Intensive Digestion System Using Sludge Solubilisation and Solid Oxide Fuel Cell

M. Matsuhashi*, R. Maeda**, H. Miyake***, Y. Shiratori****, A. Tajima*

* National Institute for Land and Infrastructure Management, Asahi 1, Tsukuba, Ibaraki 305-0804, Japan, matsuhashi-m92ta@mlit.go.jp
** Mitsubishi Kakoki Kaisha, Ltd, 2-1 Ohkawa-cho, Kawasaki-ku, Kawasaki, Kanagawa 210-8560, Japan, maeda1@kakoki.co.jp
***Japan Sewage Works Agency, 2-31-27 Yushima Bunkyo-ku Tokyo 113-0034, Japan, Miyake@jswa.go.jp
****International Research Center for Hydrogen Energy, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka 819-0395, Japan, shiratori.yusuke.500@m.kyushu-u.ac.jp

Abstract: Digester (500 m³) with sludge solubilisation facility and solid oxide fuel cell (SOFC) system was installed in a sewage treatment plant to demonstrate the intensive utilization of regional biomass wastes as energy resources. Superiority of this system in terms of life cycle cost (LCC), power consumption and power generation were evaluated. Compared to a conventional digester, LCC can be reduced by about 14.1% (considering the period after widespread dissemination of SOFC), and 22.1% increase in power generation can be achieved.

Keywords: Sewage sludge; solubilisation; biogas; life cycle cost (LCC); solid oxide fuel cell (SOFC)

INTRODUCTION Sewage sludge, which is generally disposed in landfill as a waste, is expected to be an important biomass resource to produce biogas, sludge fuel, etc. In Japan, the energy potential of sewage sludge is almost equal to the electricity consumption for 1.1 million households, which can be further boosted up if unused biomass wastes such as food residues are considered. However, at present, utilization rate of these biomass resources is rather low level (about 27% in 2016), and has to be promoted by introducing an efficient system. For this purpose, in this study, digester with sludge solubilisation facility and SOFC was installed in a sewage treatment plant, and LCC, power consumption and power generation were evaluated for this system.

MATERIAL AND METHODS Efficient biogas production system consisting of digester with unpowered stirring system, solubilization facility, and SOFC shown in Figure 1 was constructed to demonstrate efficient utilization of sewage sludge. Sludge treatment capacity of the constructed system is 25 t d⁻¹. The biogas production was based on the mesophilic digestion at hydraulic retention time (HRT) of 20 days. In this study, food waste discharged from a food processing factory was also put into the digester. Energy-saving operation of the digester was realized by using water head difference in the digester (biogas pressure) for stirring the slurry. Dewatered sludge discharged from the digester was further treated in the solubilization facility together with the sludge discharged from other small scale sewage treatment plants at 170°C for
30 min. This treatment contributes to the reduction of sludge volume. The generated biogas (CH₄: 60%, CO₂: 40%) was passed through the absorption towers to remove trace H₂S and siloxane, then supplied to 10 kW SOFC system in which humidified biogas is reformed to hydrogen which electrochemically oxidized to generate electricity. Among several types of fuel cells, SOFC exhibits highest electrical efficiency (ca. 50%) due to its high operating temperature (600-900°C). This is Japan’s first SOFC system installed in sewage treatment plant to demonstrate highly-efficient biogas power generation. Excess biogas is supplied to gas engine generator.

**RESULTS AND CONCLUSIONS** Power consumption for mixing the slurry in the digester was reduced by 99.3 and 97.3% compared with the cases using blower and agitator, respectively. The solubilization facility could keep the temperature in the digester at 35-40°C throughout the year without additional heating facility, and contributed to the enhancement of biogas production by more than 15%. COD and concentrations of phosphorus and nitrogen in the effluent from the sewage treatment plant did not change. The amount of excess sludge discharged from this system decreased by 50%, and its water content was reduced by about 5% compared to a conventional system. The 10 kW biogas-fuelled SOFC system exhibited electrical efficiency of 50% with voltage degradation of about 3% within the initial 500 h. As shown in Figure 2, for the average daily water volume of 30,000 t d⁻¹, estimated reductions of LCC and power consumption were 14.1% (corresponding to 386,330 USD) and 7,400 kWh y⁻¹ (corresponding to 1,003 USD), respectively, and the power generation increase was 291,100 kWh y⁻¹ (corresponding to 39,452 USD). These estimations proved that the digestion system constructed and demonstrated in this study, superior to the conventional technology in terms of LCC, power consumption, and power generation, is promising technology to promote the utilization of regional biomass wastes as energy resources.

![Figure 1.1 Schematic diagram of the process in the present study.](image)

![Figure 1.2 Superiority of the digestion system proposed in this study; (A) LCC evaluation and (B) electricity cost. For the estimation, electricity price in Japan = 0.136 USD kWh⁻¹ (at USD = 110.68 JPY) was considered.](image)
Innovative Ex-Situ Biological Biogas Upgrading Using Immobilized Biomethanation Bioreactor (IBBR)

K. Baransi-Karkaby*, M. Hassanen*, S. Muhsein*, N. Massalha*, I. Sabbah***

* The Institute of Applied Research, The Galilee Society, P.O. Box 437, Shefa-Amr 20200, Israel. katie.b.karkaby@gmail.com; isabbah@gal-soc.org
** Prof. Ephraim Katzir Dept of Biotechnology Engineering, ORT Braude College, Karmiel, Israel.

Abstract: Biogas, which typically consists of about 60-70% of methane gas, is produced by anaerobic digestion of organic waste and wastewater. Biogas is considered a potentially important energy resource; however, it has limited application and utilization. In this regard, upgrading it to natural gas quality (above 90% methane) can enable broad applications. In this work, we used novel ex-situ immobilized biomethanation bioreactors (IBBR) for biogas upgrading as a post treatment. The reactors contained immobilized microorganisms within a polymeric-based matrix. The innovative ex-situ biogas IBBRs showed promising results. CH4 content of 80-90% was achieved by reducing CO2 to CH4 (biomethanation) through supplying hydrogen gas as an electron donor outside the anaerobic digester.

Keywords: Biogas upgrading; polyfoam bioreactor; ex-situ biogas upgrading.

INTRODUCTION Although biogas is considered a potentially important energy resource, it has limited application and utilization. Biogas typically consists of 60-70% methane and 30-40% CO2, which reduces the heating value and limits the biogas economic feasibility. In this regard, upgrading biogas to natural gas-quality (CH4% over 90%) will broaden its applications.

Our strategy for biogas upgrading is based on biological approach, where CO2 is reduced by the hydrogenotrophic methanogens to CH4 using H2 as electron donor. An innovative up flow immobilized biomethanation bioreactors (IBBR) is proposed for ex-situ biogas upgrading. The granular methanogenic microorganisms were immobilized using a novel polymeric-based matrix, which was shown to secure the biomass from sudden inhibitory shock loads as well as prevents biomass washout from the reactor 1,2. In addition, the immobilized-matrix based system enables the application of higher gas circulation ratio. This proposed concept was examined at lab and pilot-scale levels.

MATERIALS AND METHODS Two IBBRs containing anaerobic sludge-based hydrophilic polyurethane matrix1,2 were used in this study. Lab scale of 440 ml, and pilot scale reactor (2.7 L) were used. A mixture of H2 and CO2 was injected into the bottom of the IBBRs to enrich the hydrogenotrophic pathway, thereafter biogas and H2 was injected, while keeping liquid circulation from the upper part of the reactors towards the bottom.

RESULTS AND DISCUSSION The first experiment examined the methane produced by the hydrogenotrophic methanogens by injecting CO2 and H2 in a ratio of 1:4 to the lab scale IBBR. 90% of methane was achieved after 28 days of operation (results not shown). Thereafter a ratio of 1:5 (CO2 :H2) was injected into the lab scale IBBR. Figure 1 shows the three different operating periods at ratio of 1:5 (CO2 :H2) respectively. In the first period, H2 and CO2 mixture feed flow was 1.3 ml/min until the 55th day, at the same time the ratio of liquid circulation flow relative to the gas feed flow was 10 times.
On day 55 to day 86 gas flow in the feed was raised to 1.5 ml/min and circulation ratio that was maintained at 10. On the 86th day feed flow was increased to 1.7 ml/min and the circulation ratio was also increased up to 15.

Figure 1.1 shows the percentage of normalized methane (by subtracting the excess hydrogen) and the percentage of hydrogen consumption as a function of operating time. It can be seen from the first operational period that consumption of hydrogen and carbon dioxide led to the formation of methane that reached around 80%. The hydrogen consumption was above 90% and at a stable behaviour during 20 days of operation. The second period was less technically stable thus caused a slight decrease in methane content; however, its recovery was highly fast with a methane percentage of around 80%. In the last operational period, the methane content was stable at 75%, with almost no excess of hydrogen in the system.

The second experiment was conducted at a pilot scale system. A mixture of CO2 and H2 was injected into the IBBR in a 1:4 ratio respectively. After reaching the enrichment of the hydrogenotrophs, a mixture of biogas and hydrogen was fed at optimal ration of 1: 4 for testing biogas upgrading (dark blue colour in Figure 1.2). Figure 2 shows the percentage of normalized methane at different feed flows and circulation ratios (the upper side of the figure). It can be seen from figure 2 that during the different operating periods, the obtained methane was between 70% to 85%. Moreover, when synthetic biogas with hydrogen was injected into the IBBR, an increase in methane content from 59% to 80% was observed (circulation ratio was between 15 and 20). The hydrogen consumption for the high feed flow (between 14-20 ml/min) ranged from 50-65%. However, when biogas and hydrogen mixture was injected into the IBBR, the consumption of H2 dropped to 48%, apparently due to the competition in dissolving between hydrogen and methane. results not shown)

The immobilized biomethanation bioreactors shows promising results. However, a process optimization is still required to increase the operational stability of this system for more broad application.

REFERENCES


High Rate Immobilized Anaerobic System Treating Wastewater- Evaluation and Simulation at a Pilot-Scale System


* Braude College, Israel (isabbah@braude.ac.il) and the ** Institute of Applied Research – The Galilee Society, Israel (sabbah@gal-soc.org, mahdi.hs@hotmail.com, nedal@gal-soc.org); AgRobics Ltd. (morad@agrobics.com). *** Institute of Experimental Biology and Technology (IBET), Portugal (dfc.dias@fct.unl.pt, jmnds.ribeiro@campus.fct.unl.pt, jmm.santos@campus.fct.unl.pt)
**** Mekorot, Israel National Water Company, Israel (aharoni@mekorot.co.il, slavash@MEKOROT.CO.IL); ***** School of Chemical Engineering, The University of Queensland, St Lucia, QLD, 4072, Australia (a.oehmen@uq.edu.au)

Abstract: An evaluation and simulation of an Advanced high rate Anaerobic Treatment technology (AAT) system applied at demo-scale with focus on methane production was performed in Karmiel (Israel) WWTP. The reactor is composed of an impregnated active biomass foam matrix to guarantee process stability and increase biogas production efficiency while reducing OLR shocks. Two different scenarios were investigated, 1st scenario: AAT preceded by a primary clarifier and; 2nd scenario: AAT received raw sewage. Average removal efficiencies were higher during the 2nd scenario, with biogas production at 1.3 and 6.7 m3.d-1 during scenario 1 and 2, respectively. The ADM1 showed applicability for the AAT (COD and gas flow).

Keywords: Advanced anaerobic treatment; municipal wastewater; biogas; ADM1.

INTRODUCTION

Anaerobic treatment of wastewater is more energy-efficient than aerobic processes because of the reduced oxygen consumption and the added value of biogas production. In addition, less biomass is produced and higher organic loads are handled in comparison to aerobic processes (Lettinga, 1996). However, operational stability obstacles still limit wide application of anaerobic technologies for wastewater treatment (Dupla et al., 2004). Moreover, anaerobic processes are highly vulnerable to organic and hydraulic load fluctuation, suffer active biomass washout, are sensitive to inhibitors, and require lengthy periods of acclimation (Chen et al., 2008; Derelei et al., 2012). To overcome these limitations a unique immobilization technique using hydrophilic polyurethane foam was applied. This advanced anaerobic technology (AAT) is a modified high rate up flow anaerobic biofilter, composed of a primary clarifier for sedimentation and biomass impregnated in the polymer-based matrix (Massalha et al., 2015, Sabbah et al., 2016).

This study is aimed at implementing the AAT at a demo-scale receiving real municipal wastewater for two scenarios over more than one year, i.e., preceded by a primary clarifier and no primary clarifier. The Anaerobic Digestion Model n°1 (ADM1) (Batstone et al., 2002) was used to characterise and predict expected results for different scenarios, as well as demonstrate its robustness in fitting with different anaerobic treatment units.

METHODS

The wastewater treatment plant (WWTP) serves the city of Karmiel (Israel) and consists of a conventional Activated Sludge system. The pilot AAT system was operated for over a year on the premises. The immobilized biomass (within the matrix) was inserted in the 25 m3 cylindrical-shaped reactor. The reactor is composed of a sedimentation zone (lower part) and immobilized anaerobic bio-matrix (upper
The bio-matrix occupies 1.875 m$^3$ of the total volume, resulting in a useful reactor volume of 23.125 m$^3$. Two scenarios were evaluated during the operation period (flow rate 48–120 m$^3$·d$^{-1}$): Scenario 1: raw sewage flowed first to the primary clarifier (PC) before flowing into the AAT. Scenario 2: raw sewage flowed directly into the AAT.

**RESULTS AND CONCLUSIONS** Overall, total COD and TSS removal efficiency was higher during the 2nd scenario (Table 1) due to the better established bacterial consortium, higher influent concentration and supported by the higher biogas production. Removal efficiencies are comparable to typical UASB reactors operating in tropical countries, however higher OLR and lower HRTs were applied for the current research (Table 1.1).

A small modification was performed to the ADM1 by considering the system as three compartments in series: Immobilized matrix compartment (infinite SRT), normal anaerobic reactor (with SRT similar to UASB) and headspace for biogas. This assures the assumption that biomass in the first compartment does not leave in the effluent because of the characteristics of the reactor. The data adjusted well to the ADM1 (Figure 1.1 – 2nd scenario), therefore proving its robustness. 3 biochemical parameters were estimated to fit total and soluble COD concentrations in the final effluent.

**Table 1.1 Removal efficiencies for both scenarios and typical removal efficiencies from UASB reactors in the literature.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>1st scenario PC + AAT</th>
<th>2nd scenario AAT</th>
<th>UASB operating in Brazil (Dias et al., 2018)</th>
<th>Typical UASB (Chernicharo 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume (m$^3$)</td>
<td>23.125</td>
<td>23.125</td>
<td>14.2</td>
<td>-</td>
</tr>
<tr>
<td>OLR (kgCOD·m$^{-3}$·d$^{-1}$)</td>
<td>2.5/2.3/4.3(1.06)</td>
<td>6.3/6.2/11.7(1.66)</td>
<td>0.87/0.87/-</td>
<td>-</td>
</tr>
<tr>
<td>HRT (d)</td>
<td>0.3/0.3/0.5(0.09)</td>
<td>0.2/0.2/0.2(0.09)</td>
<td>0.43/-/-</td>
<td>-</td>
</tr>
<tr>
<td>Total COD</td>
<td>17.5/19.2/29.1(6.8)</td>
<td>47.7/50.1/74(13.1)</td>
<td>-62.8/-64.5/-64.5</td>
<td>65 to 75%</td>
</tr>
<tr>
<td>Filtered COD</td>
<td>12.6/10.8/35.2(7.8)</td>
<td>25.3/25.4/45.2(11.4)</td>
<td>-59.1/-58.5/-58.5</td>
<td>-</td>
</tr>
<tr>
<td>Particulate COD</td>
<td>22.6/22.6/35.9(12.2)</td>
<td>56.6/59.9/80.4(15.8)</td>
<td>-59.1/-58.5/-58.5</td>
<td>-</td>
</tr>
<tr>
<td>TSS</td>
<td>29.7/30.8/68.3(17.2)</td>
<td>54.5/61.8/8718.8</td>
<td>-85.1/-85.1/-85.1</td>
<td>-</td>
</tr>
<tr>
<td>Biogas production (m$^3$·d$^{-1}$)</td>
<td>1.3/1.2/1.7(0.31)</td>
<td>4.5/4.9/6.8(1.9)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

All variables are in %, except: OLR in kgCOD·m$^{-3}$·d$^{-1}$; HRT in d and only in respect to the AAT;

**Figure 1.1** Simulation for 2nd scenario at steady state.

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**REFERENCE**


Free Nitrous Acid Pre-Treatment of Waste Activated Sludge Enhances Efficiency and Rheological Behaviour of Anaerobic Sludge Digester


*Advanced Wastewater Management Centre, The University of Queensland, St. Lucia, QLD 4072, Australia. z.yuan@awmc.uq.edu.au
** State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, 73 Huanghe Road, Harbin 150090, China, j.meng@uq.edu.au, mengjia2726688@126.com
*** Queensland Urban Utilities, Brisbane, QLD 4000, Australia

Abstract: Previous laboratory studies demonstrated that, with FNA pre-treatment of Waste Activated Sludge (WAS), an anaerobic sludge digester can achieve higher (~30%) VS destruction and methane production at a shorter solids retention time, with a highly favourable economic outcome. This pilot-plant study not only confirmed the enhancing effect of FNA pre-treatment on VS destruction and methane production, but also revealed that FNA pre-treatment of WAS reduced the viscosity of digested sludge by 75%. It also saves the polymer requirement for dewatering by 24%. These benefits further enhances the business case of the technology.

Keywords: Anaerobic digestion; waste activated sludge; free nitrous acid

INTRODUCTION Anaerobic digestion (AD) of WAS has been carried out widely due to its reasonably effective volatile solids (VS) destruction at a low cost. The hydrolysis of WAS is the rate limiting step in anaerobic sludge digestion, caused by the resistance to biodegradation from microbial cell walls. Therefore, anaerobic sludge digestion usually needs a long hydraulic retention time (HRT) to reach an acceptable level of VS destruction and biogas production. In order to enhance the efficiency of the AD process, many pre-treatment methods including mechanical, chemical and heat pre-treatment have been proposed (Zhang et al., 2010), which all require significant energy or chemical input yet often resulting in limited improvement. Recently, sludge pre-treatment using free nitrous acid (FNA) has been shown to enhance both the methane yield and kinetics of anaerobic digestion of waste activated sludge (WAS) in biochemical methane production tests (Wang et al., 2014;). This effect was confirmed in a recent laboratory studies involving the use of continuously operated AD reactors (Wei et al, 2018). Using the same laboratory reactors, Zhang et al. (2019) demonstrated that FNA-based pre-treatment of WAS could enhance VS destruction and methane production by ~35% at an HRT of 7.5 days, in comparison to the control reactor running at 15 days. The results indicate that FNA pre-treatment of WAS can substantially increase the capacity of an anaerobic sludge digester, with a highly favourable economic outcome.

The rheological behaviour of activated sludge is an important property related to process performance and economics. The aims of this study are (1) to demonstrate the effect of FNA pre-treatment on VS destruction and methane production in pilot-scale; (2) to investigate the effect of FNA pre-treatment on the rheological behaviour of WAS and digested sludge.
MATERIAL AND METHODS Two identical pilot-scale AD reactors, each with a liquid volume of 235 L, were established. Full-scale WAS with a TS concentration of 4.0-4.5% was fed to each reactor at a flow rate of 15.7 L/day, giving rise to an HRT of 15 days for both reactors. Following a baseline period, which allowed both reactors to reach steady state, WAS fed to the experimental AD reactor was pre-treated for 24 h at an FNA concentration of 6.1 mgN/L (pH=5.0; NO\textsubscript{2}-N =250 mg/L; T=22\degree C). Methane production, viscosity, dewaterability, ammonium release were monitored and compared between the two reactors.

RESULTS AND CONCLUSIONS A summary of the results is shown in Figure 1. Methane production in the control and experimental ADs in the baseline period averaged 115.6±3.1 and 115.6±4.2 mL/gVS\textsubscript{added}, respectively. The average NH\textsubscript{4}\textsuperscript{+}-N release in the two systems in this period was 119±69 and 1094±29 mg/L, respectively. In the experimental period, the methane production was enhanced to 156.0±4.0 mL/gVS\textsubscript{added}, which is 37% higher than that of the control reactor (114.3±3.6 mL/gVS\textsubscript{added}). In comparison with control, NH\textsubscript{4}\textsuperscript{+}-N release increased by 18% in the experimental reactor. The polymer consumption for dewatering the experimental AD sludge to achieve a solids concentration of 17% was 24% lower than the polymer consumption for the control AD sludge to reach a similar solids content in the cake. FNA pre-treatment also caused a significant reduction in the treated sludge viscosity, with the infinite viscosity and shear viscosity at 100s\textsuperscript{-1} reduced by 65% and 51%, respectively, compared with the un-treated WAS. The reduction in viscosity of the AD sludge was even higher, by ~75% for both the infinite viscosity and shear viscosity at 100s\textsuperscript{-1}. Part of the reduction was due to lower TS concentration of experimental AD sludge due to enhanced VS destruction. When the control AD sludge was diluted to the same concentration as the experimental AD sludge, there was still a 20% difference in viscosity. The reduced viscosity implies that, with FNA-pretreatment, the sludge digester can be operated at a higher solids concentration, further increasing the capacity of the digester.

In conclusion, this study (1) confirmed, at a pilot-scale, that FNA pre-treatment of WAS enhances biogas production and VS destruction, and (2) revealed that FNA pre-treatment of WAS reduces viscosity of treated WAS and also the digested sludge, and reduces polymer consumption for dewatering.

![Figure 1.1](image)

Figure 1.1 Methane production (A); Ammonium concentration (B); Dewatered solids content and polymer consumption (C); and viscosity (D) at the steady state of the two pilot-scale AD reactors.

REFERENCES


Long-term Operation of Anaerobic Municipal Wastewater Treatment of Low-Loaded Wastewater for Fertigation Purposes

*a.foglia@pm.univpm.it
**a.l.eusebi@univpm.it
***Life and Environmental Sciences Department, Polytechnic University of Marche, Via Brecce Bianche, 12, Ancona, Italy.

Abstract: Anaerobic municipal wastewater treatment by UASB and AnMBR has been investigated at pilot scale in operational environment, aiming at reuse for fertigation purposes and focusing even on emerging contaminants such as microplastics (MPs). In AnMBR, 85% COD and 100% TSS removals were achieved as well as TN and TP releases from 75% to 85%. Therefore, the permeate could be suitable for fertigation. The removal of MPs in UASB was in the range of 40%-50%, while less than 0.1 MPs/L (100 MPs/m3) were found after AnMBR. In the last step, Ozone and Sodium Hypochlorite treatments were also conducted to verify their effects on MPs further to disinfection.

Keywords: Anaerobic wastewater treatment, fertigation, reuse, microplastics

INTRODUCTION Anaerobic municipal wastewater treatment might be the core of water resource recovery facility and allow for fertigation. The advantages of AnMBRs are clear considering the necessity of low-cost energy technologies in wastewater treatment plants (WWTPs). Moreover, anaerobic processes result in lower generation of waste sludge and the conversion of organic matter into high-value products (volatile fatty acids (VFAs)) and energy (Mohino et al., 2017). However, removal and fate of emerging contaminants, including microplastics (MPs) (Lares et al., 2018), should be further investigated in operational environment.

MATERIALS AND METHODS A pilot scale anaerobic system was operated to treat real low-loaded wastewater for about 18 months. In order to evaluate best treatment performances, different schemes were tested to increase organic loading rate (OLR) by feeding only raw wastewater (Period 1), then adding methanol (Period 2) and further separated liquid from fermentation of primary cellulosic sludge (Period 3). Membrane filtration performances was studied by investigating the critical flux and effect of gas sparging.

RESULTS AND DISCUSSION Thanks to this strategy the OLR increased from 1 kgVS/m3*d to 2 kgVS/m3*d, biogas production increased from 0.1 m3Biogas/kgCODadded to 0.5 and 0.2 m3Biogas/kgCODadded during Period 2 and Period 3, respectively. Critical flux of membrane filtration was identified as 14 L/m2/h. Moreover, nitrogen gas sparging at 2m3/m2/h by alternating 10 seconds ON-
OFF cycles was found to be the optimal strategy. In AnMBR, 85% COD and >>99% TSS removal were achieved, while TN and TP releases (from 75% to 85%) allow P and N recovery by fertigation reuse (Song et al., 2018). The removal of \textit{E. coli} was investigated in the effluent from UASB and in the permeate from AnMBR process. When membrane was clean, complete removal of bacteria (99%) was obtained. The effluent fits the limit values for reuse according the new EU resolution on water reuse, also in terms of \textit{E. coli} (EU-ENV, 2015).

Several emerging compounds were monitored including microplastics (MPs), where the focus concerned even the effect of advanced oxidation processes commonly used for disinfection. MPs occurrence and removal were studied both in the pilot-scale anaerobic and in the parallel full scale conventional activated sludge (CAS) plant. MPs removal in UASB was in the range 40%-50%, while less than 0.1 MPs/L (100 MPs/m$^3$) were found after AnMBR. On the contrary, CAS removed 82% of MPs and this is the typical removal for conventional WWTPs (Sun et al., 2019).

Ozone and hypochlorite were tested to treat the secondary effluent and study the possible additional side effect on microplastic degradation (Talvitie et al. 2017). For both the oxidants, high specific dosages (1000 mgO$_3$/L and 95 lNaOCl/m$^3$) caused modifications in the characteristics of MPs polymers. In particular, NaClO and O$_3$ treatments showed the characteristics of polyethylene adsorbance bands located at 2850 cm$^{-1}$, 1470 cm$^{-1}$ and 700 cm$^{-1}$, together with a new band at 1540 cm$^{-1}$, related to NO$_3$ group. This band could be attributed to an additive, probably used during the polymer production phase. Current investigation is being considered on the effect of the toxicity before and after the oxidation treatments.

**REFERENCES**


Non-ideal Mixing Model of Anaerobic Digestion: Linking the CFD Model and ADM1

Y. M. Tobo*, **, J. Bartacek**, I. Nopens*

* BIOMATH, Department of Data Analysis and Mathematical Modelling, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium. (YohannisMitiku.Tobo@UGent.be, Ingmar.Nopens@UGent.be)
** Department of Water Technology and Environmental Engineering, University of Chemistry and Technology Prague, Technicka 5, 166 28 Prague 6, Czech Republic (jan.bartacek@vscht.cz)

Abstract Renewable energy (biogas) is one of the resources recovered from wastewater treatment facilities. Most of the anaerobic digestion (AD) kinetics model assume the digester as ideally mixed, however, non-ideal mixing is more common in real AD operation. So far, a mathematical model connecting AD kinetics and CFD model has not been developed. In this work, the non-ideal mixing model of AD was developed by combining Computational Fluid Dynamics (CFD) and Anaerobic Digestion Model 1 (ADM1) using a compartmental model (CM) approach. The computed results showed that the biogas and methane production reduced by 14 and 16%, respectively, under non-ideal mixing compared to ideally mixed digester. Furthermore, the biomass and pH distribution are not uniform in non-ideally mixed AD opposing ideally mixed digester.

Keywords: ADM1; anaerobic digestion; biogas production; compartmental modelling; Computational Fluid Dynamics; dead volume

INTRODUCTION Several kinetics model of AD that have been reported mainly focused on understanding the effects of fed substrates and operational mode assuming AD as ideally mixed (Siegrist et al. 2002; Batstone et al. 2002). A non-ideal mixing kinetics model reported by Bello-Mendoza and Sharratt (1998) and Keshtkar et al. (2003) by dividing AD into flow through and retention region showed that any deviation from ideally mixed digester decreases the AD performance. Dedicated AD modelling studies investigating the interplay of hydrodynamics and kinetics are scarce in the literature. The objective of this work is, therefore, developing a method of non-ideal mixing model and understanding the impact of non-ideal mixing on AD performance based on the CFD model results.

RESULTS AND DISCUSSION It was found that AD velocity distribution decreases with increasing the sludge TSS. Treating the sludge as water, about 90% digester volume
velocity distribution is nearly uniform. For sludge with TSS 4%, the uniformity of velocity distribution decreases to 58%. The amount of biogas and methane production reduced by 14% and 16%, respectively, in non-ideal mixing model compared to ideally mixed AD. This is caused by non-ideal distribution of biomass and soluble substrate inside the digester. For instance, Figure 1.1 shows the variation of biomass concentration in different regions of the digester opposing the constant value in ideally mixed digester.

![Figure 1.1. Biomass concentration distribution in non-ideal mixing.](image)

**CONCLUSION**  The concept of non-ideal mixing model based on CFD model flow behavior in AD presented in this work improves understanding of the local mixing process. Non-ideal mixing flow based on the CFD model flow behavior of AD is more accurate and was shown to have a profound impact on AD performance prediction via kinetics model.

**REFERENCES**


Exploring Forward Osmosis for Production of Reclaimed Water and Concentrated Wastewater for Anaerobic Treatment

F. Ferrari*, I. Rodríguez-Roda*,**, M. Pijuan*, G. Blandin**

* Catalan Institute for Water Research (ICRA), Emili Grahit Street, 101, H2O Building, Scientific and Technological Park of the University of Girona, 17003 Girona, Spain
** LEQUiA, Laboratory of Chemical and Environmental Engineering, University of Girona, Campus Montilivi, 17071 Girona, Spain

Abstract: Forward osmosis (FO) is a promising technology for wastewater (WW) treatment due to its lower energy requirements, higher permeate purity and lower fouling. Applying FO directly on raw municipal WW is of high interest to simultaneously produce a high quality permeate for water reuse while pre-concentrating wastewater for anaerobic digestion towards energy and nutrients recovery. This bench scale study investigated the feasibility to concentrate real raw municipal WW using FO to reach 70% water recovery with a home-made submerged plate and frame membrane module, assembled using Toray’s flat-sheet TFC membrane. Process showed high COD rejection and high differences in ion rejection depending on the charge (SO\(_4^{2-}=99\pm2\%\), PO\(_4^{3-}=99\pm2\%\), NH\(_4^+\)=17\pm4\%, Ca\(^{2+}=10\pm2\)\%). Three different gas sparging strategies (continuous air sparging, alternating nitrogen sparging and no gas sparging) were tested to control membrane fouling, being the continuous air sparging the most favorable.

Keywords: Forward Osmosis; municipal wastewater; COD concentration.

INTRODUCTION

FO is among the promising technologies for wastewater treatment due to its lower energy requirements, higher permeate purity and lower fouling tendency compared to pressure driven membrane technologies. Energy and nutrient recovery from WW can be initiated through the combination of FO with anaerobic treatment by pre-concentrating WW through FO and increase the COD concentration in the WW for biogas production while producing a nutrient rich permeate (Ansari et al., 2017). Treating the concentrated WW with an anaerobic membrane bioreactor (AnMBR) in turn would generate a high quality permeate with which conventional nutrient recovery techniques would be more efficient. Despite the potential of this combination, several challenges associated with the FO process for direct raw WW treatment still remain, including salinity accumulation, membrane fouling control, system scale-up and anaerobic system integration. This is the first study to attempt the concentration of raw sewage with a plate and frame FO module at a bench scale. We have investigated the effect of different gas sparging procedures on filtration performance and contaminants rejection.

MATERIAL AND METHODS

The bench scale set-up consisted of a WW tank, a membrane tank and a draw solution tank. The FO module was assembled using a Kubota plate and a Toray TFC membrane sheet and had a surface area of 0.34 m\(^2\). The membrane was vertically positioned in the membrane tank (9 L volume methacrylate structure) equipped with a gas sparging system (Air/N\(_2\)). Three gas sparging procedures were tested: continuous air sparging, intermittent N\(_2\) sparging.
(1min/15min) both at 5 L min⁻¹ and absence of gas sparging. Every test was carried out using 50 L of real municipal WW and 10 L of draw solution (11.5 g/L of sea salt) keeping the draw solute concentration constant throughout the test. Fouling during WW filtration was assessed by comparing water flux before and after each WW filtration batch.

RESULTS AND DISCUSSION Figure 1.1a shows the different duration to reach 70% water recovery for the different tests conducted. Continuous air sparging resulted in the highest flux obtained during the first 24 h, followed by intermittent N₂ sparging. The lowest flux was obtained when operating without gas sparging probably due to the increased fouling in the membrane. Results of flux tests before and after each test (Figure 1.1b) showed no relevant flux decline when continuous air sparging and intermittent N₂ sparging were applied while showed a decrease of 20% when no gas sparging was applied. TOC analysis showed a concentration factor of 3.3 equal to theoretical values for the three gas sparging procedures. Process showed high differences in ion rejection depending mainly on the charge (SO₄²⁻=99±2%, PO₄³⁻=99±2%, NH₄⁺=17±4%, Ca²⁺=10±2%). This phenomenon was probably due to the negative charge of the active layer of Toray’s membrane. These results are relevant when a further treatment for the reject stream is considered via an anaerobic process. Since SO₄²⁻ and COD rejection were both higher than 98% (same COD/ SO₄²⁻ ratio for raw WW and concentrated WW), the competition between sulfate-reducing bacteria and methane-producing archaea is expected to be the same in an anaerobic reactor treating raw WW and concentrated WW via a FO process. However, the fact that most of the NH₄⁺ passes through the FO membrane implies that no NH₃ inhibition in the subsequent anaerobic treatment is expected. pH increased in both solutions for each test from 7.6 to 8.6 in the wastewater and from 7.1 to 8.1 in the draw solution while feed conductivity increased from 1.3 to 9.9 mS cm⁻¹ in the wastewater due to both actions of decreasing feed volume and reverse solute flux (average RSF= 5.0 g m⁻² h⁻¹).

Figure 1.1a) Water fluxes decline with different gas sparging procedures; b) Results of water flux tests to assess membrane fouling.

This study showed that FO is a promising technology to concentrate raw WW while producing a nutrient rich permeate. Although good membrane performance and results were obtained, further studies are ongoing to examine effect of long term performance.

REFERENCES
Long-term Performance of Two Pilot Scale Anaerobic Reactors for Thermal Hydrolyzed Sludge Digestion under Mesophilic and Thermophilic Conditions

Z. Chen*, W. Li**, J. Wang**, X. Wen*

* School of Environment, Tsinghua University, Beijing 10084, China, sxtymt@163.com
** Research and Development Centre, Beijing Drainage Group Co. Ltd., Beijing 100124, China.

Abstract: In this study, the performance of two pilot scale anaerobic reactors that operated in parallel under mesophilic (MAD) and thermophilic (TAD) conditions for 368 days to treat thermal hydrolyzed sludge was evaluated. MAD was more appropriate for thermal hydrolyzed sludge digestion in terms of better performance in methane production than TAD. In contrast, methane production in TAD might be inhibited by ammonia nitrogen, especially free ammonia, accumulation. Resulted from the two temperatures, microbial community composition displayed a great difference between MAD and TAD. The microbial community structure in MAD was more beneficial for methane production.

Keywords: thermal hydrolyzed sludge; anaerobic digestion; temperature

INTRODUCTION Excess sludge has been dramatically increased in recent decades and would pose a significant threat to the ecological systems without effectively treatment and disposal. Anaerobic digestion (AD) is widely applied in sludge treatment, which can achieve energy recovery. But the initial sludge hydrolysis is usually the rate-limiting step during AD, which significantly restricted its application. Thermal hydrolysis (TH) is an effective sludge pretreatment technology with great application potential since it can enhance hydrolysis and improve sludge anaerobic digestibility. In this study, the long-term performance and microbial community structures of two pilot scale mesophilic anaerobic digestion (MAD) and thermophilic anaerobic digestion (TAD) reactors for thermal hydrolyzed sludge were revealed. The results are expected to provide theoretic basis for optimization of downstream AD for TH pretreated sludge.

MATERIAL AND METHODS The thermal hydrolyzed sludge (160°C) and seed sludge (37°C) were obtained from Gaobeidian WWTP with Cambi process. Two digesters with volume of 500L were respectively operated for MAD (37°C) and TAD (55°C) to produce methane for 368d under stepwise increased HRTs. Biogas production and composition, sludge pH, SCOD, total volatile fatty acids (TVFAs), ammonia nitrogen and free ammonia were measured. In addition, microbial community structure was also analyzed by high throughput sequencing for better understanding of these two anaerobic processes.
RESULTS AND CONCLUSIONS As depicted in Table 1.1, the average methane yield in MAD achieved the highest of 381 m³/t-VSₘ when HRT was 15d. In comparison, the methane yield in TAD increased with HRTs and reach a maximum of 365 m³/t-VSₘ at the HRT of 30d. On the other hand, when both of the two digesters operated under the same HRT of 15d, the methane yield in MAD was significantly higher than that in TAD, which were 381 and 221 m³/t-VSₘ, respectively. In addition, the gas production in MAD were more stable. These results indicated that MAD had a better performance of methane production.

As can be seen in Table 1.1, firstly, the concentration of SCOD and TVFAs in TAD were 7.24-7.83 g/L and 1.15-1.96 g/L, which was approximately 2-3 times that of ones in MAD. This may indicated that high temperature led to organic matter transformation from solid phase to liquid phase in sludge floc. Secondly, the ratio of TVFAs to SCOD in both reactors were about 10%-20% and there were no VFAs accumulation under all HRTs. Thirdly, the concentration of ammonia nitrogen in TAD was relatively higher than that in MAD, especially for free ammonia. In all, the higher pH and free ammonia in TAD could be the reason of the lower methane yield in it.

The microbial community composition in seed sludge, MAD and TAD was showed (at phylum) in figure 1.1. The microbial community structure in MAD was similar to the one in seed sludge, but different from that of TAD. The relative abundance of Bacteroidetes in MAD was 46.2%, which was dramatically higher than that of 3.8% in TAD. Thus, temperature variation resulted in differences in microbial community structure between MAD and TAD. The type of microbial community composition in MAD was more beneficial for methane production.

CONCLUSION MAD showed a better performance of methane production than TAD. Ammonia nitrogen accumulation especially free ammonia in TAD could inhibit methane yield. Owing to temperature difference, microbial community composition displayed a great difference between MAD and TAD, and the type of microbial community structure in MAD was more beneficial for methane production.

<table>
<thead>
<tr>
<th>Process</th>
<th>HRTs (d)</th>
<th>CH₄ yield (m³/t-VSₘ)</th>
<th>pH</th>
<th>SCOD (g/L)</th>
<th>TVFAs (g/L)</th>
<th>Ammonia nitrogen (g/L)</th>
<th>Free ammonia (g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAD 20</td>
<td>368 ± 20</td>
<td>7.62 ± 0.06</td>
<td>3.31 ± 0.23</td>
<td>0.69 ± 0.25</td>
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<tr>
<td>15</td>
<td>381 ± 35</td>
<td>7.73 ± 0.07</td>
<td>4.07 ± 0.82</td>
<td>0.40 ± 0.24</td>
<td>1.76 ± 0.19</td>
<td>0.31 ± 0.06</td>
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</tr>
<tr>
<td>12.5</td>
<td>355 ± 60</td>
<td>7.69 ± 0.05</td>
<td>4.72 ± 0.62</td>
<td>0.49 ± 0.15</td>
<td>1.80 ± 0.16</td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>271 ± 100</td>
<td>7.66 ± 0.19</td>
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<td>N/A</td>
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<td>N/A</td>
<td></td>
</tr>
<tr>
<td>TAD 30</td>
<td>365 ± 153</td>
<td>7.81 ± 0.30</td>
<td>7.24 ± 1.93</td>
<td>1.96</td>
<td>2.05 ± 0.30</td>
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<tr>
<td>25</td>
<td>345 ± 49</td>
<td>8.11 ± 0.09</td>
<td>7.88 ± 0.89</td>
<td>1.51 ± 0.31</td>
<td>1.93 ± 0.22</td>
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</tr>
<tr>
<td>20</td>
<td>343 ± 77</td>
<td>7.87 ± 0.07</td>
<td>7.83 ± 1.81</td>
<td>1.15 ± 0.19</td>
<td>2.14 ± 0.16</td>
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</tr>
<tr>
<td>15</td>
<td>221 ± 100</td>
<td>7.95 ± 0.14</td>
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<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Notes: ‘N/A’ means date were not available.

**Figure 1.1** Relative abundance of microbial community structure in seed sludge, MAD and TAD sludge.

REFERENCES
Intensifying Energy Recovery via Biological In-Situ Biogas Upgrading by Means of Hydrogenotrophic Methanogenesis in WWTP

V. Corbellini*, F. Malpei*

* Department of Civil and Environmental Engineering – DICA, Politecnico di Milano, Environmental Section, Piazza L. da Vinci 32, 20133, Milano, Italy, viola.corbellini@polimi.it, francesca.malpei@polimi.it

Abstract: In a circular economy context, anaerobic digestion (AD) of sewage sludge permit to recover energy in the biogas form and a further biogas upgrading process allows boosting this recover. The biologically-mediated biogas upgrading in which exogenous H2 is provided into an AD to couple with endogenous CO2 via hydrogenotrophic methanogenesis is gaining more and more attention. This study investigated biological in-situ biogas upgrading continuously fed on sewage sludge for 217 days. 2 parallel CSTRs (11L) at mesophilic conditions; organic loading rate (OLR) of 1.5 gCOD L⁻¹d⁻¹ and with H2/CO2 ratio progressively increased from 0:5:1 to 7:1 (OLR_H2 0-0.4 gCOD L⁻¹d⁻¹ with pH controlled (7.4±0.2). Maximum methane content of 83% and a minimum of 5% of CO2 and 91% of H2 utilization were achieved at 7:1 H2/CO2 ratio. An ethanol accumulation, during first H2 Phase, occurred (2.5-3 gCOD L⁻¹) but rapidly depleted. Furthermore, alkalinity reductions (50% and 17% in R1 and R2) registered indicated a possible in-situ constraint.

Keywords: In-situ biogas upgrading; hydrogenotrophic methanogenesis; sewage sludge.

INTRODUCTION In the last decade, biogas upgrading into biomethane has been representing a great opportunity to boost the energy recovery also from sewage sludge. Raw biogas from wastewater treatment plant (WWTP) is composed by 55-70% CH4, 30-45% of CO2 and other traces gas (nitrogen oxygen, water, hydrocarbons ammonia, and siloxanes) (Awe et al., 2017). Recently in literature, a novel biological biogas upgrading process by means of hydrogenotrophic methanogenesis is intensively investigated. Furthermore, the proposed Power-to-Gas technology consisting of methanize energy off-peaks from naturally fluctuant renewable sources to generate hydrogen via electrolysis can be coupled with biological biogas upgrading. The smart integration of such renewables technologies could allow at the same time to capitalize biogas and renewable sources off-peaks in the most profitable way towards a sustainable energy development. The novel upgrading process is based on a well-known archaeal metabolism of hydrogenotrophic methanogens, which are able to convert carbon dioxide to methane, according to the following reaction (Eq. 1):

\[ \text{CO}_2 + 4\text{H}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O} \quad \Delta \text{G}^0 = - 135.6 \text{ kJ-mol}^{-1} \quad (1) \]

So far, it has been studied in three different set-ups, distinguished by where the H2 is provided: in-situ option, H2 is delivered directly inside the biogas digester (Luo et al., 2012); the ex-situ, in which CO2 from external sources and H2 are both injected inside a dedicated reactor containing selected or pure hydrogenotrophic cultures (Luo
& Angelidaki 2012); and the recent hybrid configuration in which in-situ and ex-situ were coupled in one operational unit in a two-stage series reactors (Corbellini et al., 2018).

The present study was focused on the experimental trial of biological in-situ biogas upgrading carried out for 217 days. 2 parallel CSTRs (11L) were fed on a mixture of sewage sludge (OLR of 1.5 gCOD L\(^{-1}\)d\(^{-1}\)) at mesophilic conditions (37°C), and in which H\(_2\) gas injections were progressively increased from 0:5:1 to 7:1 (H\(_2\)/CO\(_2\) ratio); pH controlled (7.4±0.2). Major outcomes demonstrate that the process was stable, a gas output containing 82% of CH\(_4\) and 5% of CO\(_2\) was achieved in 7:1 H\(_2\)/CO\(_2\) period and 91% of the injected H\(_2\) was utilised. A noteworthy ethanol accumulation, during the very first H\(_2\) Phase (H\(_2\)/CO\(_2\) of 0.5:1) occurred (up to 2.5-3 gCOD L\(^{-1}\)) Figure 1.1. Nonetheless, maintaining the H\(_2\) feeding, ethanol was depleted indicating the system was able to withstand the new operative conditions. A significant alkalinity reduction due to CO\(_2\) depletion in the liquid phase of 50% and 17% in R1 and R2 was also registered (Table 1.1). Results from 16S rRNA gene amplicon analysis revealed a new shape of the core microbial community: a slight variation of the bacterial community including homoacetogens and an archaeal community mostly composed by hydrogenotrophic methanogenic species and only one acetoclastic methanogenic were observed.

![Figure 1.1](image-url) Methane rate [LCH\(_4\)/d] for the in-situ (R2) biogas upgrading reactor and TVFA + Ethanol [gCOD/L] trends on the left; TVFA speciation concentrations and alcohols of the in-situ (R1) and (R2) biogas upgrading reactors on average for each experimental phase; in brackets the H\(_2\)/CO\(_2\) ratio adopted on the right.

| Table 1.1 Summary of reactors performance, for all experimental phases. |
|---------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                            | Ph-I            | Ph-II           | Ph-III          | Ph-IV           | Ph-V            |
|                           | R1             | R2             | R1             | R2             | R1             |
|                           | R1             | R2             | R1             | R2             | R1             |
| Gas yield (H\(_2\), 100%) [mol/d] | 0.496 | 794 | 1238 | 2011 | 3438 | 4403 | 5236 |
| CH\(_4\) rate [mol/d]     | 2.5 | 2.6 | 2.7 | 3 | 2.8 | 3 | 3.1 | 3 | 3.4 | 3.6 | 3.9 | 3.9 | 4.2 | 3.5 | 3.7 | 3.3 | 4.5 |
| CH\(_4\),mol [%V/V]       | 0.26 | 0.28 | 0.24 | 0.27 | 0.26 | 0.28 | 0.23 | 0.28 | 0.23 | 0.28 | 0.27 | 0.34 | 0.35 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.54 |
| CH\(_4\) [%]              | 22 | 23 | 25 | 23 | 22 | 21 | 21 | 19 | 21 | 13 | 18 | 12 | 15 | 5 | 6 |
| CH\(_2\) [%]              | 72 | 71 | 70 | 71 | 71 | 71 | 71 | 71 | 71 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| H\(_2\) [%]               | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 4 | 5 | 5 | 4 | 6 | 6 |
| H\(_2\) percentage [%]    | 94 | 95 | 95 | 99 | 98 | 88 | 97 | 97 | 95 | 91 | 96 | 95 | 97 | 94 |
| Alkalinity [mg\(\text{Na}_2\text{CO}_3\)/L] | 4364 | 4329 | 4042 | 4087 | 4044 | 4014 | 3953 | 4024 | 3992 | 4369 | 3361 | 4664 | 4340 | 3918 | 1260 | 3631 |
| pH\(_4\) [mg\(\text{Na}_2\text{CO}_3\)/L] | 0.18 | 0.18 | 0.28 | 0.23 | 0.17 | 0.18 | 0.14 | 0.16 | 0.14 | 0.12 | 0.21 | 0.14 | 0.08 | 0.06 | 0.15 | 0.09 |

REFERENCES


Full-scale Anaerobic Co-Digestion of Sludge and Organic Waste: Rovereto Four-Year Experience


*Department of Environmental Sciences, Informatics and Statistics, University Ca’ Foscari Venice, Via Torino 155, Mestre Venice, Italy, giulia.moretto@unive.it
**Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, University of Campania “Luigi Vanvitelli”, Italy
***Wastewater treatment agency, Provincia Autonoma di Trento, Italy
****Department of Biotechnology, University of Verona, Italy

Abstract: Energy production from renewable resources can be integrated with waste management by means of the anaerobic co-digestion (ACoD) technology application. In urban contexts two of the most abundant organic refuses are sludge from wastewater treatment and organic fraction of municipal solid waste (OFMSW). This study reports a four-year full-scale co-digestion experience of mixed primary and secondary sludges and pretreated OFMSW applied in the Rovereto wastewater treatment plant (WWTP). Biogas production was equal to 7,000 m^3/d and the electric energy production covered about 80-85% of the total energy requirements. Different sludge and OFMSW co-digestion approaches are compared both from an economic and environmental point of view.

Keywords: Waste valorization; energy recovery; anaerobic co-digestion

Energy demand, waste generation and disposal and natural resources depletion are only some of the main issues of recent years. In this scenario, policies are moving towards energy production from renewable resources and waste recycling and valorisation, especially the European Union (EU) (European Commission, 2015). Sometimes, the road towards renewable energy and waste treatment is paved with difficulties, namely the initial capital cost required for investments and the energy cost of infrastructures. Municipal wastewater treatment accounts for about 3% of global electric consumption and 5% of global greenhouse gas emission (Nghiem et al., 2017). A consolidated technology that allows to increase biogas and energy yields in which two or more organic substrates are converted together into bioenergy is ACoD (Mata-Alvarez et al., 2014). With this approach, existing structures such as WWTPs can be valorised through the production of energy and new marketable added-value products (Smart-Plant and Res Urbis Horizon 2020 projects).

The present case study focuses on the four-year full-scale implementation of the ACoD technology in Rovereto WWTP, where primary and secondary sludges are mixed together and sent to co-digestion with OFMSW. The organic fraction is collected in three districts of the Trento province and sent to Rovereto WWTP, where is conveyed to a hammer mill for mechanical pretreatment. This pretreatment is able to maximise the energy recovery, since the squeezed liquid fraction accounts for 80% of total waste (Figure 1.1). Biogas production reached up to 7,000 m^3/d with 80-85%
of electric energy coverage. A complete economic balance has been made, together with a preliminary environmental assessment.

Figure 1.1 Energy recovery maximisation approach applied in Rovereto WWTP.

This study concludes the full-scale monitoring of a previous work (Mattioli et al., 2017) and is then compared to the Treviso case study (Moretto et al., 2019), where a different OFMSW pretreatment was applied, with a liquid fraction production yield of 25-30%. Even with a different pretreatment approach, ACoD is the linking element between renewable energy production and new advanced processes for resource recovery, e.g. polyhydroxyalkanoates (PHAs) from mixed microbial cultures (MMCs) (Valentino et al., 2017).

REFERENCES

European Commission 2015. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions. Closing the loop – An EU action plan for the circular economy.


Blend Quality and Logistics Optimisation of Anaerobic Co-Digestion in a Real Multi-Plant Case Study

D.Palma*,**, M.Verdaguer*, M.Poch*, M.À. Cugueró-Escofet**

*LEQUIA, Institute of the Environment, Universitat de Girona, 69, Mª Aurèlia Capmany, 17003 Girona, Spain
** CCB Serveis Mediambientals – Consorci del Besòs-Tordera. St Julia, 241. 08403 Granollers (Spain)
davidpalma@lequia.udg.edu, marta.verdaguer@udg.edu, manel.poch@udg.edu, macuguero@besos-tordera.cat

Abstract: Implementation of circular economy strategies is a must for sustainable development. Regarding water sanitation processes, maximization of anaerobic digesters capacity at WWTPs is a well-established strategy, known as co-digestion. Many optimization tools have been developed to optimize blend composition. However, associated logistics to each component of the blend remain as a relatively unexplored field, which can yield to significant planning problems. Here, an Ant Colony Optimisation (ACO)-based approach is proposed to tackle these problems. The proposed algorithm maximizes an objective function composed by: a first term, related to the quality of the sludge; and a second term, related to the distance between the sludge generator and the anaerobic co-digester. It is expected to provide a wider perspective by including logistics considerations in the solution provided, and thus to improve co-digestion planning strategies in a real case study composed of 16 WWTPs.

Keywords: Anaerobic codigestion; ant-colony optimisation algorithm; waste management

Anaerobic digestion process in Waste Water Treatment Plants (WWTPs) plays an important role amongst circular economy potential technologies, since it is one of the most well-established and promising processes in these installations, as stated by Batstone et al. (2014). Furthermore, co-digestion of sewage sludge and organic wastes has arisen as a promising strategy of circular economy due to its capability of merging both wastewater and waste valorisation value chains. However, the anaerobic digestion process optimization and improvement still requires further work to be done in order to achieve its full-potential. In this line of work, a remarkable number of anaerobic digestion optimization tools have been recently developed, as reported by Hagos et al. (2017). These tools have been mainly focused on the modelling and control of the optimum co-substrate blend. However, to the knowledge of the authors, the complex logistics related with these co-substrates has not been assessed, mainly due to the ad-hoc nature of each study case and the lack of data from the organic waste transportation sector which may be found in the literature. Besides, critical factors for co-substrate selection underlies not only at characterization-related level, but also at its associated logistics. The objective of this work is to develop a new co-digestion optimisation tool based on conventional quality and quantity parameters, as well as novel transportation-related impacts. Such method would be applied in a real case study composed of 16 different WWTPs —4 of which implementing anaerobic digesters— which are managed by Consorci Besòs Tordera, a local water authority in charge of these facilities. In order to achieve this goal, the selection of blend quality...
and logistics of anaerobic co-digestion in a multi-plant system may be stated as an optimisation problem, which aims to maximise the following objective function:

\[
B = \sum_{w=1}^{n_w} \sum_{z=0}^{l_w} y_{w,z}^2 \nu_w T_w \left( \sum_{c=1}^{3} \rho_c^w \right) \rho_d + \frac{\rho_r}{x_{w,z} d_w l_w} \tag{eq. 1}
\]

The first term in the objective function in eq. 1 (Verdaguer et al. (2016)) aims to obtain the optimal characteristics of the anaerobic digestion input regarding different specifications of interest of this input e.g. toxicity, biogas production ability. Here, a novel second term is introduced taking into account the importance of the transport costs for anaerobic co-digestion of different types of sludge and industrial co-substrates. Specifically, this new term is related to the cost of the sludge/co-substrate transport, the distance between sludge/co-substrate generation and the corresponding digester —determined by the transport route—, and the social impact of this transport (depending on the routes considered). This proposal uses normalized values for the terms related to the quality and the transport. Also, the objective function in eq. 1 is constrained by the sludge/co-substrate characteristics —volume, composition, and toxicity level—, which are acceptable for the digester input in order to be suitable for the digestion process. The optimisation problem is solved by means of the Ant Colony Optimization (ACO) algorithm (Dorigo and Stützle, 2004). ACO algorithm searches a solution using a probabilistic and iterative methodology. The specific procedure proposed by the authors is an adaptation of the Max-Min Ant System (Stützle and Hoos, 2000) to a multidimensional knapsack problem, using an specific heuristic expression \(\eta_{w,z}\),

\[
\eta_{w,z} = \frac{\nu_w \sum_{c=1}^{3} \rho_c^w}{d_w} \tag{eq. 2}
\]

Hence, this is set as an optimisation problem which aims to find a solution towards favourable sludge/co-substrate characteristics and short distances/low social impact sludge/co-substrate transports. In addition, the algorithm implements mechanisms to avoid a rapid stagnation of the solution due to problem constraints. The proposed approach will be applied to the optimization problem of a real multi-plant case study, allowing the optimization of anaerobic digestion blends of 4 real WWTPs. These blends will be composed of: in-situ WWTP sludge, 12 ex-situ WWTPs sludge generators and 11 ex-situ industrial organic waste generators. The novel approach presented here considers both quality and logistics aspects of each waste contributor, providing an integral co-digestion planning strategy for a real multi-plant case study.

REFERENCES


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Session 9

VFA AND ORGANICS RECOVERY AND REUSE
Cellulose Recovery and Carbon Upgrading by Integrating Microsieving and Fermentation Technologies in Wastewater Treatment Plants: A Plant-Wide Modeling Study

R. Boiocchi*, D. Santoro*, M.C.M. Van Loosdrecht***

* 9211 116 Street, TG6 1H9 AB (Canada), boiocchi@ualberta.ca
**Trojan Technologies, 3020 Gore Rd, London, ON N5V 4T7 dsantoro@trojanuv.com
*** Dept. Biotechnology, TU Delft, van der Maasweg 9, Delft, The Netherlands m.c.m.vanloosdrecht@tudelft.nl

Abstract: In this work, the Benchmark Simulation Model n°2 was extended to a resource recovery application by first extending the model with the incorporation of a rotating microsieving technology (Salsnes Filter) and, consequently, by tracking the fate of cellulose across the typical municipal wastewater treatment processes as an independent state variable. Separating in the BSM2 model cellulose, mostly in the form of particulate fibers, from other forms of particulates allows not only for precise mass balance in every location of interest of the plant, but also the exploration of seasonal impact due to the strong (non-Arrhenius) temperature sensitivity of the cellulose hydrolysis rate constant both in the anaerobic and aerobic processes. Different temperature dependency functions were needed for the hydrolysis of cellulose in the activated sludge unit and the fermenter/anaerobic digester.

To determine the potential of carbon upgrading from a slowly biodegradable form (i.e., cellulose) to a readily available form (i.e., VFAs, etc.), hence helping carbon-limited denitrification and bio-P plants, we simulated the presence of a hydrolysis unit (fermenter) to utilize part of the cellulose from the influent in the form of readily available COD or denitrification. Scenario analysis has been performed in order to understand the impact of cellulose diversion under different operating temperatures and the impact of the new hydrolysis unit.

Keywords: Wastewater, resource recovery, cellulose, rotating belt filter, hydrolysis, modelling

INTRODUCTION From an energy balance perspective, toilet paper is considered to be more conveniently treated in an anaerobic digester of a typical wastewater treatment plant (WWTP) rather than in the mainstream activated sludge unit (Ruiken et al., 2013). A novel treatment technology that has recently gained attention for its capability in capturing more efficiently influent toilet paper is the rotating-belt filter system (RBF). RBF technologies implementation in full-scale has to be investigated carefully, alone and in combination with potentially complementary technologies such as enhanced fermentation, with the aim of accurately quantifying its plant-wide benefits.

MATERIALS AND METHODS In order to carry out this investigation, models represent a useful tool. The Benchmark Simulation Model n°2 (BSM2) by Jeppsson et al. (2007) provides a simulation environment describing the typical processes occurring in full-scale WWTPs. In this platform, the degradation of toilet paper in the activate sludge unit is degradation fraction of the particulate organic matter.
components, as a single state variable. In this work, we used the model structure suggested by Reijken et al. (2018) and extended the model to include more accurate temperature-dependent functions, obtained from a detailed literature review and data analysis, for the hydrolysis of cellulose in both the biological main line and the anaerobic digester. Moreover, we incorporated such updated model structure into the BMS2 platform, together with a dynamic Salsnes Filter (SF) model validated on data collected at the Greenway Research Facility in London, Ontario, Canada. As can be seen from Figure 1.1, temperature dependent trend lines were identified.

Figure 1.1 Estimation of the hydrolysis rate coefficient for (a) the activated sludge and (b) digester.

The model by Sherratt et al. (2018), extended by Boiocchi et al. (2018), was used to describe the cellulose diversion performed by a rotating-belt filter technology (Salsnes Filter). To study the impact of hydrolysing recovered cellulose on the carbon requirements in the activated sludge unit, a new hydrolysis compartment working at different temperatures receiving the sludge separated by the rotating belt filter and diverting its effluent in the activated sludge unit is implemented (see Figure 1.2).

Figure 1.2 Layout of the Benchmark Simulation Model nº2 for microsieving and fermentation included.

RESULTS AND DISCUSSION Steady-state simulations of the model presented in Figure 2 are performed at three different temperatures of 10, 15 and 25°C by controlling the oxygen concentration in the aerated zone at 1 mg.L⁻¹ and the TSS concentration at 3000 mg.L⁻¹. Results with regards to cellulose degradation (for both activated sludge unit and anaerobic digester), aeration energy, effluent nitrate and ammonium concentrations, and methane production are presented in Table 1.1. As
expected, cellulose is found to be degraded much more efficiently in the AD. Aeration energy requirements are proportional to environmental temperatures, due to a larger sludge mineralisation. Effluent nitrate concentrations decrease with temperature, since the activity of heterotrophic bacteria using cellulose and other organic carbon sources to reduce nitrates speeds up. Effluent ammonium concentrations are very low in all the three cases, but sensibly increase when environmental temperatures decrease due to the lower activity of nitrifiers.

**Table 1.1** Steady-state results of the BSM2 for cellulose at temperatures of 10, 15 and 25°C.

<table>
<thead>
<tr>
<th>Weather temperature [°C]</th>
<th>Cellulose Degraded in AS [g COD/d]</th>
<th>Cellulose Degraded in AD [g COD/d]</th>
<th>Effluent Nitrate Concentration [mg N/L]</th>
<th>Effluent ammonium Concentration [mg N/L]</th>
<th>Aeration energy requirements [kWh/d]</th>
<th>Methane production [kg CH₂/d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>8.18·10⁴</td>
<td>1.36·10⁶</td>
<td>18.3</td>
<td>0.4</td>
<td>3850.7</td>
<td>5273</td>
</tr>
<tr>
<td>15</td>
<td>1.74·10⁵</td>
<td>1.3·10⁶</td>
<td>15.1</td>
<td>0.02</td>
<td>4281.1</td>
<td>4573</td>
</tr>
<tr>
<td>25</td>
<td>2.73·10⁵</td>
<td>1.25·10⁶</td>
<td>9.5</td>
<td>0.012</td>
<td>4953.8</td>
<td>3519</td>
</tr>
</tbody>
</table>

Steady-state results are presented in Table 1.2. As can be seen, by diverging a maximum fraction of sieved sludge equal to 15% in winter seasons, the hydrolysis unit is able to increase the amount of soluble carbon fed to the activated sludge unit and thus enhance heterotrophic denitrification (see lower effluent nitrate) while increasing only slightly the effluent ammonium concentration. On the other hand, hydrolysing a higher amount of cellulose from the primary sludge and recycling the entire soluble carbon produced thereby to the AS unit enhances heterotrophic bacteria which compete with nitrifiers over oxygen and space. Nitrifying bacteria activity is slowed down, which in turn raises effluent ammonium concentration. As more cellulose is used in the AS unit as carbon source, less methane is produced from the anaerobic digestion.

**Table 1.2** Steady-state results of the BSM2 for cellulose at a temperature of 10 with hydrolysis unit.

<table>
<thead>
<tr>
<th>Sieved sludge fraction to hydrolysis unit [%]</th>
<th>Cellulose Degraded in AS [g COD/d]</th>
<th>Cellulose Degraded in Hydrolysis [g COD/d]</th>
<th>Cellulose Degraded in AD [g COD/d]</th>
<th>Effluent Nitrate Concentration [mg N/L]</th>
<th>Effluent ammonium Concentration [mg N/L]</th>
<th>Aeration energy requirements [kWh/d]</th>
<th>Methane production [kg CH₂/d]</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>9.741·10⁴</td>
<td>5.86·10⁴</td>
<td>1.301·10⁶</td>
<td>16.3</td>
<td>1</td>
<td>3823.9</td>
<td>5168.2</td>
</tr>
<tr>
<td>15</td>
<td>1.0473·10⁵</td>
<td>8.8·10⁵</td>
<td>1.27·10⁶</td>
<td>14.7</td>
<td>2.1</td>
<td>3772.6</td>
<td>5113.7</td>
</tr>
<tr>
<td>20</td>
<td>1.1193·10⁵</td>
<td>1.17·10⁵</td>
<td>1.24·10⁶</td>
<td>10</td>
<td>7.6</td>
<td>3514.6</td>
<td>5050.4</td>
</tr>
</tbody>
</table>

**CONCLUSION** It was found that recovering 15% of the cellulose separated by a rotating belt filter as readily available COD enhances heterotrophic denitrification at low activated sludge temperatures and thus improves effluent nitrate concentrations. The novel simulation model obtained can be used to evaluate the impact of cellulose recovery in WWTPs and develop and test control strategies and scenarios maximizing its advantages and minimizing its drawbacks.

**REFERENCES**
Volatile Fatty Acids Production: Effect of Bacterial Community under Various Operational Conditions

Merve Atasoy*, Ozge Eyice**, Zeynep Cetecioglu***
*merve@kth.se; ** o.eyice@qmul.ac.uk; ***zeynepcg@kth.se

Abstract: In this study, various operational conditions and bacterial community were evaluated to enhance VFA production. Three different inoculums were operated under various pH and retention times by using glucose as a substrate. According to results the VFA composition changed by pH and retention time, whereas the production efficiency depended on the inoculum type. The highest VFA production efficiency (0.97 gVFA/gscOD) was achieved under pH 10 on the fifth day. The dominant acid type was butyric acid (58%). The bacterial community was analysed by next-generation sequencing of 16S rRNA gene, which showed that 51.3% Clostridiaceae is the most dominant taxa in the samples.

Keywords: Volatile fatty acids; operational conditions; bacterial community

INTRODUCTION Depletion of petroleum source and their adverse environmental effects make obligatory to find environmentally friendly and economical feasible new materials and energy source. One of them is Volatile Fatty Acids (VFAs) are valuable intermediate products of anaerobic digestion. They have wide range of application area in the several industries as well as they can be used as raw materials for bio-based products such as bioplastic, biohydrogen, biogas etc. (Park et al., 2014; al., Zheng et al., 2017). Nevertheless, VFAs are derived from fossil fuel sources via chemical routes. To make the latter method economically feasible, its efficiency and sustainability must be improved. Therefore, several studies have been conducted to investigate the effects of operational conditions on VFA production such the effects of pH, temperature, retention time, organic loading rate and additives to improve production efficiency. Further research has been suggested for not only regulating the operational conditions but also examining the microbial community for more feasible VFA production (Kawaguchi et al., 2017; Mansouri et al., 2017). In this scope, we operated anaerobic batch reactors seeded by three different inoculums with glucose under a range of pH and retention time. The aims of this study were (1) to determine the effect of operational conditions on VFA production and composition, (2) to identify the bacterial diversity and their composition, (3) to find out the relation between operational conditions and acids types with bacterial community shift (4) to determine specific operational conditions to obtain one-type of VFA.

MATERIALS AND METHODS The experiments were designed to reveal VFA production and composition with bacterial community shifts under various operational conditions by using three different inoculums: two of them were anaerobic granular seed sludge with different granule sizes and one was anaerobic digester sludge. They referred to inoculum 1, inoculum 2, and inoculum 3 for small
granular, large granular and anaerobic digestion sludge, respectively. Experiments were conducted under pH 5, pH 8, pH 10, and without pH control for 1, 5, 10, and 15 days with 120 rpm mixing at 35°C. The volatile solid content (VS) in each reactor was adjusted to 2000 mg/L. Glucose was used as a model substrate with 3000 mg/L COD (VWR Chemicals, Sweden). During the experiments, chemical oxygen demand, organic acids, VFA compositions, and pH were observed at both influent and effluent. The production and composition of VFA (acetic, butyric, and propionic acids) in the effluents were analyzed by gas chromatography (GC 6890, Agilent) with a flame ionization detector. Also, the difference between the VFA (sum of acetic, butyric, and propionic acids) with organic acids were assumed as “other” acids. Bacterial diversity in the batch tests was determined by next-generation sequencing (NGS) of the 16S rRNA gene.

RESULTS AND DISCUSSION According to results of the study, the maximum VFA production (2953±24mgCOD/L) was reached under alkali conditions (pH 10) on the fifth day using Inoculum 2. The dominant VFA type was butyric acid in most of the reactors, and the composition of VFA was similar in all sets. Nevertheless, total VFA production varied according to the inoculum type. 

![Figure 1.1 Effluent VFA compositions according to the pH and RT for Inoculum 2](image)

The main parameter affecting acid type in the production process was pH. The dominant acid type was observed as acetic acid (44%) in neutral conditions (no pH control), acetic acid (35%) and butyric acid (37%) in acidic conditions and butyric acid (60%) in alkali conditions. Our results show that the most effective parameters on VFA composition are pH and retention time, whereas the production efficiency is changed by the bacterial composition of inoculum. Also, the granular sludge formation is more suitable for efficient VFA production.

![Box 1. Comparison of initial inoculum with the highest VFA was obtained at each inoculum in Phylum and Family level bacterial diversity](image)

The results of correlation analysis (p<0.05) with bacterial community data and operational conditions showed that the bacterial community was more correlated (0.329) with butyric acid concentration than other parameters.

CONCLUSIONS Within this study, the following conclusions were made based on results;
• Operational parameters affect the type of VFA. Under alkali conditions, the dominant acid type was butyric acid (60%), while the highest acid type was acetic acid (44%) under neutral pH.
• Inoculum type is the key parameter for the VFA production efficiency.
• Clostridium is directly responsible for VFA production efficiency, while the operational conditions do not affect the dominance of Clostridium.
• Granular sludge formation is more suitable for high VFA production efficiency.

REFERENCES


Targeting Specific Volatile Fatty Acid Production through pH Shifts during Protein Fermentation


Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain - riccardo.bevilacqua@usc.es

Abstract: There is very limited literature on the influence of pH on volatile fatty acids (VFA) selectivity from protein-rich substrates fermentation and available information is controversial. The objective of this work was to analyse the influence of pH (i.e. 5, 7 and 9) during the continuous mixed culture fermentation of two model proteinic compounds (casein and gelatine) and to discern whether protein composition determines pH effect. Casein achieved higher acidification degrees than gelatin at all tested pHs. Moreover, VFA spectra noticeably changed with pH shifts, although the extent of the variations depended on the protein composition as well: acetic acid increases with pH values, n-butyric and n-valeric are linked to acid environments, while iso-valeric is favoured at alkaline pHs. In general, more reduced and valuable VFAs are produced at low pHs. This knowledge helps to better predict the outcome of protein-rich substrates fermentation and consequently drive it towards desired products.

Keywords: Protein fermentation; pH; VFA production

INTRODUCTION Volatile fatty acid production from waste and sidestreams is an appealing alternative to biogas generation because of the countless applications they have as precursors of other commercial compounds (Bathia and Yang, 2016). Selectivity is a key aspect of anaerobic fermentation which needs further investigation in order to make this process viable and profitable.

Targeting specific VFA production is theoretically possible through adjustment of operational parameters, such as pH. Studies about pH influence on sugars fermentation are relatively extensive (Temudo et al., 2007) with significant variations in products composition between acid and alkaline environments. In contrast, not much is known about protein fermentation and available information is controversial. Proposed degradation models only underline the importance of the substrate composition (Ramsay and Pullammanappallil, 2001), even though changes in products composition were detected at different pH values (Breure and Van Andel, 1984). For this reason, this study focuses on evaluating pH influence on protein fermentation outcome as a tool to drive the production towards desired VFAs. In addition, the relation between protein composition and the extent of pH effect was investigated.

MATERIALS AND METHODS Two continuous stirred tank reactors of 1 L working volume were operated at 25°C with a hydraulic retention time of 1.5 days. Two model compounds, casein and gelatin, were used as sole carbon source with an organic loading rate of 5.3 g COD/L·d. HCl and NaOH 3M solutions were used to control the pH at three different levels: 5, 7 and 9. Nitrogen sparging (≈ 10 mL/min) was implemented to reduce hydrogen concentration in the liquid phase and maintain
anaerobic conditions. Reactors inoculum came from a lab scale fermenter (1.0 g VSS/L) fed with a mix of glucose, casein and sodium oleate. Standard analytical methods were used to monitor reactors performance. VFAs from C2 to C7 and headspace gas composition were measured through gas chromatography.

RESULTS AND CONCLUSIONS Close-to-steady states were achieved in 20-30 days after each pH shift and were maintained for approximately 110-150 days. No methanisation of the substrate was detected during the whole operation. Casein acidification was close to 50% (COD basis henceforth) at neutral and alkaline pH values but lower at pH 5 (∼30%). Gelatin acidification was always lower than in casein case, with the highest values at pH 7 (40%) and approximately 20% at the other pHs.

In terms of VFA composition, casein fermentation showed specific trends with the pH shifts (Figure 1.1A), while they were less evident in the case of gelatin (Figure 1.1B), suggesting that the extent of their influence is connected to the substrate composition.

![Figure 1.1 Molar fractions of the individual VFAs produced in casein (A) and gelatine (B) reactor at different pH values.](image)

Acetic acid is the major product in all the experiments performed during the study, especially at higher pH values. Propionic and iso-butyric acids do not show substantial variations with pH shifts, while higher concentrations of n-butyric are linked with acidic environments. Iso-valeric acid is favoured in acid or alkaline environments, while n-valeric acid is most relevant between pH 5 and 7. Interestingly, iso-caproic acid is only produced during casein fermentation at low pH.

In conclusion, neutral pH values appear to be the best environment for mixed culture fermentations of proteins in terms of acidification degree (40 to 50%). Yet, pH can be used as a tool to drive the fermentation of protein-rich substrates towards target VFAs, given that the extent of its influence is apparently correlated to protein composition. In general, more reduced and valuable VFAs are produced at low pHs. This knowledge is very useful to better predict the outcome of protein-rich substrates fermentation and consequently design fermentation processes which are able to target the production of specific VFAs.

REFERENCES


Biorefinery Pilot Plant for VFAs and Nutrients Recovery from Agro-waste Material

S. Nortilli*, E. Righetti*, N. Frison**, D. Bolzonella**

*Innoven srl, Strada Le grazie 15, 37134 Verona, Italy
**Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy

Abstract: The Horizon 2020 NoAW project aims the application of the circular economy approach by exploring the potential of agro-waste to be converted into a portfolio of eco-efficient products such as bio-energy, bio-fertilizers, bio-packaging and bio-molecules, in symbiosis with urban waste conversion. In this work, a biorefinery pilot plant was implemented in an Italian livestock farm (La Torre srl, Isola della Scala - Verona, Italy) with the target to convert agricultural residues into VFAs building blocks through acidogenic fermentation. The pilot plant consisted of a fermentation unit fed with liquid manure and maize silage/grass residues, a screw-press separator and an anaerobic digester to valorize as biogas/biomethane the solid fraction from the solid/liquid separation. The enhanced solid/liquid separation of the liquid fraction through rotating ceramic membrane allows the potential recovery of VFAs and high quality of phosphorus based fertilizer from the fermentation liquid and anaerobic digestate respectively.

Keywords: NoAW project; nutrients recovery; scale-up; solid/liquid separation; volatile fatty acids

In July 2014, the European Commission delivered the Circular Economy Packages, where an action plan was adopted to establish a new economic model based on the principles of the circular economy (EC, 2014). The target of these principles should be the achievement of low-emissions economy, where agriculture and livestock are the main responsible for water pollution and greenhouse gas emission (GHGs). On the other hand, an important role can be played by bio-based chemicals, such as Volatile Fatty Acids, and phosphorus based nutrients (such as struvite) recovered from agro-waste residues. Among the innovation action in the framework of the Horizon 2020, the NoAW project aims to apply a circular economy approach to agricultural wastes on a territorial and seasonal scale. NoAW intends to explore the potential of agro-waste to be converted into a portfolio of eco-efficient products which are produced using fewer resources and creating less pollution such as bio-energy, bio-fertilizers, bio-packaging and bio- molecules, in symbiosis with urban waste conversion. According with the described scenario, this work report the results obtained by the first biorefinery pilot plant aiming the conversion of existing anaerobic digestor for biogas production in resource recovery facilities for VFAs and nutrients recovery form agro-waste residues. The pilot plant was implemented in La Torre livestock farm (around 8000 heads) located in Isola della Scala (Verona, Italy), in order to test the process at real environment. Briefly, the description of the units is reported below: 1) Complete mixed storage tank, working volume 3.5 m³ the tank was filled twice per week with raw biomass, mainly with liquid manure, corn cob flour and/or grass
residues. The characteristics of the single raw materials were reported in the following table:

<table>
<thead>
<tr>
<th>Feedstock composition</th>
<th>Fraction in the feeding (%)</th>
<th>TS (kg/t)</th>
<th>TVS (kg/t)</th>
<th>Total N (kgN/t)</th>
<th>Total P (kgP/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liquid Manure</td>
<td>50-77</td>
<td>90.4-95.5</td>
<td>73.2-75.5</td>
<td>1.9-2</td>
<td>0.3-0.4</td>
</tr>
<tr>
<td>Water (if required)</td>
<td>Up to 34</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maize Silage/Grass Residues</td>
<td>16</td>
<td>450-470</td>
<td>434-399</td>
<td>4.72-4.75</td>
<td>1-1.2</td>
</tr>
</tbody>
</table>

2) Sequencing Batch Fermentation Reactor (SBFR), working volume 4.0 m³, the unit operate at mesophilic conditions (37°C) and hydraulic retention time (HRT) of 4 days. Then, the fermented biomass enriched of VFAs was treated by a screw-press for solid/liquid separation. 3) The fermentation liquid fraction from the previous step was stored in a storage tank with 2.0 m³ of working volume; 4) Anaerobic digestor with 1 m³ of working volume, for the conversion into biogas/biomethane of the solid fraction obtained from the screw-press; 5) Enhanced separation of the solids through a rotating ceramic membrane (RCT, model Smart-Lees, JUCLAS) to enable the VFAs and the nutrient recovery from the fermentation liquid and anaerobic digestate.

According with the collected data, a preliminary mass balance of the biorefinery plant is reported below:

**REFERENCES**


- NoAW (No Agricultural Waste), Horizon 2020 research and innovation programme under grant agreement No 688338, noaw2020.eu
Pilot Scale Acidogenic Fermentation of Microsieved Cellulosic Sludge for Short Chain Fatty Acids Production

C. Da Ros*, N. Frison*, V. Conca*, A.L. Eusebi**, F. Fatone**

*Department of Biotechnology, University of Verona, Strada Le Grazie 15, I-37134, Verona – Italy
**Department of Science and Environmental Engineering (SIMAU), Marche Polytechnic University, Brecce Bianche St., 60131, Ancona, Italy (VE) – Italy.

Abstract: In this work, cellulosic sludge was recovered from municipal wastewater by means of microsieving through pilot rotating belt filter and fed in a fermentation unit for Short Chain Fatty Acids production. According with loadings, the removal efficiencies varied between 17-76% for suspended solids and 10-61% for the COD, while less than 27% for nitrogen and phosphorus. The acidogenic fermentation of the CS was conducted initially in batch mode to evaluate the short chain fatty acids production yields at different pH. The higher value was obtained at pH 9 (521 mgCOD per g of volatile solids) while without any pre-treatment the yield was of 232 mgCOD per g of volatile solids. Then, a 2.6 m$^3$ Sequencing Batch Fermentation Reactor was operated at 4 days of hydraulic retention time and mesophilic temperature (37°C). The VFAs production achieved were as high as 2.1 kgCOD$_{VFAs}$/m$^3$ day reactor, where up to 50% was propionate.

Keywords: wastewater micro-sieving; cellulosic sludge; acidogenic fermentation; short chain fatty acids.

Water resource recovery facilities (WRRF) move further toward the goal of net-zero energy with technologies that maximize carbon recovery from wastewater. The rotating belt filter has been recently applied to replace primary clarifier as primary treatment. Rusten and Lundar (2006) reported the economic benefits of this technology because reduced of 50 % the costs compared with primary clarifiers. Moreover this technology reduces the energy need for aeration without negative effect on the denitrification, while the high biodegradability of produced sludge determines a potential methane production of 323-366 NmLCH$_4$/gVSS (Paulsrud et al., 2014). Ruiken et al, 2013, reported that the net energy need for the wastewater treatment would amount to at least 40% less compared with the reference without fine-mesh sieving (Stowa 2010-19). Moreover, the resulting filtered material could represent up to 30% of the total COD and use efficiently biomass power plants for energy generation whereas the resulting sieved wastewater gives advantages in optimizing the wastewater treatment process. On the other hand, Crutchik et al. (2018) evaluated the on-site conversion of the cellulosic sludge to SCFAs through acidogenic fermentation whether the SCFAs are considered as high value-added precursors for the production of energy, polyhydroxyalkanoates, chemical industry, etc.

Currently, the development of new technologies aiming the valorisation of the cellulosic primary sludge is a target of the EU through innovation action in the framework of Horizon2020. Among the others, the scale-up of the short-chain fatty acids (SCFAs) production by the acidogenic fermentation of CS was the task of the Horizon 2020 Smart-Plant project. During the project, municipal wastewater was sieved by Salsnes Filter (Salsnes Filter, PO BOX 279, N-7801 Namsos, Norway),
obtaining average removal efficiencies of 44% for suspended solids (range 17-76%), 35% for COD (range 10-61%), 27% for nitrogen while regarding the phosphorus removal is not significant. The total solids (TS) content in CS was the most variable parameter that ranged between 21 and 73 gTS/kg. The sludge composition was quite constant on dry basis with a volatile fraction of 92% dw. The COD/N and COD/P ratios were 55 mgCOD/mgN and 266 mgCOD/mgP respectively, indicating the lower presence of nutrients compared with a secondary sludge. Potential SCFA production was investigated with batch tests varying the initial pH. The maximal yield was reached with pH 9 and was 521 mgCODSCFA/g VS, corresponding to increase of 125% compared with untreated sludge (Figure 1.1 a).

Semi-continuous trials were operated in a 2.6 m³ sequencing batch fermentation reactor (SBFR) fed daily with untreated CPS to reach solid retention time (SRT) of 10 and 4 days. Performances and effluents characteristics were reported in Table 1.1. Although the SCFA concentrations were comparable in the different operational conditions, the flow rate determined productivity of 0.8 and 2.1 kg/m³d using 10 and 4 days of SRT, respectively.

<table>
<thead>
<tr>
<th>SRT (days)</th>
<th>$Y_{SCFA}$ (mgCOD/g VS)</th>
<th>SCFA (mg/L)</th>
<th>Acetic acid (%)</th>
<th>Propionic acid (%)</th>
<th>Butyric acid (%)</th>
<th>NH₄⁺ (mgN/L)</th>
<th>PO₄⁻ (mgP/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>150</td>
<td>8347</td>
<td>24%</td>
<td>49%</td>
<td>10%</td>
<td>290</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>165</td>
<td>8360</td>
<td>30%</td>
<td>46%</td>
<td>13%</td>
<td>370</td>
<td>101</td>
</tr>
</tbody>
</table>

The study will be completed with currently underway semi-continuous test adjusting sludge pH at value 9 and operating with SRT of 4 days. Preliminary results under this condition confirms the higher yield observed in the batch test (almost 290 mgCOD/gVS) and propionic acid contributes for 50% of total SCFA. The cost-benefit analysis of the CPS biorefinery was carried out considering different scenarios: the highest benefit would be reached accomplished acidogenic fermentation, nutrients removal and bio-polymer production.

REFERENCES


Direct Membrane Filtration of Municipal Wastewater by Ceramic Flat-Sheet Membranes for Recovery of Organic Matter

K. Kimura*, M. Kato*

*Division of Environmental Engineering, Hokkaido University, N13W8, Kita-ku, Sapporo 060-8628, JAPAN

Abstract: Ceramic flat-sheet MF membranes were used for concentration and recovery of organic matter in municipal wastewater. The use of ceramic membrane allowed us to carry out intensive physical cleaning and chemical cleaning. Continuous 50-fold concentration of organic matter in municipal wastewater was possible with a ceramic membrane under the condition of relatively high fluxes. Recovery of organic matter reached >75%.

Keywords: Membrane fouling; mechanical scouring with granules; chemically enhanced backwash

We have demonstrated that 50-fold concentration of organic matter in municipal wastewater could be continuously carried out by using a hollow-fiber PVDF membrane (0.1 µm) when combined with chemically enhanced backwash (CEB) using high concentrations of chemical reagents (Lateef et al., 2013; Kimura et al., 2017). Although irreversible fouling in direct membrane filtration (DMF) of municipal wastewater could be almost perfectly controlled by implementation of CEB, the formation of cake (reversible fouling) became significant in some experiments in our previous studies. We have demonstrated that circulation of granular materials in the filtration tank could completely control the formation of cake in the MBR, although it caused damage to the surfaces of PVDF membranes (Kurita et al., 2015). It was thought that cake formation in DMF could be efficiently controlled if granular materials work properly. For frequent and sufficient contact between the membrane surface and granular materials, flat-sheet type of membranes should be used. Also, to avoid damage to the membrane, material of the membrane should have sufficient physical strength. In this study, we examined the applicability of ceramic flat-sheet membranes for DMF. The use of a ceramic membrane enabled us to carry out intensive CEB, which should control the evolution of irreversible fouling. Reversible fouling should be mitigated by granular materials. Thus, it might be possible to carry out efficient DMF of municipal wastewater that is not possible with organic hollow-fiber membranes.

Figure 1. shows a schematic diagram of the filtration unit used in this study. Continuous 50-fold concentration of organic matter in municipal wastewater, which was found to be possible in our previous study using an organic hollow-fiber membrane (Lateef et al., 2013; Kimura et al., 2017), was attempted in this study. Feed water in this study was the influent to the primary sedimentation basin of an existing wastewater treatment plant connected to a combined sewer. Wastewater is concentrated by 2-fold...
in the first tank (Tank 1) and the retentate is transferred to the second tank (Tank 2) where wastewater is further concentrated by 25-fold. The final product that is supposed to be used for energy production (anaerobic digestion) is continuously obtained from Tank 2. Constant-flow mode of the operation was carried out by using peristaltic pumps, and intermittent operation (12-minute operation and 3-minute pause) was carried out. Each tank was separated into two compartments by a baffle. In one compartment, agitation (340 rpm) was carried out to create circulation flow in the tank. Using the circulation flow, granules moved in the tank and cleaned the membrane surface. The granular materials used in this study were made from PEG and had a cylindrical shape (Nisshinbo, Tokyo, Japan). Diameter and height of the granules were 4 mm. In this study, 30% of granules were introduced to the two tanks. Membrane fluxes in Tank 1 and Tank 2 were set at 6.5 LMH and 4.2 LMH, respectively. These fluxes were the same as those that were achievable with organic hollow-fiber membranes (Kimura et al., 2017). Citric acid (1250 ppm) was used for the CEB reagent. CEB was carried out every 6 hours. Compared with the previous study using hollow-fiber membranes (Kimura et al., 2017), the intensity of CEB in this study was reduced by 87.5%.

Increases in TMP in the two tanks are shown in Figure 1.2. Increase in TMP was very slow in both tanks. This reflects the efficient control of membrane fouling by scouring with the granules. Recovery of organic matter was continuously carried out: >75% of COD contained in raw wastewater was captured as the product in this study. Based on these results, increase of membrane fluxes in the two tanks (7.8 LMH in Tank 1 and 5.0 LMH in Tank 2) was attempted at the operation time of 320 hours. This slight increases in membrane fluxes, however, caused rapid increases in TMP, particularly in Tank 1. At 450 hours of operation, membrane fluxes in the two tanks were reset to the original values of 6.5 LMH and 4.2 LMH in Tank 1 and Tank 2, respectively. After reducing the membrane fluxes, stable operation of the system could be carried out again.

To enable DMF with higher membrane fluxes, several trials such as switching source wastewater to the effluent from the primary sedimentation of tank, changing frequency and intervals of CEB, intermittent aeration, addition of chemical coagulants were examined. Intermittent aeration was found to be promising for more efficient control of membrane fouling in DMF, without experiencing reduction in recoverable organic matter.

REFERENCES
Hydrothermal Carbonization of Sewage Sludge: Process Optimization by Response Surface Methodology


* Department of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino, 56122 Pisa, Italy, monica.puccini@unipi.it, andreasilstella@gmail.com, sandra.vitolo@unipi.it
** Department of Civil & Environmental Engineering, University of Florence, via S. Marta 3, 50139 Florence, Italy, gemma.mannarino@unifi.it, riccardo.gori@dicea.unifi.it
*** Department of Chemistry and Industrial Chemistry, University of Pisa, Via G. Moruzzi, 13, 56124 Pisa, Italy, anna.maria.raspolli.galletti@unipi.it

Abstract: Hydrothermal carbonization (HTC) may be considered a promising process for the conversion of sewage sludge into valuable products such as fuel, sorbent materials or amendment. In this study the optimization of HTC of sewage sludge from urban wastewater treatment was conducted by using the Response Surface Methodology (RSM) approach for studying the effects of temperature, residence time and solid content loading. The hydrochar produced by hydrothermal carbonization of sewage sludge under different reaction conditions was characterized in term of physical, chemical, and morphologic properties. The HTC process enhanced dewaterability, higher heating value and C content of the raw material, offering a promising alternative in the management of sewage sludge.

Keywords: Design of experiments; hydrochar; sewage sludge

Hydrothermal carbonization (HTC) is a thermochemical technique for the conversion of wet biomass into a water-soluble organic fraction, gas and a solid porous product, known as hydrochar. Different materials may be used as raw source for the process, including energy crops, forestry residues and organic fraction of municipal solid waste.

Figure 1.1. Preliminary analysis of the standard design error.

Moreover, HTC may be designed as a promising alternative for the management of sewage sludge. Compared with incineration, the high moisture content does not
represent a risk of energy shortage, and high ash and heavy metals content are not related to poor combustion efficiency and ash issues. However, only very recently a few investigations have been carried out on the HTC of sewage sludge. HTC operates at autogenous pressure (up to 2 MPa), in sub-critical water (Puccini et al., 2008); hence, if compared with conventional thermochemical techniques, energy requirements related to pre-drying are reduced or avoided.

In this study, the operative parameters of HTC (i.e.: reaction temperature, residence time and initial solid content of sewage sludge) were studied with the Response Surface Methodology (RSM) design called a central composite design (CCD). This method is suitable for fitting a quadratic surface and it helps to optimize the effective parameters with a minimum number of experiments, and also to analyze the interaction between the parameters. Generally, the CCD consists of $2^n$ factorial runs with $2n$ axial runs and $n_c$ center runs (six replicates). The number of experimental runs from the central composite design (CCD) for the three variables chosen for the study consists of eight factorial points, six axial points and six replicates at the center points indicating that altogether 20 experiments were required (Table 1.1). A preliminary analysis of the standard error in the design space are reported in Fig. 1.1.

In view of the hydrochar post-treatment and use as fuel or for the production of a sorbent material, dewaterability, higher heating value (HHV) and C yield were chosen as responses to the variations of the HTC reaction conditions.

<table>
<thead>
<tr>
<th>Run</th>
<th>Space Type</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Solid Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Factorial</td>
<td>220.00</td>
<td>85.00</td>
<td>5.00</td>
</tr>
<tr>
<td>2</td>
<td>Factorial</td>
<td>190.00</td>
<td>240.00</td>
<td>12.00</td>
</tr>
<tr>
<td>3</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>4</td>
<td>Factorial</td>
<td>220.00</td>
<td>240.00</td>
<td>5.00</td>
</tr>
<tr>
<td>5</td>
<td>Factorial</td>
<td>190.00</td>
<td>85.00</td>
<td>5.00</td>
</tr>
<tr>
<td>6</td>
<td>Axial</td>
<td>205.00</td>
<td>162.50</td>
<td>2.61</td>
</tr>
<tr>
<td>7</td>
<td>Factorial</td>
<td>190.00</td>
<td>240.00</td>
<td>5.00</td>
</tr>
<tr>
<td>8</td>
<td>Factorial</td>
<td>220.00</td>
<td>85.00</td>
<td>12.00</td>
</tr>
<tr>
<td>9</td>
<td>Axial</td>
<td>205.00</td>
<td>292.84</td>
<td>8.50</td>
</tr>
<tr>
<td>10</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>11</td>
<td>Axial</td>
<td>205.00</td>
<td>32.16</td>
<td>8.50</td>
</tr>
<tr>
<td>12</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>13</td>
<td>Axial</td>
<td>230.23</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>14</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>15</td>
<td>Factorial</td>
<td>220.00</td>
<td>240.00</td>
<td>12.00</td>
</tr>
<tr>
<td>16</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>17</td>
<td>Axial</td>
<td>179.77</td>
<td>162.50</td>
<td>8.50</td>
</tr>
<tr>
<td>18</td>
<td>Factorial</td>
<td>190.00</td>
<td>85.00</td>
<td>12.00</td>
</tr>
<tr>
<td>19</td>
<td>Axial</td>
<td>205.00</td>
<td>162.50</td>
<td>14.39</td>
</tr>
<tr>
<td>20</td>
<td>Center</td>
<td>205.00</td>
<td>162.50</td>
<td>8.50</td>
</tr>
</tbody>
</table>

The optimal processing conditions have been identified, by taking into account the interactions between the variables involved, not considered in classical step-by-step analyses. The HTC process was successfully conducted also with samples characterized by a very low initial solid content (5%). The technique increased the dewaterability, HHV and C content of sewage sludge, even when short time (less than 1.5 hours) and low temperature (190 °C) treatment was carried out.

REFERENCES

Pretreatment and Process Optimization for Brewery Spent Grain Conversion into Chemical Building Blocks

J. Castilla-Archilla*,+, S. Papirio**, P.N.L. Lens*

* Microbiology, School of Natural Sciences and Ryan Institute, NUI Galway, Ireland
** Department of Civil, Architectural and Environmental Engineering, University of Napoli Federico II, Via Claudio 21, 80125, Napoli, Italy

+email: j.castillaarchilla1@nuigalway.ie

Abstract: Food-agricultural wastes have significant potential for use in a circular economy. Hemicellulose and lignocellulose represent the most abundant source of carbohydrates for biotechnological purposes, but their complex nature results in a low biodegradability. The present work investigates the use of brewery spent grain as a valuable substrate for the production of volatile fatty acids (VFAs), alcohols and lactic acid. Firstly, a thermal diluted acid hydrolysis of the substrate was performed. Then, acidogenic fermentation of the liquid fraction was carried out at 37°C and different pH (uncontrolled, 4.5, 5.0, 6.0 and 8.0), using anaerobic granular sludge as inoculum. The highest VFA concentrations were observed at pH 6.00 (± 0.05), with 16.89 (± 1.33) gCOD/L.

Keywords: hydrolysis, acidogenic fermentation (AF), volatile fatty acids (VFAs)

INTRODUCTION Anaerobic digestion is a naturally occurring microbially-mediated process whereby microorganisms ferment organic substrates to biogas (CH4 and CO2). Partial inhibition can lead to the accumulation of intermediate compounds, such as volatile fatty acids (VFAs), which are base chemicals for the production of added-value products (Albuquerque et al., 2011).

Environmental and sustainability concerns have increased the use of waste in a biorefinery approach. Lignocellulose and hemicellulose represent the most abundant source of carbohydrates available in agricultural and industrial wastes. However, these materials have a complex structure and are highly recalcitrant to microbial degradation. Many studies have focused on pretreatment methods to enhance their bioavailability (Mancini et al., 2016; Silveira et al., 2018).

This study covers the feasibility for production of VFAs from by-products of the brewing industry, such as brewery spent grain (BSG). The use of BSG for VFAs production was evaluated after performing a thermal diluted acid hydrolysis (TDAH) pretreatment. TDAH was conducted at different total solids (TS) concentrations of BSG and different sulfuric acid concentrations. Subsequently, acidogenic fermentation (AF) under different pH was applied to optimise the VFA production.

METHODS BSG was supplied by a local brewery (Galway, Ireland). TDAH was carried out at 6 different sulfuric acid concentrations (0.0, 0.5, 1.0, 1.5, 2.0 and 3 % v/v) and 3 BSG concentrations (4, 7 and 10 % w/w as TS) in an autoclave (400 mL, at 121°C for 20 minutes). The hydrolysate was centrifuged and filtered. Optimal
conditions were 1.5% H₂SO₄ and 7% BSG based on the final TCs, liquid recovered, and the amount of BSG and sulfuric acid used.

The leachate was used for the AF in a continuously stirred tank reactor (1.75 L at 37°C) operated in batch mode. The pH was controlled at 4.5, 5.0, 6.0 and 8.0. One operation was conducted without pH control. The leachate was diluted to a soluble chemical oxygen demand (sCOD) concentration of 23.07 (± 2.14) gCOD/L, where 16.19 (± 1.51) gCOD/L corresponded to total carbohydrates (TCs). Anaerobic granular sludge from an industrial UASB (Kilconnel, Ireland) reactor was used as inoculum without pre-treatment.

RESULTS In total, 18 different combinations for pre-treatment were carried out. For the AF the relationship between the TCs, proteins, organic fermented compounds and VFAs was studied. In the case of the first batch without pH control, the initial pH was 6.98 (± 0.02), with the lowest pH being 4.08 (± 0.08).

In all cases, at pH’s above 4.5 the TCs consumption exceeded 90% and increased further at higher pH. Acetic and butyric acid were the most significant VFAs in all the experiments Figure 1.1. Acetic acid production increased with pH, whereas butyric acid production peaked at pH 5. The highest VFAs concentration was at pH 6, where from a total sCOD of 18.16 07 (± 0.54), VFAs contribution represented 93.00 (± 2.14) %.

Figure 1.1 Main parameters for AF under 5 different pH conditions: a) total sCOD and the VFA concentrations and b) TCs rate consumption, acetic and butyric rate production and ratio of VFAs present in sCOD.

CONCLUSION This study showed the feasibility of BSG hydrolysis and AF for VFAs production using granular sludge without pretreatment. The use of sulfuric acid for TDAH did not negatively affect the AF. BSG appears promising as feedstock for VFAs production at pH 6 with a VFAs concentration of 16.89 (± 1.33) gCOD/L.

REFERENCES


Selective Separation of Organics and Inorganics by Ion-Exchange Membranes

L. MA*, L. Gutierrez*, M. Waqas*, A. Verliefde*
* Particle and Interfacial Technology Group (PaInT), Faculty of Bioscience Engineering, Ghent University. Coupure Links 653, 9000 Gent, Belgium.

Abstract: This study contributes to the field of selective organics/inorganics separation using ion-exchange membrane (IEM) technologies (i.e., electrodialysis, reverse and assisted-reverse electrodialysis) in the treatment and resource recovery of organics-rich industrial wastewater. The diffusive and convective transport of uncharged (i.e., phenazone, paracetamol, and theophylline) and charged organics (i.e., clobifric acid and atenolol) in IEMs were investigated in diffusion cells. The transport of uncharged organics in the absence of salt was purely diffusion-driven, while the presence of salt had a slight influence on the transport of organics (<5% transported mass difference). However, other mechanisms play a role in the transport of charged organics, as their transport was not constant with the absence of salt, and the presence of salt in the receiving solution highly promoted the transport of organics (by 59% transported mass higher for clofibric acid) while inhibited their transport when the salt present in the feed (by 13% transported mass lower for clofibric acid). The observation could indicate that convective transport is limited while electromigration was playing a dominant role. The experimental validation of the solution-diffusion model showed that the model underestimated the uncharged solutes transport in IEMs.

Keywords: Ion-exchange membrane; organic transport; selective separation.

INTRODUCTION

Selective separation of organic and inorganic components is of great value in industrial wastewater treatment, to improve recovery of both organics and inorganics (Han et al. 2016). Ion-exchange membrane (IEM) technologies could be the key to addressing this issue. However, only a limited number of studies have focused on separation mechanisms of organics and inorganics in complex streams by IEMs (Zhang et al. 2011). Also, the transport mechanisms of organics through IEM has often been overlooked. Therefore, this research aims to investigate the convective transport of organics, as well as to build a predictive model for diffusive transport of uncharged organics in IEMs.

MATERIAL AND METHODS

Five pharmaceutical compounds (phenazone, paracetamol, and theophylline as uncharged; clobifric acid and atenolol as negatively and positively charged organics, respectively) and 4 commercial IEMs (Fujifilm) were selected to perform the diffusion and convection experiments in diffusion cells. In the diffusion experiment, the organics concentration gradient across the membrane was the only driving force applied for solute transport, while salt (NaCl) gradient was applied to the convection experiments. The process of the transport of uncharged organics in dense membranes has been described by the solution-diffusion model (Eq. 1) (Verliefde et al. 2013),

\[ J_s = -\frac{D_{m,\text{sol}} \varphi \varepsilon}{\Delta x} \Delta C \]  

(Eq. 1)

Where \( J_s \) is the solute flux, \( D_{m,\text{sol}} \) is the diffusion coefficient of solute in the membrane, \( \varphi \) is the partition coefficient, \( \varepsilon \) is the membrane porosity, \( \Delta C \) is the concentration difference across the membrane, \( \Delta x \) is the thickness of the membrane.
$D_{s,m}$ was determined by $^1$H NMR. $\varphi$ was determined solute radius $r_s$/membrane pore size $r_p$. The solute-membrane affinity ($\Delta G$) was determined via contact angle. $\Delta x$ was measured by ESEM. The flux data obtained in the diffusion experiments and the experimentally determined parameters were used to fit the model to solve for $r_p$ and $\varepsilon$. The predictive model was validated by comparing predicted with measured fluxes.

**RESULTS AND CONCLUSIONS** The linear increase of phenazone flux ($R^2=0.92$) as a function of its concentration difference (Fig. 1a) indicated purely (solution-) diffusion driven transport of phenazone, which is similar to the other membranes under the same condition with other organic solutes in terms of $J_s / \Delta C$ (Fig. 1b). However, the transport of negatively charged clofibric acid in AEM I was not constant indicating other mechanism playing a role rather than diffusion (Fig. 1c). In the presence of salt, the transport of uncharged paracetamol was still constant, but with less than 5% difference of transported mass compared to in the absence of salt, regardless of the transport direction of salt (Fig. 1d). However, the transport of clofibric acid was highly promoted (by 59%) when the transport direction of salt was opposite to the transport of organics (condition R), while the same transport direction (condition F) inhibited the transport of organics (by 13%). It could be deduced that it was not convective transport which was driving the transport of organics in the presence of salt, but electromigration and diffusion were governing the transport of organics.

The modeled slope ($J_s / \Delta C$) of phenazone in CEM I was 14% lower than the experimental slope, indicating the underestimation of the solution-diffusion model to the transport of the solutes (Fig. 1a). Monte Carlo analysis indicated that the discrepancy between modeled and measured fluxes could not be ruled out even after considering experimental errors. The method for determining contact angle and the definition of diffusive hindrance factor may lead to these discrepancies, requiring further investigation.

**REFERENCES**


Pathogen Inactivation and Resource Recovery from Sanitation Waste through *in-situ* Accumulation of Carboxylic Acids


*Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY 14853, USA
**Department of Microbiology and Immunology, College of Veterinary Medicine, Cornell University, Ithaca, NY 14853, USA
***Center for Applied Geosciences, University of Tübingen, 72074 Tübingen, Germany

Abstract: Through lab-scale and pilot-scale trials, we have developed a bioprocess that utilizes open cultures of anaerobic bacteria to ferment human fecal material (HFM) and accumulate carboxylic acids. The process requires only inputs of HFM and carbohydrate-rich food waste, which reduces the pH within the bioreactor to keep carboxylic acids in the undissociated form that is toxic to pathogens. In a pilot-scale trial with 45-L batch containers, we produced 43.1 mM *n*-caproate, with 13.1 mM in the undissociated form. We also demonstrated successful pathogen inactivation in this system using *Ascaris* eggs as indicators. This process inactivates pathogens and initiates biological degradation of HFM, leaving a product that is primed for further conversion into value-added products such as biogas and black soldier fly larvae.

Keywords: Sanitation, carboxylic acids, *Ascaris*

There are 4.5 billion people in the world who currently lack access to safely managed sanitation (WHO and UNICEF, 2017). Improving this figure requires more than simply building more toilets. It also requires innovative solutions for waste treatment that are both economically and technically viable. Resource recovery from human excreta through processes such as anaerobic digestion, composting, and black soldier fly production for animal feed is a pertinent way of reducing treatment costs. Pathogen inactivation is a critical component of these systems to protect workers who handle excreta during resource recovery processes and to protect the end users. However, many pathogen inactivation methods require either long treatment times (as in the case of composting) or expensive inputs such as commercial chemicals or heat to produce high temperature.

To address this challenge, we have developed a bioprocess whereby open cultures of anaerobic bacteria ferment human fecal material (HFM) to accumulate carboxylic acids (CAs). Through a chain elongation pathway, we specifically target CAs with longer hydrocarbon chains, such as *n*-butyrate and *n*-caproate, which are more effective at inactivating pathogens. A series of lab experiments and a culminating field trial demonstrated that a mixture of fecal sludge and carbohydrate-rich food waste produces high concentrations of CAs and a reduced pH, which are both critical...
for pathogen reduction. Pathogen reduction is demonstrated using eggs of the roundworm *Ascaris suum* due to their extreme resilience to disinfection processes.

Initial trials used lab-scale batch reactors with undiluted HFM as substrate and produced up to 257 mM \( n \)-butyrate and 27 mM \( n \)-caproate (Harroff et al., 2017). We also exposed *Ascaris suum* eggs to solutions of CAs and demonstrated that *A. suum* inactivation was directly controlled by exposure time and the concentration of the undissociated form of CAs, which indicated that bioreactors must have a pH below the pKa of CAs (~4.8) to successfully inactivate pathogens. In the lab-scale trials, the pH of bioreactors remained nearly neutral, and the accumulated CAs were, therefore, primarily in the dissociated form, which is not toxic to pathogens.

We then conducted field trials using 45-L seeded plastic containers by collaborating with Sanergy, who is a sanitation provider in Nairobi, Kenya. For substrate, we used a mixture of HFM collected from urine-diverting dry toilets and banana waste. Carbohydrate-rich food waste, such as bananas, is more easily degradable than HFM, which we hypothesized would be quickly converted to lactic acid to help reduce the pH. We found that the food waste both reduced the pH to 5.2 and provided substrate for additional carboxylic acid production and chain elongation. After adding the food waste, the concentration of \( n \)-caproate increased from 8.4 (±2.0) mM to 43.1 (±5.5) mM within 14 days. At a pH of 5.2, 30.4% of the total concentration or 13.1 mM is in the undissociated form, which is higher than we saw in any other fermentation trials.

**CONCLUSIONS AND IMPLICATIONS** The development of low-input processes to inactivate pathogens in HFM is critical for recovering resources, creating value-added products, and reducing the financial and energetic costs of effective waste treatment. The bioprocess discussed here utilizes an open culture at anaerobic conditions to produce CAs with increasing hydrocarbon chains to inactivate pathogens. Anaerobic systems are simpler to maintain and cheaper to operate than aerobic systems because they eliminate the need for aeration, and the use of an open culture compared to a single organism makes the system more robust and able to withstand the high variability of HFM. The cost of the treatment process is also low because the only required inputs are waste materials in the form of human fecal material and food waste. The output of the bioreactor is then pathogen-free and has already undergone the initial, often rate-limiting stages of biological degradation, making it a strong candidate for further processing into value-added products such as biomass to an anaerobic digester to produce biogas or feed for black soldier fly larvae.

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**REFERENCES**


Impact of Advanced Separation Technologies on the Fermentation Products of Municipal Sludge

A.N.L. Brison*, N. Derlon*

*Eawag: Swiss Federal Institute of Aquatic Research, Überland Str. 133, 8600 Dübendorf, Switzerland
antoine.brison@eawag.ch, nicolas.derlon@eawag.ch

Abstract: Anaerobic digestion without biogas production is a relevant approach for the valorisation of organic substrates. We evaluated fermentation of particulate organic matter (POM) captured using a conventional primary settler as opposed to advanced technologies such as micro-sieving and the high-rate activated sludge (HRAS) process. Our results demonstrate that volatile fatty acids (VFAs) are the main fermentation products whatever the origin of the POM, and that all fermentates are thus suitable for polyhydroxyalkanoate (PHA) production. Also, the POM composition governs the composition of the produced VFA cocktails; protein rich HRAS for example yields higher fractions of longer-chained acids. The average conversion yields of POM to VFAs however, did not exceed 0.3 g_{VFA,COD} g_{VSS,fed}^{-1}. High-pressure thermal pre-treatment of POM is thus considered to reduce rate-limitation by hydrolysis and further increase VFA production rates.

Keywords: VFA production; anaerobic carbon valorisation; fermentation of particulate organic matter

Anaerobic digestion without biogas production and with conversion of POM to high-value end-products (PHAs, esters or microbial proteins) is a relevant alternative over conventional aerobic treatment (Alloul et al. 2018). A relevant carbon valorisation route must include: (1) an enhanced capture of POM, e.g., using advanced separation technologies such as micro-sieves and HRAS systems, (2) hydrolysis of POM followed by fermentation, (3) conversion of fermentation products into high-value end-products. The nature of the fermentation products dictates the nature/characteristics of the end-products and ultimately their potential industrial applications. However, our understanding of the link between the origin of the POM and the composition of the fermentation products is limited. Previous studies focused on producing PHAs from fermented secondary sludge or on assessing the impact of advanced separation technologies on biogas production. We close the gap of combining advanced capture of POM and its fermentation for PHA production purposes; a crucial step to advance the carbon valorisation route. Our study evaluates the solubilisation and fermentation of POM captured by a conventional primary settler as opposed to advanced technologies, e.g., micro-sieving and HRAS process.

Three anaerobic digesters with identical operating conditions were fed in continuous mode with: (1) primary sludge (PS), (2) micro-sieved materials (MSM) and (3) HRAS. A clarifier was used to separate the fermentation products from the sludge. Solid retention time was controlled to prevent methanogenesis. The three influents had a chemical oxygen demand (COD) of approximately 2.5 g_{COD} L^{-1}. Temperature was kept at 20°C while pH was not controlled.

Our results demonstrate that VFAs are the dominant fermentation product, whatever the influent POM composition. VFAs always accounted for the major fraction of the
soluble COD (86-87%) in all three digester effluents, indicating that those effluents are particularly suitable for PHA production using mixed microbial cultures. The composition of the POM however governs the composition of the VFA cocktail, which ultimately determines the produced PHA monomers (Valentino et al. 2017). Acetic acid was the main fermentation product in all systems and made up for 45-50% of the soluble COD (Figure 1). In the PS and MSM digesters, the remaining VFA fraction consisted primarily of propionic acid. The VFA composition in the HRAS digester was more complex and contained higher concentrations of longer-chained acids at the expense of propionic acid. A nitrogen-rich POM (0.06 gN/gCOD) indicated that the HRAS consisted mainly of biomass, resulting in elevated fractions of iso-valeric and iso-butyric acids, i.e., products of amino acid fermentation. On the other hand, the PS and MSM had a negligible nitrogen content of POM, indicative of a high cellulose content. Finally, our results suggest that specific solubilisation rates are considerably higher for flocculent biomass-type solids, e.g. HRAS (78 gCOD,prod gVSS,system⁻¹ d⁻¹), than for fibrous, cellulose-rich organic solids as in PS (36 gCOD,prod gVSS,system⁻¹ d⁻¹) and MSM (25 gCOD,prod gVSS,system⁻¹ d⁻¹). However, net conversion yields (0.2 gSCOD,prod gPCOD,fed⁻¹) and net VFA production (0.3 gVFA,COD gVSSfed⁻¹) were similar in all three digesters.

High conversion rates of POM to VFAs are crucial for a sustainable carbon valorisation in form of PHAs, but remain rate-limited by hydrolysis. Thus, solids pre-treatment such as high-pressure thermal hydrolysis is required to increase the biodegradability and solubilisation of the sludge. Tests are ongoing to evaluate how hydrolysis pre-treatment affects the fermentation products and ultimately impacts the cultivation of PHA accumulating organisms. Overall, our results provide relevant insights for the anaerobic treatment of municipal wastewaters and the development of Water Resource Recovery Facilities with a focus on products other than biogas.

REFERENCES


Anaerobic Co-Digestion of Sewage Sludge and External Organic Waste: Strategy to Shift Production from Biogas to Volatile Fatty Acids

I. Owusu-Agyeman*, Elzbieta Plaza**, Z. Cetecioglu***

*Department of Chemical Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, isaacoa@kth.se
**Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, elap@kth.se
*** Department of Chemical Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, zeynepcg@kth.se

Abstract: Volatile fatty acids (VFAs) have higher value and wider usage range than biogas. The study sought to devise strategy to shift anaerobic digestion production from biogas to VFA by systematically investigating the impact of substrate ratio of sewage sludge and external organic waste (OW). Co-digestion was carried out in batch reactors of 500 mL volume, at pH 5 with OW proportion of 0%, 25%, 50%, 75%, 100%. VFA production increases with increase in the percentage of organic waste in the influent due to the availability of higher biodegradable organics. The volume of biogas produced decreases with increase in organic waste percentage in the substrate and was explained by different kind of VFA formed by the two substrate and the inhibitory effect of high VFA concentration.

Keywords: Volatile fatty acids, biogas, co-digestion, sewage sludge

INTRODUCTION Resource recovery from waste streams is an important contributing factor dealing with the United Nations Sustainable Development Goals 6, 7 and 11. Anaerobic digestion of sewage sludge offers an opportunity for resource recovery from wastewater treatments plants. Anaerobic digestion leads to a final product of biogas while volatile fatty acid (VFA) is a valuable intermediate product. Recently, VFA production is getting attention due to its higher value and wider range of usage than biogas.

Anaerobic co-digestion of sewage sludge with external organic wastes such as food waste, beverage waste, diary waste, has the potential to enhance resource recovery efficiency from waste streams (Xie et al., 2018). While there are a number of studies on co-digestion of sewage sludge and organic waste for biogas production, there are limited literature on VFA production through co-digesting of sewage sludge and external organic wastes. Moreover, the studies on VFA production through co-digestion are usually narrowed to sewage sludge and a specific organic waste. The current study sought to systematically investigate the impact of substrate ratio of sewage sludge and external organic waste with complex composition on VFA and biogas production.

MATERIALS AND METHODS Primary sewage sludge (PS) and organic wastes (OW) were collected from the Hammarby Sjöstadsverk research facility (Sweden) and Himmerfjärden WWTP (SYVAB, Sweden), respectively. The external OW consisted of alcohol and soda beverage, food, dairy, fruit, fat and oil wastes. Digested sludge taken from a full-scale anaerobic digestor (Henriksdal WWTP, Stockholm, Sweden) was used as seed sludge.

Batch experiments were carried out using an automatic methane potential test system (AMPTS II, Bioprocess Control, Sweden) with biogas measurement unit and...
500 mL glass reactors. The amount substrate was maintained at initial total chemical oxygen demand (COD) concentration of 15 g/L, whereas the initial amount of seed sludge set at VS of 10 g/L. Co-digestion was carried out at pH5 with OW proportion of 0%, 25%, 50%, 75%, 100% as total COD. Thus, 0% OW and 100% OW represent mono-digestion of PS and OW respectively.

**RESULTS AND DISCUSSION** The VFA concentrations in the effluents of all experiments increased sharply from day 0 up to about day 8 and levelled off (Figure 1.1). The result suggests that the maximum VFA production can be obtained within retention time of 8 days regardless of substrate ratio. The VFA production increased with increase in the percentage of OW. This is attributed to the increase in the biodegradable organics which were readily available for utilization by acid producing bacteria. It has been shown that co-digestion enhances the solubilization of hard-biodegradable organics which can improve VFA productivity.

![Image](image.png)

**Figure 1.1** VFA production as a function of retention time.

The cumulative volume biogas was up to 175 NmL CH₄ at retention time of 7 day for the 0% OW experiment (Figure 1.2). Interestingly, the cumulative volume of biogas decreased with increase in the percentage of the organic waste. It can be inferred from the results that PS has higher tendency to form biogas even at acidic pH of 5 where methanogenic activities are minimal. This can be attributed to the composition of VFA formed by PS substrate. Shin et al., 2001 have shown that different kinds of VFA resulted in different biogas yield. Moreover, the relatively higher VFA formed with the addition of OW could have resulted in the inhibition of biogas production in the reactors with higher percentages of OW (Jiang et al., 2018). The study is situated in the context of devising strategy to shift anaerobic digestion’s production from biogas to volatile fatty acids.

![Image](image.png)

**Figure 1.2** Cumulative biogas.

**REFERENCES**


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Session 10

BIOPOLYMERS AND VALUE-ADDED PRODUCTS RECOVERY: NOVEL TECHNOLOGIES
Valorisation of Complex Wastewater for the Production of PHA

A. Roibás-Rozas*, L. Argiz, A. Pedrouso, A. Val del Río, A. Hospido, A. Mosquera-Corral

*Department of Chemical Engineering, School of Engineering, Universidade de Santiago de Compostela, Rúa Lope Gómez de Marzoa, s/n, E-15782 Santiago de Compostela, Spain, alba.roibas.rozas@usc.es

Abstract: A two-stage system was operated to produce polyhydroxyalkanoates (PHAs) using complex wastewater, with high concentrations of sodium chloride, ammonia and proteins. In a first anaerobic reactor, organic matter was transformed into Volatile Fatty Acids (VFAs). A second reactor was fed with this VFA-rich stream to enrich the system in halophilic PHA accumulating bacteria. Adding small amounts of NaHCO₃ (from 20 to 360 mg/L) to the feeding of the anaerobic reactor, pH remained stable in values around 4.5, hence higher VFA concentrations were achieved, and higher organic loading rates could be imposed to the enrichment reactor. Under these conditions, the concentration of accumulating biomass increased and higher accumulation capacities (from 7.5% to 32.8%), productivities (from 14.31 to 48.20 mg PHA/(g biomass·h)) and PHA concentrations (from 0.10 to 2.00 g PHA/L) were achieved.

Keywords: Acidification; complex wastewater; PHA; valorisation

Polyhydroxyalkanoates (PHAs) are natural, renewable and biocompatible biopolymers that are produced by some microorganisms under transient conditions as energy storage. PHAs have plastic properties and are expected to substitute conventional petrochemical plastics. Mixed Microbial Cultures (MMC) are used to produce PHA under unsterile conditions with inexpensive carbon sources (waste streams), lowering significantly the overall costs. The traditional feedstocks used in the PHA production process are easily biodegradable carbon rich and nitrogen limited streams. However, the present study aims at evaluating the use of complex wastewater. Mussel boiling wastewater from fish canning industry, containing 20.8±2.1 g NaCl/L, 5.4±3.4 g carbohydrates/L, 1.8±0.5 g protein/L and 0.31±0.13 g NH₄/L, was used to produce PHA in a three-reactor system.

The first stage (substrate conditioning) was an anaerobic continuous stirred-tank reactor (CSTR) in which carbohydrates and proteins were transformed into Volatile Fatty Acids (VFA). In the second stage (PHA production), the VFA-enriched stream was fed to a Sequencing Batch Reactor (SBR) applying the aerobic dynamic feeding to establish a feast-famine regime to enrich the MMC in accumulating microorganisms. Once the MMC was enriched, accumulation experiments were performed in a Fed-Batch Reactor (FBR), where the same VFA-rich effluent from the CSTR was fed in pulses to the enriched biomass to evaluate its maximum accumulating capacity.

Several challenges were faced during the operation of the system. On one hand, since transient salt concentrations seem to negatively affect the accumulation capacity of PHA (Palmeiro-Sánchez et al., 2016), halophilic conditions with constant salt concentrations were imposed to the SBR enrichment reactor. On the other hand,
proteins were not transformed into VFA in the CSTR, causing a decrease in the overall efficiency of the system. In addition, the presence of Chemical Oxygen Demand (COD) during the famine phase has been proved another obstacle for the enrichment process (Oliveira et al., 2017). To avoid this negative effect, sodium bicarbonate was added to the feeding of the CSTR (Table 1). In this way, the pH of the reactor slightly increased, enhancing the VFA conversion. When the conversion of COD into VFA increased in the CSTR, higher Organic Loading Rates (OLRs) were applied in the SBR, with a higher percentage of COD in form of VFA. Under these circumstances, more accumulating biomass was produced in the enrichment reactor (Table 2); therefore, the enrichment process was improved.

**Table 1.1** VFA generated in the CSTR when different concentrations of NaHCO₃ were added to the reactor feeding

<table>
<thead>
<tr>
<th>NaHCO₃ (mg/L)</th>
<th>pH</th>
<th>VFA generation (g COD-VFA/L·d)</th>
<th>VFA in effluent (g COD/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.03±0.41</td>
<td>0.28±0.19</td>
<td>4.74±1.65</td>
</tr>
<tr>
<td>20</td>
<td>4.42±0.42</td>
<td>0.27±0.16</td>
<td>3.28±1.03</td>
</tr>
<tr>
<td>80</td>
<td>4.84±0.18</td>
<td>0.39±0.12</td>
<td>4.28±1.18</td>
</tr>
<tr>
<td>320</td>
<td>4.40±0.22</td>
<td>0.48±0.15</td>
<td>5.18±0.85</td>
</tr>
</tbody>
</table>

In this situation, in the accumulation experiments, the productivity of the system and the PHA concentration increased (from 14.31 to 48.20 g PHA/(g biomass·h) and from 0.10 to 2.00 g PHA/L, respectively). In addition, a higher storage capacity (from 7.5% to 32.8%) and lower biomass yields (from 35.9 to 0.4 g COD-biomass/g COD-VFA) were achieved, meaning that the carbon fed to the FBR was used to store PHA instead of being used for biomass growth (Figure 1). The properties of the biopolymer changed as well, since larger amounts of polyhydroxyvalerate (HV) were produced, decreasing the polyhydroxybutirate (HB) to HV ratio.

**Table 1.2** Average values of the OLRs applied to the enrichment reactor and biomass generated.

<table>
<thead>
<tr>
<th>OLR Phase</th>
<th>OLR (g COD-VFA/L·cycle)</th>
<th>VFA (COD%)</th>
<th>Biomass (g VSS/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Low</td>
<td>0.47±0.12</td>
<td>23.20±5.80</td>
<td>1.44±0.11</td>
</tr>
<tr>
<td>II. Medium</td>
<td>0.74±0.13</td>
<td>34.35±8.04</td>
<td>2.40±0.48</td>
</tr>
<tr>
<td>III. High</td>
<td>2.80±0.37</td>
<td>63.97±8.44</td>
<td>3.56±0.80</td>
</tr>
</tbody>
</table>

Figure 1.1 Characteristics of the accumulation experiments for each condition tested in the SBR. Where yellow squares (■) represent the concentration of PHA (g/L), grey crosses (×) the yield of biomass (X) (g COD-X/g COD-VFA), orange dots (●) the HV% (PHA%), white columns (□) the PHA productivity (qPHA, mg PHA/g X·h) and grey columns (■) the accumulation capacity (wt. %, g PHA/g VS).

Despite the complexity of the wastewater (containing ammonia, non-readily biodegradable COD and high salinity), the MMC was successfully enriched. Applying high OLRs in the enrichment reactor, accumulation capacity, productivity and PHA concentration increased. These results show that the production of PHA is feasible to valorise complex wastewaters, after applying simple operational strategies (pH correction) to enhance the overall efficiency of the system.
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REFERENCES


Recovery of ALE (Alginate-like Exopolymer) from Aerobic Granular Sludge and Application as Phosphorus Adsorbent


*Federal University of Santa Catarina, Sanitary and Environmental Engineering Department, Trindade University Campus, Delfino Conti Street., PO Box 476, Zip Code 88040-970, Florianópolis, Santa Catarina, Brazil. patricia.dall@gmail.com*, nelson.libardi@ufsc.br**, jes_antunes@hotmail.com***, rejane.costa@ufsc.br****

Abstract: This work aims the recovery of ALE (alginate-like exopolymer) from aerobic granular sludge and its application as phosphorus adsorbent in liquid samples. The solution pH, adsorbent mass, temperature and initial phosphorous concentration were tested through the factorial experimental design to determine the best adsorption conditions. The ALE yield of 21% was recovered from aerobic granules. The highest phosphorus removal efficiency (72.8%) was achieved using solution pH of 8.0, initial phosphorus concentration of 100 mg/L and adsorbent mass of 0.158 g at 45 ºC. The highest adsorption capacity (57.7 mg/g) was achieved using lower ALE beads mass (0.016 g).

Keywords: Alginate-like exopolysaccharide; aerobic granular sludge; phosphorus adsorption.

INTRODUCTION According to the circular economy concept, the recovery of value-added products is an interesting and sustainable alternative for the excess sludge produced in wastewater treatment plants (WWTP’s). The use of sludge as adsorbent material (Li et al. 2018) and the recovery of alginate-like exopolysaccharides (ALE) from aerobic granular sludge have been proposed (Lin et al. 2010; Felz et al. 2016). ALE have similar characteristics compared to seaweed alginate, like the hydrogel behavior (Lin et al, 2010). Phosphorus is a necessary nutrient for plant and human growth and its mining rocks sources are becoming scarce. Meanwhile there is a huge availability of this nutrient in effluents like piggery waste, a potential source of nutrient recovery. So, this study aimed to use of ALE extracted from aerobic granular sludge to adsorb phosphorus from liquid samples, focusing on the evaluation of experimental conditions that increase the phosphorus removal efficiency and adsorbent capacity.

MATERIAL AND METHODS ALE was extracted from aerobic granular sludge discharged from a pilot-scale (1000 L) Granular Sequencing Batch Reactor (GSBR) fed with sanitary wastewater. The extraction method was adapted from Felz et al., (2016). Adsorption experiments were conducted in Erlenmeyer flasks with 40 mL of K2HPO4 solution, with reciprocal agitation in water bath, during 2 hours. The K2HPO4 initial concentration, adsorbent (alginate or ALE beads) mass, pH and temperature were tested in a 2^4 full factorial design (four factors each, at two levels), according to the Table 1. The characterization of ALE as adsorbent material before and after adsorption tests was performed with scanning electron microscopy (SEM), dispersive energy spectroscopy (EDS) and Fourier transform infrared spectroscopy (FTIR).
RESULTS AND DISCUSSION The ALE recovering process resulted in a concentration of 208 ± 31 mg VS_{ALE} / g VS_{sludge} (representing a yield of 21 ± 3 %). Similar value (16 %) was obtained by Lin et al. (2010), using the same extraction method. The Figure 1A shows the ALE beads before the adsorption process, whereas in the SEM images of ALE spheres after the adsorption process (Figures 1B and 1C). It is possible to observe the presence of particles adhered to the beads surface, probably related to the adsorbed phosphorus. The highest phosphorus removal efficiency (72.8%) was achieved using pH value of 8.0, initial phosphorus concentration of 100 mg/L and adsorbent mass of 0.158 g at 45 ºC, while the use of alginate beads resulted in removal efficiency of 53.16%. However, the highest adsorption capacity (q_e) (57.7 ± 1.90 mg/g) was achieved using lower ALE beads mass (0.016 g), pH value of 8.0, initial phosphorus concentration of 100 mg/L at 45 ºC, resulting in removal efficiency of 22.4 % (Figure 1D). The higher the pH value and the adsorbent mass, higher the removal efficiency of phosphorus using ALE as adsorbent (Figure 1E). Li et al., (2018) obtained removal efficiencies around 75% and adsorption capacity of 11.84 mg/g testing beads of drinking water treatment sludge to adsorb phosphorus from liquid solutions.

CONCLUSION ALE recovered from aerobic granules can be efficiently used as phosphorous adsorbent, even compared to the commercial alginate. These findings clearly contribute to technological development of phosphorus recovery from waste, an important nutrient for the humankind.

Table 1.1 Treatments tested for phosphorus adsorption using ALE and alginate beads at 25 °C and 45 °C.

<table>
<thead>
<tr>
<th>Treatment pH</th>
<th>Initial phosphorus concentration (mgP/L)</th>
<th>Adsorbent mass (g)</th>
<th>Treatment pH</th>
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<th>Adsorbent mass (g)</th>
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</tbody>
</table>

Figure 1.1 External morphology photography of ALE beads (A), ALE beads SEM magnification of 50x, (B) ALE beads SEM magnification of 1000x (C), removal efficiency for different treatments using ALE and alginate beads (D), three dimensional response surface for P removal (E).

REFERENCES


Optimization of a PHA Production Process with Nitrifying Surplus Activated Sludge via Dissolved Oxygen Control

A. Estevez-Alonso*,**,1, R. Peia,b, R. Kleerebezem*, M.C.M van Loosdrecht*, A. Werker**,2

* Department of Biotechnology, Faculty of Applied Sciences, Delft University of Technology, Delft, the Netherlands
** Wetsus, European Centre of Excellence for Sustainable Water Technology, Oostergoweg 9, 8911 MA Leeuwarden, the Netherlands
1angel.estevezalonso@wetsus.nl, 2alan.werker@wetsus.nl

Abstract: When surplus activated sludge is directly used for PHA production from fermented organic streams that often contain excess ammonia, nitrifying bacteria could challenge the process performance (oxygen and alkalinity consumption). It has been hypothesized that low dissolved oxygen concentration (DO) can be used for partially limit nitrification while maintaining the PHA production rate. However, previous research was unable to effectively limit nitrification when working at low DO. Here an evaluation of the influence of the Monod affinity constant for oxygen under different DO was carried out. Limitation of nitrifying activity without affecting PHA production was predicted when PHA accumulating bacteria showed higher apparent affinity compared to nitrifiers. Simultaneous nitrification denitrification could be used to partially maintain the PHA production process under low DO, however longer accumulation times are predicted to be required. The model promises to be a tool towards establishing optimal dissolved conditions in industrial process with accumulating PHA biomass compounded by active nitrifiers.

Keywords: dissolved oxygen; polyhydroxyalkanoates; simultaneous nitrification denitrification.

INTRODUCTION If a volatile fatty acid (VFA) stream is made sufficiently available, surplus activated sludge (SAS) can be used to directly produce polyhydroxyalkanoates (PHAs). However, SAS might be rich in other kinds of metabolic activity than PHA accumulation and this could challenge the process performance e.g. other heterotrophic bacteria or nitrifying bacteria, if a nutrient rich VFA stream is used (Bengtsson et al., 2017). Nitrification could significantly contribute to the oxygen demand of the process and consumption of alkalinity, affecting its performance and process control (Wang et al., 2019). Nitrifying activity can be partially limited by chemical inhibitors, high pH or low dissolved oxygen concentrations(DO) (Wiesmann, 1994). However, at industrial scale the addition of chemicals should be minimized and subsequently, the use of low DO concentration could emerge as bioprocess control strategy (Wang et al., 2019).

It was proposed that the affinity for oxygen in PHA accumulating microorganisms is higher than for nitrifying bacteria (Wang et al., 2019). However, in this previous evaluation, predictions were not reflected in the accumulation performance, probably due to the effect of oxygen consumption in the floc by active nitrification, which influences the apparent affinity constant for oxygen (ko). In the present work, a kinetic model was developed to study the influence of the apparent affinity constant in the process and to make a generic prediction for the strategy to sustain simultaneous nitrification denitrification (SND) while maintaining the PHA production rates.
MATERIALS AND METHODS

Model Description The mathematical model was based on the one proposed by Beun et al. 2002 for PHA production under aerobic with acetate as only substrate. For modelling nitrification, the ASM approach was used, by including the two-step nitrification proposed by Iacopozzi et al. 2007. The kinetic data of PHA production by slow growing microorganisms under aerobic and anoxic conditions were obtained from Beun et al. 2000a and Beun et al. 2000b while the kinetics of nitrifying bacteria were taken from Wiesmann et al. 1994.

1-L batch reactor, pH 8, at 20°C and 24h reaction time was used for the simulations. The biomass concentration was 1 gVSS/L where 1% was assumed to be nitrifying biomass. For simplicity, growth of PHA accumulating bacteria was assumed negligible.

RESULTS AND DISCUSSION

Limitation of Nitrifying Activity at Low DO Only in those cases where the apparent affinity constant for heterotrophic bacteria was clearly lower than for nitrifiers, was it predicted to be possible to limit nitrifying activity without affecting PHA production e.g. \( k_{o,PHA} = 0.1 \ mgO_2/L \) and \( k_{o,NOB} = 1.91 \ mgO_2/L \) (Wang et al., 2019) (Figure 1A). Because different biomass will have different apparent affinity for oxygen, depending on the reactor conditions and floc morphology, this model has application as a tool to determine the optimal DO concentration for each accumulation run if the \( k_o \) of the biomass is known. The measurement of \( k_o,PHA \) under active nitrification is part of ongoing research.

Simultaneous Nitrification Denitrification Partially Maintained the PHA Production At low DO, if PHA storing biomass is partially O_2 limited, NO_3 could be used as electron acceptor for anoxic PHA accumulation. Maximum denitrification rate was predicted when both the DO and the apparent affinity constants had the same value, e.g. 1 mgO_2/L (Figure 1B). However, the final PHA content was also predicted to be affected, suggesting that exploitation of SND may require longer accumulation times. The optimal solution is anticipated to be a compromise of OPEX and productivity. Further experiments at laboratory and pilot scale with different types of biomass in order to confirm the model outputs are planned to be finished by summer. Further discussion on how productivity can be influenced by other aspects such as feeding strategy or temperature would be part of a broader publication.

CONCLUSIONS The model introduced here promises to be a tool towards establishing optimal dissolved oxygen conditions in industrial process with accumulating PHA biomass compounded by active nitrifiers. Exploitation of simultaneous nitrification denitrification to maintain the PHA production process at low DO was predicted to impose a trade-off due to the lowering of the PHA production rate.

Figure 1. Influence of dissolved oxygen (DO) on the removal of ammonium (NH_4), production of nitrate (NO_3), di-nitrogen gas (N_2) and PHB content in a 24h accumulation run when (A) \( k_{o,NOB} = 2.87; k_{o,NOB} = 1.91; k_{o,PHA} = 0.1 \ mgO_2/L \) (Wang et al., 2019) and (B) \( k_{o,NOB} = k_{o,NOB} = k_{o,PHA} = 1 \ mgO_2/L \).
ACKNOWLEDGMENTS This work was performed in the cooperation framework of Wetsus, European Centre of Excellence for Sustainable Water Technology (www.wetsus.nl). Wetsus is co-funded by the Dutch Ministry of Economic Affairs and Ministry of Infrastructure and Environment, the European Union Regional Development Fund, the Province of Fryslân and the Northern Netherlands Provinces. This research has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874. The authors thank the participants of the research theme “Biopolymers from water” for fruitful discussions and financial support.

REFERENCES


Influence of Wastewater Composition and Bioaggregates Types on the Properties of Alginate-Like Exopolymers

C. M. Schambeck1,*, L. Böni2,**, P. Fischer3,***, E. Girbal-Neuhauser4,***, Y. Bessière5,****, E. Paul6,****, R.H .R. Da Costa7,*, N. Derlon8,*****

* Sanitary and Environmental Engineering Department, Federal University of Santa Catarina, Delfino Conti Street., 88040-970, Florianópolis, Brazil, ** Department of Health Science and Technology, ETH Zürich, 8092 Zürich, Switzerland, *** Laboratoire de Biotechnologies Agroalimentaire et Environnementale (LBAE), Université Paul Sabatier, Toulouse, France, **** LISBP, Université de Toulouse, Toulouse, France, ***** Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland.

1cassioschambeck@hotmail.com, 2lukas.boeni@hest.ethz.ch, 3peter.fischer@hest.ethz.ch, 4elisabeth.neuhauser@iut-tlse3.fr, 5yolaine.bessiere@insa-toulouse.fr, 6paul@insa-toulouse.fr, 7rejane.costa@ufsc.br 8nicolas.derlon@eawag.ch

Abstract: This work assessed the influence of wastewater (WW) composition and bioaggregate types on the content, chemical and gelling properties of alginate-like exopolymers (ALE). Results indicated that the WW composition/bioaggregate type have limited influence on the ALE content. ALE was mainly composed of proteins, humics acids and uronic acids. Only the ALE extracted from granules fed with acetate/propionate featured mannuronate content. ALE extracted from bioaggregates fed with real WW had high humic acids content. All extracts were suitable to form gels, what is attributed to the presence of uronic acids. The rheological properties of the gels were directly influenced by the composition of the ALE extract: ALE from granules fed with soluble COD had the highest and from activated sludge fed with real WW the lowest storage modulus G’. Linking growth conditions to the gel properties is relevant for full-scale recovery of ALE and its industrial application.

Keywords: waste biological sludge; biopolymer properties; alginate-like exopolymers (ALE)

INTRODUCTION

Alginate-like exopolymers (ALE) are gel-forming biopolymers found in activated sludge (AS) or aerobic granular sludge (AGS). ALE is a relevant high-value material produced during biological wastewater (WW) treatment, with possible applications in agriculture, paper and construction industries (Van Leeuven et al., 2018). Recovery facilities will soon be implemented towards commercial extraction of ALE (Royal HaskoningDHV, 2017). However, full-scale recovery of ALE requires understanding the link between operating conditions and resulting biopolymer properties. Therefore, this study aimed at evaluating how WW composition and the type of bioaggregates influence the content, chemical and gelling properties of the recovered ALE.

MATERIALS AND METHODS

Four different types of biological sludges were tested for ALE extraction and characterization: AS and AGS fed with real WW, AGS fed with simple synthetic (acetate/propionate) and AGS fed with complex synthetic (acetate/propionate/amino acids/glucose/starch and peptone) WW. ALE extraction, quantification and gelation tests were performed in triplicate according to Felz et al.
Extracted humic acids and proteins were quantified by modified Lowry method and expressed respectively as mg of equivalent bovine serum albumine or mg of equivalent humic acid. Uronic and neutral polysaccharides were quantified by anthrone method and expressed respectively as mg of equivalent glucose or mg of equivalent glucuronic acid. FTIR and Raman spectroscopy were used to assess the chemical composition of the ALE extracts. The influence of ALE (normalized to 2.3 % of dry matter) chemical composition on the rheological properties was evaluated. ALE hydrogels were submitted to enzymatic attacks to follow their disintegration.

RESULTS AND DISCUSSION The four types of sludge presented nearly the same amounts of extracted acidic ALE (200-300 mg VS_{ALE}/g VS_{sludge}) with slightly higher ALE content in AGS cultivated with acetate/propionate. ALE composition was complex comprising proteins, humic acids and both neutral and uronic polysaccharides (Fig. 1). High content of proteins likely results from the harsh extraction protocol causing cell lyses while high humic acids content may originate from the influent.

The uronic acids content was the highest in ALE from AGS fed with simple synthetic WW. ALE from real WW had high humic acid contents and a humic acid/proteins ratio near 1. Both FTIR and Raman spectra confirmed the complex composition of ALE, with amines, amides and carboxylic acids. FTIR spectrum of ALE from simple synthetic WW showed weak peaks attributed to mannuronate. It is noteworthy that spectroscopy sensitivity may limit the differences between ALE extracts.

Formation of hydrogels was achieved with all ALE extracts. However, the composition of the ALE extracts determined the rheological properties of the gels expressed by the storage modulus: AGS simple synthetic > AGS real > AGS complex synthetic > AS real. Enzymatic tests further revealed that alginate lyase was able to disintegrate ALE beads while papain, savinase and lysozyme had no effect, which suggests that gelling properties are mainly governed by the uronic acids.

CONCLUSIONS Influent composition governs the content, chemical and rheological properties of ALE. ALE is a complex mixture mainly composed of humic substances, proteins and uronic acids. High acetate/propionate concentration in WW resulted in high uronic acid content in ALE. Differences in the chemical composition of the ALE extracts ultimately result in different rheological properties of the gels. Our findings may help to better tailor and explore potential uses for this novel biomaterial.

REFERENCES


Biopolymers Recovered from Waste Anammox Granular Sludge as Paper-Coating Additives to Enhance Water and Grease Resistance

C. Feng*, T. Lotti**, F. Malpei*

*Department of Civil and Environmental Engineering, Polytechnic University of Milan, Via Golgi 39, 20133 Milan, Italy. E-mail: cuijie.feng@polimi.it, tommaso.lotti@unifi.it, francesca.malpei@polimi.it

**Civil and Environmental Engineering Department, University of Florence, Via di Santa Marta 3, 50139 Florence, Italy, E-mail: tommaso.lotti@unifi.it

Abstract: The waste sludge, like granular sludge, produced from wastewater treatment processes, is considered as a waste product. Extracellular polymeric substances recovery from anammox granular sludge provides a renewable resource for waste sludge recovery. The results in this paper show that by using renewable biopolymers as paper agents, the water and grease resistance performance of coated paper can be improved.

Keywords: Anammox granular sludge; extracellular polymeric substances recovery; paper coating

INTRODUCTION Biological wastewater (WW) treatments rely on microorganisms, which degrade the contaminants such as substrates and gain energy for growth. Anaerobic ammonium oxidation (anammox) bacteria Planctomycetes, which are of great significance for ammonium removal. Biofilm technologies, like the granular sludge gain more attention due to the advantages of efficient biomass retention and more compact than conventional activated sludge system. Extracellular polymeric substances (EPS) excreted by microorganisms are responsible for the formation, stability, persistence and physicochemical behaviour of biofilms. EPSs form a complex biopolymeric matrix containing proteins, polysaccharides, nucleic acid, and lipids. Currently, the waste sludge produced from WW treatment processes, including anammox granular sludge is considered as a waste product. The processing cost of waste sludge accounts for up to 50% of the WW treatment cost (Leschber, 2002). Biomaterials recovered from the waste sludge provide a sustainable way to achieve resource recovery. Thereby, it is necessary to develop techniques of biomaterial recovery from waste granular sludge. The present study reused EPS extracted from anammox granular sludge as coating additives for paper industry (Figure 1.1).

Figure 1.1 Paradigm of film forming on the paper surface using biopolymers extracted from anammox granular sludge as coating agents. CMC: Carboxymethyl cellulose.

MATERIALS AND METHODS The alkaline extraction method (Lotti et al., 2019) was used for EPS extraction. The EPS products were around 40% of volatile solids in anammox granular sludge. The amount of coating solution applied on papers was 9.3 and 11.7 g/m² using the commercial agents-carboxymethyl cellulose (CMC) as the control and CMC+EPS (8.3 g/m² CMC and 3.4 g/m² EPSs), respectively. Water
absorbance capacity was measured based on Cobb method (UNI EN ISO 535:2014). The surface wettability was analysed by the evolution in time and the droplet volume (ATICELCA MC 21-72). The resistance to grease, oil and waxes was evaluated by measuring permeability (turpentine oil method, ISO 16532-1:2010) and surface repellence (ISO 16532-2:2010).

RESULTS AND CONCLUSIONS The film-forming properties of EPSs-coated paper were investigated. Water absorbance and resistance capacity of paper with and without coating was evaluated. On the coated side, the water absorbance capacity of CMC+EPS-based material was 31.5 g/m², reduced by 30% in comparison with the blank and CMC samples; On the back, with a significant drop of the 34% and 23%, respectively (Figure 1.2 A). The results were consisted with wettability tests (Figure 1.2 B). The drop volume for the CMC+EPS-coated paper is higher than the uncoated paper (blank) and CMC-coated paper. Noticeably, the contact angle for the CMC+EPS coated paper is lower than blank, while is slightly higher than the CMC-coated paper (Figure 1.2 C). These findings indicate that EPSs-based coating increased the water resistance of paper acting as a water barrier. The grease resistance of EPS-based paper coating was evaluated by a standard test. Time for turpentine oil to penetrate the CMC+EPS based paper sheet was 120 s, 4 times of that for CMC-based paper, implying that the addition of EPSs resulted in an improved paper grease resistance. Similarly, the grease resistance effect exhibited by EPSs was confirmed by an increase of the surface repellence degree observed for the CMC+EPS based paper (Table 1.1).

Based on aforementioned results, we can conclude that EPSs as paper coating additives exhibit interesting water barrier properties, as well as resistance to grease penetration and absorbance. EPSs-based biomaterials recovered from waste anammox granular sludge not only provide a sustainable resource for industrial application, but hold the promise to realize a sustainable and circular economy.

![Figure 1.2](A) Water absorptiveness (Cobb method); (B, C) Evolution in time towards drop volume and contact angle of water drops on the coated surface of paper sheets. Blank stands for the uncoated paper. The initial drop volume is 20 μl. CMC and CMC+EPS mean papers coated with CMC or CMC/EPS mixture, respectively.

<table>
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<th>Sample</th>
<th>Permeability [sec]</th>
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<td></td>
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<td>Coated side</td>
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<tr>
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<td>1</td>
</tr>
<tr>
<td>CMC</td>
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<td>3</td>
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REFERENCES
Impact of influent suspended solids on granulation and production of gel-forming polymers in an aerobic granular sludge reactor treating brewery wastewater.

F. De Vleeschauwer*, M. Caluwe*, J. Dries*

*Research group BioGEM, Faculty of Applied Engineering, University of Antwerp, Salesianenlaan 90, 2660 Antwerp, Belgium, flinn.devleeschauwer@uantwerpen.be, michel.caluwe@uantwerpen.be, jan.dries2@uantwerpen.be

Abstract: Gel-forming alginate-like extracellular biopolymers (ALE) contribute to aerobic granular sludge (AGS) formation and stability. This study investigated the impact of influent suspended solids on AGS formation and ALE production in an anaerobic/aerobic AGS reactor fed with brewery wastewater. The presence of suspended solids did have a significant impact on the ALE production and AGS formation. Whereas the AGS was more hybrid like and had a ALE MLSS content of around 10% when feeding influent with suspended solids (~233 mg/L), complete granulation was achieved when the influent suspended solids were removed. Furthermore the ALE MLSS content increased to around 30%.

Keywords: Aerobic granular sludge, influent suspended solids, alginate

AGS formation in an anaerobic/aerobic SBR in based on the selection of slow growing micro-organisms with an anaerobic COD uptake capacity (de Kreuk et al 2005). Wastewaters with high concentrations of influent suspended solids (SS) may be problematic in AGS SBRs. The suspended solids need to be hydrolysed before they can be metabolized. This study investigated the impact of influent SS on the granulation process and the production of gel-forming alginate-like extracellular biopolymers (ALE).

From day 1-106 the reactor was fed untreated brewery wastewater. Between day 107 and 150 the SS in the influent were removed though iron chloride coagulation. The influent treatment was terminated on day 255 and the reactor was again fed with untreated wastewater till day 284. NH₄-N and PO₄-P were added to maintain a N/COD and P/COD ratio of respectively 0.3% and 0.02%.

The SBR was operated using the following steps: (1) pulse feeding, (2) extended anaerobic, (3) aerobic and (4) anoxic, followed by sludge settling and discharge step. The suspended solids, MLSS, SVI5 and SVI30 were analysed according to the standard methods (APHA 1998). The COD was analysed using Hanna instruments® chemical test kits. The TOC was measured with a Sievers InnovOx® laboratory TOC analyser. Sludge particle size distribution were determined with a Master size 3000 particle size analyser (Caluwè et al 2017). ALE extraction and gel-formation testing was done according to FEZ et al. (2016) using the high temperature sodium carbonate extraction. Microscopic images were taken with a Olympus CX43 light microscope.
During the anaerobic step 95.3 ± 3.2% of the TOC was removed. The effluent COD was on average 73.5 ± 43.5 mg/l. The sludge in the reactor remained hybrid (i.e. mixed floccular granular) when feeding the reactor untreated influent. The SVI10 and SVI30 were respectively 67.4 ± 10.3 ml/g and 46.6 ± 11.0 ml/g. The mean particle size DV50 was 147.7 ± 17.2 µm. The ALE\textsubscript{MLSS} remained around 10 %.

![Figure 1](image1.png)

**Figure 1:** Evolution of (a) SVI\textsubscript{10} and SVI\textsubscript{30}, (b) particle size, and (c) ALE (MLSS) content, (1) period feeding untreated influent, (2) period feeding treated influent.

The influent treatment removed almost all the SS form the influent. The COD reduced up to 25% and the SS reduced around 98%. When fed with treated influent, complete AGS formation was achieved, and the settling properties of the sludge improved (figure 2a). The SVI\textsubscript{10}/SVI\textsubscript{30} improved from 1.48 to 1.05, while the ALE\textsubscript{MLSS} content increased from around 10 % to 30 % (figure 3c). The particle size distribution also increased (figure 2b). Microscopic images showed compete AGS formation on day 186 (figure 3). The extracted ALE exhibited significant gel-forming properties (not shown).

![Figure 2](image2.png)

**Figure 2:** microscopic images from left to right; day 100, day 186 and day 275 (bar =500µm).

The termination of the removal of the SS form the influent had an immediate impact on the settling properties (figure 2a). The particle size distribution DV90 and DV50 remained stable but a decrease of the DV10 was observed. The EPS\textsubscript{MLSS} content remained stable (figure 2b and 2c). Microscopic images show the reappearance of hybrid granular and floccular sludge (figure 3).

**REFERENCES**


Extracellular Polymeric Substances (EPS) from Anammox Granular Sludge as Biosorbent for Heavy Metals Removal


* Department of Civil and Environmental Engineering, University of Florence, Via di Santa Marta 3, 50139 Florence, Italy (benedetta.pagliaccia@unifi.it; tommaso.lotti@unifi.it; claudio.lubello@unifi.it)
** Department of Chemistry, University of Florence, Via della Lastruccia 3-13, 50019 Sesto Fiorentino (FI), Italy (emiliano.carretti@unifi.it; mirko.severi@unifi.it; debora.berti@unifi.it)

Abstract: The excess sludge is a waste, whose costs of handling/disposal represent up to 50% of the wastewater treatment operative costs. Anammox-based technologies allow reducing the excess sludge production. In addition, the recovery of biomaterial from excess sludge to be applied in other industrial sectors would increase the environmental and economical sustainability of wastewater treatment. This study investigated the application of Extracellular Polymeric Substances (EPS) recovered from Anammox granular sludge as bio-adsorbent material for the removal of heavy metals. The high adsorption capacity of EPS observed for heavy metals such as Zn, Ni, Cu and Pb was used for the development of an efficient adsorbent material in combination with granular activated carbon.

Keywords: Anammox extracellular polymeric substances; biosorption; heavy metals

Anammox-based technologies not only allow removing ammonium from wastewater with significant savings in terms of energy spent for oxygen (-60%) and organic carbon supply (-100%), but also reduce the production of excess sludge. Anammox bacteria easily form granules (self-aggregated biofilms), in which microorganisms are embedded in a matrix of hydrated Extracellular Polymeric Substances (EPS) (Flemming and Wingender, 2010). EPS are a complex mixture of polysaccharides, proteins, nucleic acids, (phospho)lipids, humic substances and intercellular polymers (Flemming et al., 2016). Since the increasing importance of the paradigm shift from wastewater treatment to biorefinery, this research investigated the feasibility to recover EPS from Anammox granular waste sludge and apply it as biosorbent material for the removal of heavy metals (Zinc, Nickel, Copper and Lead).

EPS were extracted under alkaline conditions from anammox granular waste sludge originating from a full-scale reactor in Rotterdam (0.38±0.41 gEPS_{extracted}/gVS) and then recovered under acidic conditions (0.21±0.21 gEPS_{extracted}/gVS) according to the method developed by Lotti et al. (2019). Concentrations of EPS in solution were determined through UV-vis spectroscopy. In a set of preliminary tests, aqueous solutions of EPS (3.0±0.8 gEPS/L) and metals (as bivalent ions M^{2+} with starting concentrations from 10 to 80 mgM^{2+}/L) were maintained in contact under stirring conditions for 6 hours (21±0.5°C; pH=7.04±0.04). The metal concentrations at equilibrium were determined after dialysis (cut-off 3.5 kDa) against ultrapure water. A lab scale technological application involved column adsorption tests, improving the adsorption capacity of granular activated carbon (GAC) via its functionalization with the recovered EPS (i.e. EPS were adsorbed on GAC beforehand and then the column
filled with the combined adsorbent). Metal solutions (80 mgM\(^{2+}\)/L) were filtered ensuring a contact time of 30 minutes. Metal concentrations were measured by Inductively Coupled Plasma–Optical Emission Spectroscopy (ICP-OES).

The experimental adsorption isotherms (Figure 1.1) demonstrated that the adsorption capacity increases with increasing metal initial concentration and it was not saturated under the tested conditions (i.e. maximum adsorption capacities not reached). A peculiar case was represented by Pb\(^{2+}\) which was found above detection limits (on the order of µg/L) only for initial concentrations higher than 40 mg/L, highlighting its great affinity towards EPS. The highest adsorption capacities obtained in these conditions (17.4, 9.5, 15.5, 27.1 mgM\(^{2+}\)/gEPS for Ni\(^{2+}\), Zn\(^{2+}\), Cu\(^{2+}\) and Pb\(^{2+}\), respectively) were similar to other biosorbent materials (e.g. yeast, bacterial and fungal biomass). The removal efficiencies for metal initial concentrations of 40 mg/L were 66.7%, 45.6%, 78.7% and 98.9% for Ni\(^{2+}\), Zn\(^{2+}\) Cu\(^{2+}\) and Pb\(^{2+}\), respectively. The column adsorption tests using the newly developed GAC-EPS adsorbent material (71.5±4.6 mgEPS\(_{\text{adsorbed}}\)/gGAC), showed higher adsorption kinetics compared to equivalent columns filled with GAC only (Table 1.1). The removals operated by this composite system were 75.1%, 91.2%, 99.0% and 99.1% for Ni\(^{2+}\), Zn\(^{2+}\), Cu\(^{2+}\) and Pb\(^{2+}\), respectively. In addition, in adsorption tests treating solutions with the simultaneous presence of all tested metals, adsorption capacities were found similar to the case of single-metal solutions, thus excluding competition mechanisms among the tested metal ions and proving the successful treatment of complex wastewaters.

![Figure 1.1](image)

**Table 1.1** Adsorption kinetics (mgM\(^{2+}\)removed/gadsorbent *h*) of Ni\(^{2+}\), Zn\(^{2+}\), Cu\(^{2+}\) and Pb\(^{2+}\) with GAC and GAC+EPS composite system.

<table>
<thead>
<tr>
<th>Metal</th>
<th>GAC-EPS system</th>
<th>GAC system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni(^{2+})</td>
<td>(5.2, 3.5, 3.8)</td>
<td>(5.2, 3.5, 3.8)</td>
</tr>
<tr>
<td>Zn(^{2+})</td>
<td>(5.6, 3.0, 3.4)</td>
<td>(4.6, 3.1, 3.4)</td>
</tr>
<tr>
<td>Cu(^{2+})</td>
<td>(4.8, 3.7, 3.8)</td>
<td>(3.8, 3.1, 3.7)</td>
</tr>
<tr>
<td>Pb(^{2+})</td>
<td>(8.8, 9.7, 9.9)</td>
<td>(8.8, 9.7, 9.9)</td>
</tr>
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</table>

The good adsorption properties of Anammox EPS observed for both single- and multi-metal aqueous solutions, suggest very promising future developments, with the opportunity to exploit a biosorbent material recovered from waste sludge for the removal of heavy metals from contaminated waters. Tests with higher metal concentrations and further improved technological application are currently under development and will be presented at the conference.

**REFERENCES**


Exploring Resource Recovery Potentials for the Aerobic Granular Sludge Treatment Process

P. Kehrein*, M. van Loosdrecht**, P. Osseweijer***, J. Dewulf****, M. Garfi***** , J. Posada Duque******

* Delft University of Technology, Department of Biotechnology Building 58, Van der Maasweg 9, 2629 HZ Delft, The Netherlands, p.a.kehrein@tudelft.nl
** Delft University of Technology, Department of Biotechnology Building 58, Van der Maasweg 9, 2629 HZ Delft, The Netherlands, M.C.M.vanLoosdrecht@tudelft.nl
*** Delft University of Technology, Department of Biotechnology Building 58, Van der Maasweg 9, 2629 HZ Delft, The Netherlands, p.osseweijer@tudelft.nl
**** Ghent University, Coupure Links 653, geb. B, 9000 Gent, Belgium, Jo.Dewulf@UGent.be
***** Universitat Politècnica de Catalunya BarcelonaTech, Department of Civil and Environmental Engineering, 106D c/Jordi Girona 1-3, Building D1, E-08034, Barcelona, Spain, marianna.garfi@upc.edu
****** Delft University of Technology, Department of Biotechnology Building 58, Van der Maasweg 9, 2629 HZ Delft, The Netherlands, J.A.PosadaDuque@tudelft.nl

Abstract: This study uses material and energy flow analysis to model seven different process designs that integrate resource recovery technologies into the aerobic granular sludge treatment process. The trade-offs between COD recovery as energy and biopolymers, and between phosphorous as struvite and as ash-P are quantified. It is shown that energy recovery from COD by anaerobic digestion is preferable over sludge incineration and can be optimized through COD up-concentration. Moreover, COD recovery as biopolymers decreases the potential for energy and P recovery. The results may support decision making in conceptual WWTP process designs that aim for enhanced resource recovery from aerobic granular sludge treatment processes for municipal wastewater streams.

Keywords: Aerobic granular sludge; resource recovery; wastewater treatment process design

In aerobic granular sludge (AGS) treatment, biological conversions of pollutants are carried out by microbial communities that form granules instead of flocs. The latter are typically occurring in conventional activated sludge processes (CAS). Compared to flocs, granules allow higher biomass concentrations and therefore increased biological conversion rates. In addition, they enable simultaneous nitrification and denitrification, and show much faster settling times. This results into lower operational costs and area demand of AGS processes.

However, municipal wastewater has been increasingly as a resource rather than a waste stream. Numerous technologies have been developed in past decades to recover water, energy, nutrients, and/or other products from the CAS process while little is still known about the resource recovery potential of AGS-based processes. Especially the recovery of extracellular polymeric substances (EPS) from AGS is a novel aspect. EPS are responsible for the physical and chemical structure of the granules. They are sticky biopolymers, excreted by bacteria, that evoke cell adhesion and lead to the formation of microbial granules. If extracted from the sludge, EPS can potentially be a high value product.
The decision to recover one resource from a process affects the potential to recover other resources. For example, the recovery of EPS implies that chemical oxygen demand (COD) is extracted from the process and therefore cannot become recovered in other forms (figure 1.1). We analysed how an AGS-based treatment process could be designed from a resource recovery perspective. Seven alternative process designs were modelled to conduct a material and energy flow analysis (MEFA) for COD and P. Each process design allows to recover COD and/or P on-site and/or off-site the WWTP as different products (table 1). By comparing the quantities of resources recoverable by each process design, the trade-offs between different design choices become visible. The reference process represents a large scale AGS based WWTP in The Netherlands where no resource recovery technologies are implemented on-site but electricity from COD and P are recovered off-site the WWTP in an external centralised incinerator fuelled with the waste sludge of the process.

If anaerobic digestion (AD) with subsequent heat and power generation (CHP) is integrated into the process, COD is recovered as methane and converted on-site as electricity and heat. This results in less COD leaving the process with the sludge which is reflected by a reduced off-site electricity recovery via sludge incineration compared to the reference process. Energy recovery from COD with AD/CHP has a much higher energy conversion rate than sludge incineration and therefore it is energetically favourable to convert COD on-site. Up-concentration of primary COD increases the energy recovered on-site substantially.

However, the integration of AD not only enables on-site energy recovery but also leads to a nutrient rich supernatant that is useful for on-site struvite precipitation. Therefore, in every process design that includes anaerobic sludge digestion, struvite precipitation from the digester supernatant was modelled. The analysis shows that masses of struvite recoverable by precipitation are comparable to ash-P masses recovered after sludge incineration. However, ash-P and struvite are two different products with very different P contents which suggests to rather compare ash-P with struvite-P. Since struvite contains only ca. 13% P, the P recovered as struvite is only a small fraction of the total P in the influent. Therefore, it is questionable to integrate a struvite precipitation unit into the WWTP but rather recover all P from the ash instead.

COD can also be recovered as biopolymers in form of EPS. EPS recovery affects the energy and P recovery potential of a process. In case energy recovery is no priority but the goal is to recover maximum EPS, there should be no COD up-concentration to load as much COD into the AGS reactor where it is converted into CO2 and EPS producing biomass. The trade-off between EPS and energy recovery increases therefore with increasing COD up-concentration. To still recover some energy in the process, AD can be loaded with AGS after EPS extraction to achieve at least a minimum of on-site energy recovery. If EPS is recovered, a fraction of the influent-P is incorporated into the polymeric structure before it leaves the process and hence, is not available for fertilizer recovery.

The study reveals how energy, biopolymer, and P recovery can be integrated into the AGS treatment process, how they affect each other, and what quantities can be expected. In addition, it is revealed that resource recovery technology integration into a AGS process cannot only recover wastewater constituents as energy and products, but simultaneously can reduce operational cost factors. Results may support decision making on how to optimally integrate resource recovery technologies into AGS-based WWTPs.
Table 1.1 Overview of modelled process designs with on-site recovery technologies.

<table>
<thead>
<tr>
<th>Process design</th>
<th>On-site recovery</th>
<th>Off-site recovery</th>
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<tbody>
<tr>
<td></td>
<td>COD</td>
<td>P</td>
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<tr>
<td>AD + CHP</td>
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<tr>
<td>Chemical extraction</td>
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<td>Precipitation</td>
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<td>Sludge incineration</td>
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<td>Biopolymers</td>
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<tr>
<td>Struvite</td>
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<td>Reference</td>
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<td>PS-0</td>
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<td>PS-40</td>
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<td>PS-60</td>
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<tr>
<td>EPS</td>
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<tr>
<td>PS-0 + EPS</td>
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<tr>
<td>PS-40 +EPS</td>
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<tr>
<td>PS-60 + EPS</td>
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</tbody>
</table>

Table explanations:
PS-0 = Anaerobic digester fed with only aerobic granular sludge
PS-40 = Anaerobic digester fed with mix of AGS and primary sludge with influent COD up-concentration of 40% 
PS-60 = Anaerobic digester fed with mix of AGS and primary sludge with influent COD up-concentration of 60% 
EPS = EPS are biopolymers which are extracted from the aerobic granular sludge.

Figure 1.1 Relative COD recovery as energy and as biopolymers (EPS).

REFERENCES
Puyol D., Batstone, D.J., Hülsen, T., Astals, S., Peces, M., Krömer J. 2017 Resource Recovery from Wastewater by Biological Technologies: Opportunities, Challenges, and Prospects frontiers in Microbiology 7
M. Pronk, M.K. de Kreuk, B. de Bruin, P. Kamminga, R. Kleerebezem, M.C.M. van Loosdrecht 2015 Full scale performance of the aerobic granular sludge process for sewage treatment, Water Research 84
van der Hoek, J.P., de Fooiija, H., Strukera, A., 2016 Wastewater as a resource: Strategies to recover resources from Amsterdam’s wastewater, Resources, Conservation and Recycling 113
Recovery Potentials from Aerobic Granular Sludge Treating Low C/N Real Municipal Wastewater

R. Campo*, E. Carretti, D. Berti, S. Caffaz, C. Lubello, T. Lotti**

*riccardo.campo@unifi.it, **tommaso.lotti@unifi.it; Università degli Studi di Firenze, Dipartimento di Ingegneria Civile e Ambientale (DICEA)

Abstract: In this study, aerobic granular sludge process was applied to real municipal wastewater originating from combined sewer system. A fully granular bed was obtained thank to a novel control strategy resulting in optimal effluent quality, 60% of nitrogen removed via-nitrite and a low observed yield (0.21±0.01 gCOD/gCOD). Extracellular polymeric substances recovered from the excess granular sludge produced were evaluated as soil conditioner in agriculture in the form of hydrogels. The effect of polymer extraction was studied in view of the anaerobic digestion of the remaining sludge.

Keywords: Aerobic granular sludge; EPS/ALE recovery; hydrogels; water-binding capacity; anaerobic biodegradability; methane

Aerobic granular sludge (AGS) is a promising technology for wastewater treatment able to simultaneously remove carbon (C), nitrogen (N) and phosphorus (P). Recently, the possibility to extract biopolymers extracellular polymeric substances (EPS) from AGS, having a composition similar to alginate of brown algae (alginate-like-exopolymers, ALE) and having hydrogel formation abilities, has opened new scenarios on biopolymers recovery from AGS (Felz et al., 2016). The aim of this study is to propose an innovative wastewater treatment scheme for nutrients removal and biopolymers recovery from AGS reactors, as shown in Figure 1.1, including multiple aspects: - simultaneous nutrients removal with N-removal via-nitrite; - low excess sludge production due to low observed yield (Yobs); - biopolymers recovery (EPS and ALE); - final treatment of the residual solid phase to recover methane via anaerobic digestion (AD). A fully granular (flocs fraction <5%, w/w) sequencing batch reactor (GSBR) was operated with a novel strategy based on the dynamic control of the duration of anaerobic reaction phase for the treatment of real municipal wastewater characterized by very low organic content (BOD5≈100 mg/L) and C/N ratio (4.2±3.2 g/g) (Florence, Italy). The excess AGS produced was used to test hydrogels formation from EPS/ALE. They were extracted according to Felz et al. (2016), while hydrogels were formed by extrusion of 6-10% (w/v) ALE and EPS into a cross-linking solution of 10% (w/v) CaCl2. The fraction of bound water in EPS and ALE hydrogels was assessed by differential scanning calorimetry (DSC). Effluent quality meeting standard limits was obtained from GSBR with average C/N/P removal efficiencies of GSBR next to 85/68/96%, about 60% of N removed via-nitrite and a low Yobs per COD removed (0.21±0.01 g/g). Although the high sludge retention time (SRT = 51 ± 8 days) resulting in the low Yobs compared to full-scale AGS reactors (Pronk et al., 2015), yields of EPS and ALE extraction comparable with those obtained with high organic load (Felz et al., 2016) were obtained (0.44 vs 0.33...
Regarding DSC analysis (Figure 1.2), total bound water fractions were on average higher for ALE than EPS (49.2% ± 1.0 vs 40.4% ± 1.8) suggesting that water-binding (WB) capacity of ALE is higher than EPS. Despite the increasing biopolymer concentration, the variability of bound water fraction was not evident, probably due to the high Ca²⁺ ions (cross-linkers) concentration that favoured the formation of a low-porosity hydrogels that hampered water penetration inside the biopolymer matrix (Pathak et al., 2010). The property of WB capacity of EPS/ALE can be applied in agriculture as soil conditioner to increase water retention (Milani et al., 2017). Tests of water holding capacity through dehydration are conducted using increasing polymer content (w/w). Preliminary results testing the residual excess sludge after EPS recovery, show an improvement of anaerobic biodegradability (from 18.3% to 20.5%) suggesting a positive effect of biopolymers extraction on the AD step in the proposed treatment scheme. EPS/ALE hydrogels recovery is proposed as a waste sludge valorisation pathway of excess AGS in the logic of circular economy, as well as an efficient pre-treatment for the improved valorisation of the residual organics via methane generation.

**Figure 1.1** Treatment scheme for aerobic granular sludge system with resources recovery.

**Figure 1.2** Water fractions in hydrogels formed with EPS (a) and ALE (b) extracted from AGS.

**REFERENCES**


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ECONOMIC AND ENVIRONMENTAL SUSTAINABILITY ASSESSMENT
Evaluating Construction Industry Views on Recovered Cellulose as a Component of Building Materials

E. A. Gallagher*, C. Shannon*, H. M. Smith**

*Cranfield University, Cranfield, Bedfordshire, MK43 0AL
**Cranfield University, Cranfield, Bedfordshire, MK43 0AL, h.m.smith@cranfield.ac.uk

Abstract: The construction sector is under increasing pressure to adopt more sustainable products and materials. However, the adoption of new technologies and processes can be risky and complex, with a variety of potential concerns and challenges. Cellulose recovered from wastewater can be used in building materials – namely insulation, asphalt, and polymer composites – to replace certain existing components and help drive down the overall carbon footprint of the construction industry. However, it is unclear how well this innovative material might be accepted and what kinds of concerns those within the construction industry might have about its use. The current study used an online survey, targeted at construction and development professionals, to evaluate perceptions, expectations, and factors which impact the uptake of recovered cellulose materials. Overall, preliminary findings show a support for the use of these materials, however factors such as cost were identified as being a key driver of adoption.

Keywords: recovered cellulose; acceptance; construction industry; perceptions

Interest in the circular economy, which encourages optimum utilisation of resources and recovery and regeneration from traditional waste components, is growing in many areas. While this is promising in terms of progressing towards more sustainable use and supply of materials and products, the issue of adoption and uptake is still a challenge. Some now suggest that the principle challenges to achieving a circular economy are not technological, but governance related (Owen & Liddell, 2016).

Buildings and construction together account for 39% of energy-related carbon dioxide emissions when upstream power generation (embodied carbon) is included, and there is a growing urgency to address the energy intensiveness of this sector if climate change mitigation ambitions are to be achieved (UN EIEA, 2017). Much of the embodied carbon associated with construction is linked with the materials used and how they are sourced (UK Green Building Council, 2015), highlighting a potential area for improvement through more sustainably sourced and produced materials. Recovered cellulose is potentially one such material. Recent research has demonstrated that cellulose fibres (mainly from toilet paper) can be effectively recovered from municipal wastewater and used as a component in building materials (van der Hoek, Fooij & Struker, 2016). Materials that can incorporate cellulose include insulation, asphalt and polymer composites (e.g. for decking and cladding). Moreover, the removal of cellulose can result in energy savings for wastewater treatment plants (Ruiken et al., 2013). The use of materials containing recovered cellulose (in place of other components) is therefore one potential way of reducing embodied carbon in the sector.

Due to the unsystematic nature of the construction industry, it is littered with obstacles preventing the introduction of new materials, such as rotation of stakeholders (Giesekam, Barrett & Taylor, 2016) and the necessity for other companies to be early
innovators (Pinkse & Dommiss, 2009). Early communication with the supply chain has been shown to alleviate barriers to acceptance of new materials (Giesekam et al., 2016). However, the ‘liability of newness’ associated with being an early adopter of a new product is still a concern (Roos, Woxblom & McCluskey, 2010), and companies may be unwilling to take a risk on a new product before it has been well established.

The current study used an online survey to investigate views from the construction industry around the adoption of materials containing recovered cellulose, potential expectations around those materials when they reach the market, and potential barriers to the wider uptake of such materials. Preliminary findings indicate that construction professionals from all domains were largely supportive, and are highly interested in the use of sustainable building materials. Architects were overwhelmingly identified as the most influential in terms of materials selection, while regulatory requirements, low cost, and reduced carbon footprint were viewed as the most important drivers that determine materials selection. Conversely, key barriers to the uptake of cellulose materials consisted of a lack of relationship between the producers of recovered cellulose and prospective customers in the construction sector, insufficient fit with the culture of the clients and end-users, and money sunk into existing materials. Respondents anticipated that homeowners / homebuyers would be the group with the greatest negative perceptions towards the use of materials with recovered cellulose. Finally, views on cost expectations were highly mixed, with similar levels of expectations that cost should be less, remain the same, and increase.

These findings can help producers of recovered cellulose to navigate the pathway ‘from concept to standard practice’ by signposting potential mechanisms to help encourage the wider adoption of this material within the construction sector. While the fact that the material was recovered from wastewater did not appear to be an issue, the typical ‘liability of newness’ issues which occur when attempting to introduce innovative solutions appear to be of greater concern. Important factors which must be considered are also highlighted. The potential barriers to innovation and innovative processes are identified but overall it is evident that there is a demand and an interest for more sustainable materials and some support for circular economy initiatives.

This paper is based on work undertaken as part of the project ‘Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants’ (SMART-Plant), funded under Horizon 2020 (grant number 690323, http://smart-plant.eu/).

REFERENCES


Pinkse, J., & Dommiss, M. 2009. Overcoming barriers to sustainability: an explanation of residential builders' reluctance to adopt clean technologies. Bus Strateg Environ. 18(8), 515-527.


The Sustainability of Microbial Protein as Feed Ingredient – a Comparative Life Cycle Assessment of Three Growth Metabolisms with Soybean Meal

M. Spiller*, M. Muys**, M. Sakarika, G. Papini, M. Buyle, S. E. Vlaeminck

*marc.spiller@uantwerpen.be
**maarten.muys@uantwerpen.be

Abstract: The EU is calling for the production of sustainable and local protein sources, to replace for example soybean-based feed protein. Microbial protein is one option for this, but life cycle assessment studies are lacking. This research shows that dried microbial biomass produced on potato wastewater can be more sustainable (with the exception of fossil depletion) than soybean meal. This is however dependent on the source of soybean meal due to the environmental impact of land use change.

Keywords: Consequential life cycle assessment; wastewater; land use change

Current livestock production is relying on the provision of protein-rich feed ingredients. In the EU, soybean meal supplies 64% of the protein-rich feed material, 97% of which is imported. A number of studies have provided evidence for the negative environmental impacts (e.g. greenhouse gas emissions) of soybean meal cultivation in particular as a result of land use change (Castanheira and Freire 2013).

The above issues have led the EU to call for urgent action to replace imported protein with alternative European sources (Denanot 2018). Amongst the potential alternatives are micro-organisms, so-called single-cell or microbial protein (SCP=MP), which comprises microalgae, yeasts and bacteria. Advantages of MP are their minimal arable land use, high nutrient use efficiency and an excellent protein content/quality (Matassa et al. 2016). Furthermore, MP production has the capability to (partially) treat wastewater, hereby recovering carbon, nitrogen and phosphorus.

Few studies so far, provide evidence for the environmental sustainability of MP using an LCA approach. Four studies were found that conduct a comparative LCA of MP as a feed ingredients, but the only study attempting a comparison with soybean meal is Taelman et al. (2015). They concluded that from a resource perspective it is preferred to use soybean meal as a feed ingredient. The reason for this was the high energy demand for the algae production. However, they also suggest that with further optimisation a similar resource footprint can be realised.

The objective of this study is to evaluate the environmental impact of MP production as a substitute for soybean meal. For the first time three different metabolic types of MP production will be analysed: aerobic heterotrophy, photoheterotrophy and a combination of photoautotrophy and aerobic heterotrophy. Furthermore, to the authors’ knowledge, this is the first study that evaluates the environmental impact of MP production on food and beverage wastewater, as suggested by others (Pikaar et al. 2018).
Three different MP types are grown on high-strength potato wastewater (1000 m$^3$/d, 10 kg COD/m$^3$, 0.3 kg N/m$^3$, 0.06 kg P/m$^3$): aerobic heterotrophic bacteria (AHB), a consortium of microalgae and bacteria (MaB) and purple non-sulfur bacteria (PNSB). The MP products are compared against the European soybean meal consumption mix. A consequential LCA was used to evaluate impacts in 11 impact categories. Life cycle inventory data were derived from a quantitative model. The functional unit for comparison is 1 t of crude protein.

Results show that for 9 out of 11 impact categories AHB and PNSB MP production processes score better than soybean meal; while all MP processes perform worse for the categories urban land occupation and fossil depletion, of which the latter is mainly due to spray dryer heat demand. In addition, MaB also exceeds the impacts of soybean meal for particulate matter formation and terrestrial acidification due to potential ammonia emissions from the raceway pond. Comparing the three MP production systems, AHB generally scores best (with exception of fossil depletion) due to its high biomass productivity.

The comparatively poor performance of soybean meal is largely a function of the impacts associated to natural land transformation. Literature shows that land use change can lead to a more than 10-fold increase in greenhouse gas emissions compared to a benchmark without land use change (Castanheira and Freire 2013). Indeed, also the present research suggests that, if land use change is minimised (for instance by using USA soybean meal production), MP are likely not competitive. Furthermore, MP production must also strive to find more sustainable heat sources and processes for drying, due to its high environmental impact in the category fossil depletion. Low-grade waste heat in combination with low-temperature drying should be explored.

In conclusion, producing three types of MP on potato wastewater is currently a sustainable alternative to soybean meal production at the current consumption mix in Europe. A point of attention for MP production remains the use of energy and in particular heat.

REFERENCES


From Waste to Self-Healing Concrete: A New Value Chain for Polyhydroxyalkanoates


* Department of Biotechnology, Delft University of Technology, Van der Maasweg 9, 2629 HZ Delft, The Netherlands
** Faculty of Civil Engineering & Geosciences, Delft University of Technology, Stevinweg 1, 2628 CN Delft, The Netherlands

Abstract: Using mixed microbial cultures for the production of waste-derived polyhydroxyalkanoates (PHA) is a cost-effective and sustainable method to recover secondary resources. However, large scale application of PHA as a biodegradable plastic is restricted by expensive downstream processing and fluctuating physicochemical characteristics of the produced polymer. To overcome these challenges, the application of waste-derived PHA for the production of self-healing concrete is proposed. A proof-of-concept is provided where waste-derived PHA appears to be a suitable organic substrate which can induce self-healing activity similar to current technologies. Successful implementation of this concept will facilitate a breakthrough of both waste-derived PHA technology, as well as environmental friendly and affordable substrates for self-healing concrete.

Keywords: Biobased materials; Polyhydroxyalkanoates; Self-healing concrete

Polyhydroxyalkanoates (PHA) have attracted widespread attention as an alternative to petrochemical-based plastics. A broad range of bacteria are able to produce this biopolymer as intracellular storage compound (Steinbüchel, 1991). PHA are biobased, completely biodegradable, and have thermoplastic properties (Lee, 1996). However, at this stage, large scale production of this polymer is hampered by the costly production process using a pure culture based approach.

An important attempt to make PHA production more cost-effective is the use of mixed microbial communities and secondary resources as a substrate. Implementing these concepts in the production process diminishes the relatively large expenses for raw substrates and sterilization of the equipment (Salehizadeh and Van Loosdrecht, 2004). Successful laboratory experiments have been conducted where a range of different waste streams were assessed on their PHA production potential such as whey, glycerol, activated sludge (Gómez Cardozo et al., 2016; Jia et al., 2014). Moreover, pilot projects, using food industry and paper mill waste water, have resulted in promising PHA productivities in industrial settings (Jiang et al., 2012; Tamis et al., 2014).

Despite the above described advantages the waste-derived PHA production process still faces substantial challenges. Firstly, associated with the use of microbial communities are relatively high costs for downstream processing (Gurieff and Lant, 2007). Secondly, operating with substrates with a variable composition results in fluctuations in the physiochemical characteristics of the polymer which ultimately lead
to variations in the mechanical properties of plastics. In addition, the choice of the employed downstream process also plays a role in the properties of the final product. Consequently, it can be asserted that even though biotechnological PHA production from waste is reasonably well established challenges remain in the conversion of PHA to plastic material for high quality demanding applications (Laycock et al., 2013).

To overcome these challenges, we propose a novel value chain for waste-derived PHA, using it as bacterial substrate in self-healing concrete (figure 1). The technology of self-healing concrete aims at increasing the service life of concrete structures by making use of incorporated bacterial spores that have the ability to seal cracks. Upon activation these specialized bacteria (an alkaliphilic Bacillus strain) are able to convert an organic, encapsulated substrate into an insoluble mineral deposit (Wiktor and Jonkers, 2011). Examples of self-healing concrete constructions have been established nowadays which utilize a non-waste-derived substrate. It is believed that application of waste-derived PHA in concrete on the one hand eliminates the currently unfeasible mechanical and purity requirements while on the other hand opens up an enormous, potential market.

![Figure 1.1](image)

**Figure 1.1** Schematic overview of a value chain from waste via PHA to an application in self-healing concrete. In (A) organic fraction of municipal waste (OFMSW) is converted to PHA-rich biomass. The PHA is extracted from the biomass in the downstream processing (DSP) part (B). In (C) a product is formulated which can induce self-healing activity in concrete structures.

For this research, PHA-rich biomass was received from a pilot plant that uses the organic fraction of municipal waste (OFMSW) as raw material (Orgaworld/Paques, Lelystad). Under laboratory conditions the PHA was extracted from the biomass with a solvent-based method. Subsequently, the PHA, together with bacterial spores and nutrients, was used to develop a concrete compatible product. First experiments demonstrate that PHA can be metabolized by the Bacillus strain and that the final PHA-product, once incorporated into the concrete, can induce self-healing activity followed by crack closure. These promising results provide a proof-of-concept for a new value chain. We foresee that linking waste-derived PHA with self-healing concrete technology will contribute to the large scale implementation of a sustainable, value-added product recovered from secondary resources.

**REFERENCES**


Converting paper mill wastewater to bioplastic. Water Res. 46, 5517–5530.
Cost of Sericin Recovery from Silk Effluents

T. Pilevneli*, M. Gencturk**, U. Yetis***, G. Capar****

* Ankara University Water Management Institute, tpilevneli@ankara.edu.tr  
** Ankara University Water Management Institute, ankara.merve@gmail.com  
*** Middle East Technical University Dept. of Environmental Engineering, uyetis@metu.edu.tr  
**** Ankara University Water Management Institute (corresponding author), gcapar@ankara.edu.tr

Abstract: Sericin protein is degummed from the silk fibre prior to dyeing and discarded as a waste in textile industry. The price for dry sericin ranges from €40/kg up to €100/gr. In this study, the cost of sericin recovery is calculated for a silk degumming facility via membrane hybrid processes at pilot scale. The total cost for recovering 1 kg dry sericin is found as €175. By recovering ethanol, which is used to precipitate sericin in membrane-concentrated wastewater, and increasing plant scale, it might be possible to reduce the cost of sericin recovery to competitive levels.

Keywords: sericin recovery; nanofiltration; cost

INTRODUCTION
Sericin protein, which is secreted by the silkworm to glue the silk threads together during cocoon production, is degummed from the silk fibre prior to dyeing and discarded as a waste in textile industry. Literature study shows that sericin has many uses in the industry and thus should be recovered and re-used. Sericin recovery from silk degumming processes is done through sedimentation in ethanol (Wu et al, 2007), enzymatic hydrolysis and freeze-thaw (Vaithanomsat and Kitpreechavanich, 2008), and membrane filtration (Fabiani et al., 1996; Capar et al., 2008). The estimated amount of sericin production in the silk industry is 50,000 tons per year and significant economic value can be acquired through recovery (Zhang, 2002). The price of sericin varies according to the purpose of use. The price for dry sericin ranges from €40/kg1 up to €100/gr2 according to its physical properties and purity.

METHODS
In this study, recovery of sericin from silk degumming wastewaters (sdw) was achieved via membrane hybrid processes at pilot scale. The wastewater was subjected to pretreatment prior to membrane filtration to separate soap from sericin. In the plant, nanofiltration was applied after pretreatment and neutralization processes to concentrate the wastewater. Powder sericin was obtained by applying ethanol precipitation and centrifugation, followed by lyophilisation (Figure 1.1). The cost of sericin recovery is calculated for the facility where the pilot study was conducted, using data gathered during recovery studies for a service lifetime of 15 years. Maintenance costs are estimated as 3% of the total capital costs and membrane filter lifetime is estimated as 3 years. The amount of sericin recovered from the pilot plant was 1.85 kg/treated sdw. The capital, operational, staff, energy and maintenance costs

1 Average price for ISO9001 Certified Sericin  
2 Price of Sigma-Aldrich Sericin Bombyx mori
of pre-treatment, nanofiltration, centrifugation and lyophilisation processes are taken into consideration.

**RESULTS AND DISCUSSION** The cost of sericin recovery is summarised in Table 1.1. The total cost for recovering 1 kg dry sericin is found as €175. However, the pilot studies did not cover the ethanol recovery process and was on a small scale (4 m$^3$ SDW per week). By recovering ethanol, and increasing plant scale, it might be possible to reduce the cost of sericin recovery to competitive levels.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Cost / kg sericin</th>
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<td>Capital costs</td>
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<td>Chemical costs</td>
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<tr>
<td>Staff costs</td>
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<tr>
<td>Energy costs</td>
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<tr>
<td>Maintenance costs</td>
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<tr>
<td><strong>Total</strong></td>
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**REFERENCES**


Integrated Sustainability Assessment of Wastewater Treatment Plants as Local Energy Suppliers

P. Lichtenwoehrer*, F. Kretschmer**, G. Langergraber**, G. Neugebauer*

* Institute of Spatial Planning, Environmental Planning and Land Rearrangement, University of Natural Resources and Life Sciences, Vienna, Peter-Jordan-Strasse 82, 1190 Vienna, Austria, peter.lichtenwoehrer@boku.ac.at, georg.neugebauer@boku.ac.at
** Institute of Sanitary Engineering and Water Pollution Control, University of Natural Resources and Life Sciences, Vienna, Muthgasse 18, 1190 Vienna, Austria, florian.kretschmer@boku.ac.at, guenter.langergraber@boku.ac.at

Abstract: Wastewater treatment plants can take a new role as local energy suppliers, providing excess energy in the form of thermal energy, electricity and/or biogas. In order to sustainably provide excess energy, a holistic assessment methodology, in the form of an integrated sustainability assessment, is developed. Sustainability indicators were defined and incorporated on multiple levels, using a hierarchical approach. The practical application is currently carried out in five locations across Europe in order to guarantee the feasibility of the methodology for decision-makers and practitioners.

Keywords: Sustainability indicators; integrated spatial and energy planning; decision support

Global CO₂ emissions are increasing and the effects of climate change are omnipresent. Along with the utilisation of renewable energy sources (RES) and energy efficiency measures a reduction of CO₂ emissions can be achieved. In this context, Article 2 of the recently announced directive of the European Parliament on the promotion of the use of energy from renewable sources (EU, 2018) not only defines “sewage treatment plant gas” but also “thermal energy and energy accumulated in […] sewage water” as a RES. Consequently, this emphasises the use of RES from wastewater treatment plants (WWTPs) not only on a plant internal but also on a plant external scale. Besides thermal energy from wastewater heat recovery and heat from digester gas combustion, additional excess energy from WWTPs like electricity or upgraded biogas could be utilised. Hence, different technologies and energy distribution paths can be distinguished. The utilisation of electricity and biogas, under the premise of existing supply networks is rather straightforward, since electricity and biogas can be transported across large distances. However, due to heat losses the transportation of thermal energy is limited to the local scale. In this multifaceted context a variety of different disciplines like sanitary engineering (e. g. for increasing energy efficiency at the WWTP) or integrated spatial and energy planning (e. g. for utilising excess energy in the vicinity of the treatment plant) are relevant. The complex interrelations between the WWTP and its spatial context, including the integration of several sectors, requires a holistic assessment methodology. The development of this methodology and its practical application is the main focus of this research.
The main objective of the developed integrated sustainably assessment (ISA) methodology is to provide a practical decision support framework to identify the most sustainable solution for utilising excess energy from WWTPs. Based on the general ISA framework developed during the Interreg project “REEF 2W” (Kretschmer et al. 2018), a collection of sustainability indicators was compiled. According to Pope et al. (2004) sustainability assessment is based on the three-pillar concept, emphasizing equal importance to environmental, social and economic aspects in decision-making. The identification process for relevant sustainability indicators is built on a hierarchical approach (see Figure 1.1). On the pre-assessment level of a planning process, indicators can be used as “filters” to avoid unsustainable alternatives. Once the pre-assessment on a strategic level is carried out, a detailed assessment can be followed, using specific indicators.

General indicators were defined for the energetic and spatial context of WWTPs. For instance, the “degree of thermal self-sufficiency” at the WWTP or the “degree of usable excess heat” in the vicinity of the treatment plant are important. In order to guarantee the applicability of the methodology for energy supply systems, technical aspects were added to the original three-pillar approach. Hence, a final set of specific sustainability indicators, split into four sections, was defined. By incorporating indicators of the pre-assessment, the final ISA can thus be conducted on five levels: (1) General, (2) environmental, (3) social, (4) economic and (5) technical. Alternatively, the assessment can also be conducted cumulated across all five levels. The actual rating is based on ordinal decision-matrices. Finally, the rating results of the ISA depicts the most sustainable solution and supports decision-makers on utilising excess energy from WWTPs.

Preliminary results show the practicability of the methodology, which is currently tested in five locations across Europe. The developed ISA serves as a feasible methodology to evaluate additional benefits of WWTPs for society. Simultaneously the utilisation of excess energy from WWTPs can be seen as a step to connect various energetic sectors and to gradually foster the utilisation of RES and contribute to emission reductions.

The related work is carried out within the framework of the ongoing INTERREG Central Europe project REEF 2W - Increased renewable energy and energy efficiency by integrating, combining and empowering urban wastewater and organic waste management systems (http://www.interreg-central.eu/Content.Node/REEF-2W.html).

REFERENCES


Comparative Cost Estimations of Full-scale Phosphorus-recovery Processes in German Wastewater Treatment Plants

L. Conzelmann*, F. Kraus*, C. Remy*

* Berlin Centre of Competence for Water, Cicerstraße 24, 10709 Berlin, Germany lea.conzelmann@kompetenz-wasser.de

Abstract: Due to a new legislation on sewage sludge disposal, phosphorus (P) recovery becomes obligatory for larger wastewater treatment plants (WWTP) in Germany from 2029 onwards. The new legislation requires that either sludge has a P-concentration below 20 g P/kg DM or a P concentration reduction of 50% for sludge and 80% for mono-incineration sludge ash. The present study shows the costs and benefits of phosphate recovery from wastewater. Therefore, all relevant costs and savings are presented from an operator's point of view. The results show that the economics highly depend on initial conditions like plant size, P-concentration in sludge or ash, and the market value of the P-product. But they also depend on process specific conditions like energy and chemical costs and savings due to possible operational benefits such as credits for higher biogas yields or reduced sludge/ash disposal costs.

Keywords: phosphorus recovery; municipal wastewater; cost estimation; struvite

INTRODUCTION

The German amendment of the Sludge Ordinance (2017) prohibits agricultural sludge valorisation for larger wastewater treatment plants (WWTPs), instead phosphorus (P) recovery becomes obligatory for these WWTPs in a medium-term (AbfKlärV, 2017). The aim of this study (UBA, 2019) is to show the costs and benefits of the nationwide P recovery and recycling from wastewater. The data for the investigated precipitation processes is from full-scale plants (incl. hydrolysis) and for acid extraction processes from plants in piloting phase.

METHODS

This cost estimate takes into account the annual depreciation of the investment costs as well as current energy, material and personnel costs. Special attention is paid to the side effects on the WWTP operation resulting from the P-recovery technology, e.g. by struvite recovery. Eight of the eleven assessed processes recover struvite from digested sludge or centrate and are integrated into the WWTP (“sludge route”). Three processes recover phosphate downstream of a mono-incineration plant from sewage sludge ash (“ash route”). Annual gross costs are calculated following the annuity method.

RESULTS

The principle approaches of the different P recovery routes are decisive for their cost profiles and potential savings. The annual capital costs of both routes tend to be highly dependent on the plant size due to economies of scale. Main results for the P recovery processes via sludge route (Figure 1.1) are:
• Recovery of struvite in EBPR-plants can be realized at neutral or even negative costs, mainly due to associated savings in sludge disposal costs.
• An additional pre-treatment step (e.g. thermal hydrolysis) can increase the PO4-P concentration in the water phase and therefore the product quantity. Additionally, it can increase the energy credit for biogas production.

![Figure 1.1](image-url) Annual gross costs (excl. product revenues) of integrated P recovery processes for a reference WWTP of 1 million p.e.

The main results for downstream P recovery from mono-incineration ash are:
• Acidic extraction from sludge ash (e.g. EcoPhos or TetraPhos process) are characterized by process-internal recirculation of chemicals. They produce by-products with market potential and reduce the amount of ash to dispose. The P-product – technical phosphoric acid – has a high market value.
• Thermo-chemical treatment of ash (e.g. AshDec) is characterized by comparably low investment costs, medium operational costs and the quantity of secondary residues can be reduced to a minimum, thus disposal costs for ash are saved.
• For ashes with phosphorus contents below 60 g P/kg, the cost for recovery are higher than the possible revenues (not shown).

![Figure 1.2](image-url) Annual gross costs (excl. product revenues) for P recovery processes from incineration ash with a reference size of 30,000 t ash/year.

References
Thermal Energy Recovery within Sewage Treatment Process


* CNR – Water Research Institute, Via F. De Blasio 5, 70132 Bari, Italy
** Department of Applied Physics, University of Almería, 04120 Almería, Spain
*** Hedera helix I&B, Avda. Putxeta 1, Abanto y Zierbena, 48540, Bizkaia, Spain
**** 2.-0 LCA consultants, Rendsburggade 14, room 2.345, 9000, Aalborg, Denmark

Abstract: It is widely accepted that fossil fuels are related directly to land and water degradation and global warming mainly as a consequence of greenhouse gas (GHG) emissions generated by anthropogenic activity. This explains the great attention paid to renewable energy sources during the last years. Urban wastewater is a valuable source of clean energy that can be used both for building conditioning and hot sanitary water production, thus reducing primary energy demand and greenhouse gas emissions. In the present study, the integration of a highly efficient solar-assisted fully off-grid water-source heat pump (SHP) with an innovative biological system is tested for recovering and reusing thermal energy generated during the depuration process.

Keywords: thermal energy recovery; sewage treatment; solar powered water source heat pump.

INTRODUCTION Due to the human population, urbanization and industrialization increase, the world’s energy demand has continuously increased during the last decades. Civil buildings air conditioning systems and industrial process operation activities are the major source of energy consumption and greenhouse gas (GHG) direct emissions in over-urbanized areas where heat and electricity are powered by gas and coal sources (Heinonen and Junnila, 2011). For this reason, consistent scientific efforts have been recently carried out aimed at identifying integrated renewable energy production systems capable of supplying energy-intensive users by employing different low-carbon renewable energy sources. In accordance with the so far necessary use of sustainable technologies, recovering heat content of sewage would allow to save energy costs and reduce primary energy consumption. In the present study, an innovative biological system (SBBGR - Sequencing Batch Biofilter Granular Reactor) is used, featured by complete separation between biomass and liquid phase obtained by using a particular filling material and selected operating conditions (Di Iaconi et al., 2014). This allows to have always a zone of the reactor free of suspended solids where heat pump exchanger can be placed. Moreover, SBBGR biomass is featured by a long sludge age (longer than 100 days) which leads to a low observed growth yield thus maximizing the conversion of chemical energy stored into sewage pollutants to thermal energy. The present study is aimed at evaluating the integration of SBBGR with a solar assisted fully off-grid reversible water-source heat pump designed to recover, storage and reuse thermal energy in buildings conditioning systems from municipal wastewater treatment and solar...
energy. In particular, the capacity of such integrated system to treat sewage and covering cooling/heating and domestic hot water (DHW) of an experimental test laboratory (ETL) was evaluated.

MATERIALS AND METHODS The integrated plant sketch and picture are shown in Figure 1. It consists of 5 main components: 1) SBBGR pilot plant having a treatment capacity of 0.25 m$^3$/d; 2) a wastewater solar heat pump coupled with a highly efficient tubular heat exchanger submersed in the liquid phase unit of SBBGR, whose compressor is powered by 5kWp photovoltaic panels plant, 3) two short-term thermal latent energy hot and cold storage units filled with phase-change materials, operating at 53°C and 0 °C, respectively, whose capacity is 0.3 and 0.5 m$^3$ respectively, 4) 26 m$^3$ ETL supplied with 140 L/d of DHW and conditioned at 20-25 °C, 5) energy dissipation devices (external condenser and evaporator). Real municipal wastewater coming from a local sewerage system was used as influent of SBBGR.

RESULTS AND DISCUSSION The integrated plant was in operation from July 2017 until September 2018. Three different set-point temperatures (i.e., 10, 15 and 20°C) of SBBGR liquid phase were tested. Total energy extracted from SBBGR on a daily basis, calculated by supervisory control and data acquisition system (SCADA), is reported in Table 1.1 for each temperature set-point (in terms of mean values, standard deviations and value ranges) together with environmental temperatures observed during sunlight radiation hours, that is when heat pump compressor was operated by photovoltaic panels (i.e., when radiation intensity ≥ 300 W/m$^2$). Data reported in Table 1.1 show that thermal energy extracted from SBBGR was significant. It ranged from 1 to 8.5 kWh/d as a function of environmental temperature and set-point temperature of SBBGR liquid phase. As expected, the maximum amount of heat extracted occurred in the warmest environmental conditions and at the lowest set-point temperature of SBBGR phase unit. When heat recovery is performed within wastewater treatment, three heat components need to be taken into account: biochemical heat produced by bacteria metabolism, sewage sensible heat and heat due to the environmental conditions (mainly solar radiation). Biochemical heat was calculated based on real oxygen consumption of SBBGR biomass for carbon removal, nitrification process and maintenance metabolism, and applying a 15 J/mgO$_2$ heat yield factor (Aulenta et al., 2002). Sensible heat was estimated assuming sewage temperature equal to mean environmental temperature during sunlight radiation hours. Finally, heat amount due to environmental conditions was calculated by difference between total energy extracted calculated by SCADA and the other two heat components. The three shares of thermal energy extracted from SBBGR during daylight over selected operating days are shown in Figure 1.2. Looking at this figure, it is intuitively clear that solar radiation is by far the main contributor to the energy extracted (up to 4 times the sensible and biochemical heat amount). Heat extraction had negligible impact on depuration performances for all the monitored parameters. In particular, SBBGR plant ensured high (90-99%) and stable removal of ammonium even at lowest set-point temperature (i.e., 10 °C). Finally, heat exchanger showed stable heat recovery efficiency confirming the absence of fouling phenomena.

ACKNOWLEDGMENT This work was supported by project THERBIOR, funded under the ERA-NET Cofund WaterWorks 2014.
Table 1.1 Thermal energy extracted from SBBGR during solar radiation to varying of SBBGR liquid phase set-point temperature. Environmental temperature values during sunlight radiation hours (i.e., when radiation intensity ≥ 300 W/m²) are also reported.

<table>
<thead>
<tr>
<th>SBBGR set point T (°C)</th>
<th>Total energy extracted (KWh/d)</th>
<th>Mean value ± st. dev.</th>
<th>Value range</th>
<th>Mean value ± st. dev.</th>
<th>Value range</th>
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<tbody>
<tr>
<td>10.0</td>
<td>4.7 ± 2.3</td>
<td>1.5 – 8.5</td>
<td>25.4 ± 3.5</td>
<td>21.0 - 30.0</td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td>4.1 ± 1.7</td>
<td>1.0 – 7.4</td>
<td>28.2 ± 4.1</td>
<td>21.0 - 36.1</td>
<td></td>
</tr>
<tr>
<td>20.0</td>
<td>4.0 ± 1.7</td>
<td>1.1 – 6.3</td>
<td>34.1 ± 2.8</td>
<td>28.0 - 39.0</td>
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Figure 1.1. Scheme of the integrated plant.

Figure 1.2 Shares of thermal energy extracted during selected days at 15°C set-point temperature of SBBGR liquid phase.

REFERENCES


Drinking Water Distribution Networks: An Emerging Resource for Thermal Energy Recovery


* Sanitary Engineering, Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600GA Delft, Netherlands j.i.ahmad@tudelft.nl
** Waternet, Korte Ouderkerkerdijk 7, 1096 AC Amsterdam, Netherlands
*** Oasen Water Company, P.O. Box 122, 2800AC Gouda, Netherlands
**** KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, the Netherlands,
***** IESE, School of Civil and Environmental Engineering, National university of Science and Technology, H-12 sector, Islamabad, Pakistan
****** Amsterdam Institute for Advanced Metropolitan Solutions, Kattenburgerstraat 5, 1018 JA Amsterdam, Netherlands

Abstract: Drinking water distribution networks (DWDNs) have huge potential and significance for thermal energy recovery in the form of cold. This can provide enough cooling for buildings and spaces with high cooling requirements and is helpful in reducing carbon footprints by abandoning traditional cooling methods. This study showed that recovery of cold from microbial safe water of high quality by heat exchangers, at temperatures of 15, 25 and 30 °C after the heat exchangers, provided 54, 225 and 317 PJ/y of energy respectively. Furthermore, in subsurface the temperature of water within DWDNs, after having passed the heat exchanger, will be equivalent to surrounding soil temperature within 1km. From human health perspectives, opportunistic pathogenic bacteria like Legionella will not regrow after cold recovery at these three temperatures.

Keywords: Cold recovery, carbon footprints reduction, drinking water distribution networks

BACKGROUND Global warming is raising the earth’s temperature and therefore the demand for cooling. In Amsterdam, the latter amounts to 2,162 TJ/y for non-residential spaces only. Providing this with traditional cooling methods (i.e. mechanical cooling) requires an intensive amount of electricity. Hence, there is a need to explore more sustainable cooling resources. Recently, drinking water distribution networks (DWDNs) are thought of as a source of heat and cooling, as million m$^3$ of water flow through these networks that contains a lot of thermal energy, which can be retrieved by using heat exchangers. According to a recent study (Mol et al., 2011), the cold potential of the DWDN of the city of Amsterdam, calculated by taking into account flow and temperature during the year, is very high (338 TJ/year). However, retrieving cold from drinking water means increasing its temperature, which may enhance microbial activity and proliferation of opportunistic pathogens like Legionella spp. (Hammes et al., 2008; van der Wielen et al., 2013). This may occur both in the water and biofilm phase (the layer of microbes attached to the inside of the pipes), with possible negative effects on water quality. However, the temperature difference (∆T) between water entering and exiting the heat exchangers (HE) is crucial for cold recovery, as the amount of retrievable energy grows linearly with ∆T. The allowed temperature for drinking water at the customer’s tap in the Netherlands is 25°C. This means that when the water temperature is being raised for cold recovery purposes,
a limit should be set in order to stay within the temperature threshold by the end user and not to compromise the water quality.

MATERIALS & METHODS For this purpose, three pilot DWDNs and one full scale system for cold recovery were operated, where 2 pilot systems are for cold recovery. One operating at 25°C and second at 30°C, whereas the full scale at 15°C after cold recovery. The third pilot system was used as control or reference without cold recovery. During study period, the temperature of the incoming water was ranging between 11-17°C. Further, the drinking water used for this experiment was of high quality, produced from surface water and supplied without residual disinfectant and was microbiologically stable (AOC < 2 μg/l) during distribution. The systems were investigated for drinking water quality (microbial activity and pathogens presence (Legionella spp.)) both for water and biofilm, and potential for cold recovery (van der Hoek et al., 2018). Also the temperature changes were measured in the pilot DWDNs and predicted using a temperature model (Zlatanovic et al., 2017), in order to determine the distance at which the temperature reaches its original inlet values along the length of the pipe after cold recovery units.

FINDINGS AND SIGNIFICANCE In terms of microbial activity in both water and biofilm phases, little or no significant changes were observed after cold recovery (Figure 1.1 A and B). Additionally, Legionella was not detected in the incoming water nor in the reference biofilm. In the systems with HE, with increased temperature, there was no regrowth or proliferation of this bacteria in both phases. This suggests that higher temperature exposure for a prolonged time decreases the biomass accumulation within DWDNs and also is not providing favourable conditions for regrowth of pathogens like Legionella. With respect to the temperature inside the pilot DWDNs after cold recovery, the temperature model showed that under continuous flow conditions within 700 m the temperature of the drinking water reaches the temperature as it was before entering the HE (Figure 1.3). However, in real DWDNs, with fluctuating flows over a day, it is expected that the drinking water temperature will restore even earlier. This will be studied further in the coming months. For the cold energy potential from the full scale installation, which currently has a maximum allowed temperature after cold recovery of 15°C, it was shown that raising this limit to 25°C and 30°C increased the retrievable energy, and therefore reduced the carbon footprint four and almost six times respectively (Figure 1.2 A and B). In conclusion, this study is the first of its kind and it can be used as a baseline framework for designing cold recovery system with maximised potential while maintaining good water quality.
Figure 1.1 ATP concentrations at different temperatures after cold recovery and in the reference system. A: water samples; B: biofilm samples.

Figure 1.2 Cold recovery potential from drinking water of the full scale installation. A: as function of the drinking water temperature after the recovery; B: as function of the available drinking water flow rate.

Figure 1.3 Measured and modelled drinking water temperatures at various distances after the cold recovery units in the pilot DWDNs.

REFERENCES


M. Guo*

*Department of Chemical Engineering, Imperial College London SW7 2AZ, miao.guo@imperial.ac.uk

Abstract: Wastewater (WW) and organic fraction municipal solid waste (OFMSW), represent carbon and nutrient rich resources composed of complex compositions like carbohydrates, lipid, protein, cellulose, hemicellulose and lignin. In conventional waste management value chains, OFMSW and WW components have been regarded as by-products as opposed to promising resources with energy and nutrient values. Full exploitation of waste resources calls for a value chain transformation towards proactive resource recovery and waste commoditization. This requires robust projection of OFMSW and WW composition and supply variability as well as waste recovery systems planning. Gradient boosting models were developed using historical socio-demographic, weather and waste data from UK local authorities. By integrating machine learning techniques with chemical process design and mathematical optimisation, our research highlights a systems modelling approach to inform decision-making on waste-to-resource transformation.

Keywords: machine learning; mathematical optimisation, waste recovery

The projected 50% increase in global population in the 21st century combined with non-OECD economic growth is expected to increase waste generation. Global municipal solid waste (MSW) growth is projected to exceed 11 million tons per day (59%-68% organic fraction (OFMSW)) by 2100 under ‘business as usual’ (Hoornweg et al., 2013) and a significant amount of (330km³ per year) municipal wastewater (WW) is generated (Hoornweg & Bhada-Tata, 2012). Increasing waste trends are particularly intense in less developed countries and contribute to resource stress, greenhouse gases and environmental degradation. The transition from a linear fossil-based economy to a circular bio-based economy offers a mechanism to tackle environmental changes and degradation.

In conventional waste management value chains, OFMSW and WW along with other waste streams have been regarded as by-products (carrying zero or low-value) rather than marketable commodities with well-defined grades. In fact, OFMSW and WW streams are not only carbon-rich resources as energy carrier but also contain high nutrient values (e.g. nitrogen, phosphorus). The waste sector presents promising opportunities for resources to be converted to value-added products via thermochemical and biochemical technologies under circular economy. To exploit waste resource value requires a transformative waste value chain and commoditization of waste resources, which calls for robust projection of waste quantity and quality (composition) and waste recovery systems planning.

Efficient planning (e.g. sizing and logistics) and operation of waste recovery facilities requires continuous and consistent waste feedstock supply. However, it is complex to quantity waste feedstock due to highly varying composition and low
traceability. Take food waste as an example. The UK nationwide analyses showed significantly varying carbohydrates (30-250 g/kg), lipid (10-128 g/kg), protein (5-140 g/kg), soluble sodium and potassium (1.2-55 g/kg) contents (WRAP, 2010). These are dependent on spatially-explicit factors (e.g. local diet and behaviour) and seasonally environmental variables. Despite the increasing interests in MSW volume forecast by using material flow models, regression analysis, machine learning and artificial intelligence techniques, robust projection of waste composition remains open.

By far the most widespread resource recovery in the WW and bio- solid sector is anaerobic digestion (AD). The generated biogas i.e. C recovery, is often used for onsite combined-heat-and-power generation, but could be upgraded and injected into the natural gas grid, or used for methanol and biodegradable plastic production, or reformed to hydrogen. Nutrient-rich waste recovery is of particular interest since it can replace fossil fuel forms of nutrient production e.g. N fertiliser, and can avoid depleting non-renewable mineral deposits e.g. P; these environmental benefits and values of nutrient recycling from AD are often overlooked. Concern has been raised regarding the energy-focused incentive strategies, which could hinder the penetration of other, potentially more environmentally favourable, resource recovery options. Such risks could be mitigated via systems design integrating waste-C conversion with N/P and elemental resource recovery.

This study presents a systems modelling approach which integrates machine learning techniques, mathematical optimisation and chemical process design to inform the transformation of waste-to-resource value chains. Specifically, we adopted gradient boosting model to project OFMSW composition based on their non-linear relationships with climate-related and socio-demographic variables. These models were used to forecast OFMSW generation for each of the 327 UK local authorities (Adeogba et al., 2019). The predictive performance and spatial granularity of model projections offer a promising approach to inform decision-making on waste commoditization. Further, integrating our laboratory results into a process design tool, our research derived the scaled-up technology performances to effectively co-recover energy and N/P/protein from OFMSW and WW streams. To link the process design with multi-objective optimisation, surrogate modelling techniques or scenario based optimisation were applied, which bridged the technology process design with multiple sustainability criteria. The process optimisation model was further expanded to include spatial and temporal dimensions, which highlights the spatially-explicit solutions on technology choice, sizing, location, and logistics of waste recovery facilities. A UK based study on OFMSW and fermentation industrial WW is presented in our research to demonstrate the functionality of the systems modelling approach. The optimal solutions account for AD and other biochemical and thermochemical technologies to meet the economic feasibility and environmental sustainability simultaneously. Overall, the computer-aided systems model developed in our research represents a promising tool to tackle the open challenges hindering waste-to-resource transformation.

REFERENCES


Tuesday, 10th September 2019

Session 12

ROAD TO BIOREFINERY AND WRRF IMPLEMENTATION
Full Scale Biorefinery and Territorial Strategy for Resource Recovery and Reuse: The Case of CAP Holding Italy

A. Lanuzza*

*CTO, CAP Holding

Abstract: Resource recovery needs territorial strategies rather than single projects. Gruppo CAP defined and is implementing a master plan focused on the optimization of its “network” of assets in order to optimize the engineering of its future biorefinery, also the value chain and maximize the resource recovery efficiency. Digital solutions will enhance productivity thanks to the collaboration with other utilities.
Compounds of Interest in Wastewater from Food Processing Industries: H2020 AFTERLIFE Project

A. Dominguez Martos, A.*, S. Rodríguez Pérez**, N. Frison***, M. Lopez-Abelairas****

* IDENER, Early Ovington 24-8, La Rinconada (Sevilla), Spain, andrea.dominguez@idener.es
** IDENER, Early Ovington 24-8, La Rinconada (Sevilla), Spain, santiago.rodriguez@idener.es
*** INNOVEN, Str. le Grazie, 15, 37134 Verona VR, Italy, Nicola.frison@innoven.it
****IDENER, Early Ovington 24-8, La Rinconada (Sevilla), Spain, maria.lopez@idener.es

Abstract: Water is an indispensable resource and for this reason, management strategies should be adjusted to the sustainable development concept. Human activities, such as food processing, generate a high volume of wastewater that should be treated before being discharged to remove organic matter and nutrients that can cause environmental damage. Despite the interesting potential of many of these compounds (proteins, sugars, lipids...) as raw materials for bio-based industry, their valorisation is currently limited, with the best technologies on stream, to the production of bioenergy. AFTERLIFE project develops an innovative wastewater treatment consisting of a low-fouling filtration system to recover all the solids in wastewater, which will suffer a supercritical/subcritical fluid extraction for the recovery of the value-added extracts. The rest of the organic matter will be converted into a high-volume added value biopolymer, polyhydroxyalkanoates, by means of a two-step-fermentative process.

Keywords: Advanced filtration, volatile fatty acids, polyhydroxyalkanoates, wastewater treatment, supercritical extraction

Food and beverage processing is a very water intensive sector, which is ranked as the third European industrial manufacturing sector with the largest water consumption, ahead, for example, of pulp and paper industry. Such industry consumes about 4.9 m³/inhabitant-year of water (Eurostat, average from 2003 to 2011) and generates a similar wastewater volume, that is, about 3,700 Million m³/year, which is treated in-situ and/or in a municipal wastewater treatment plant (MWWTP). Dairy, fruit processing and sweets manufacturing industries hoard around the 40% of total investments devoted to wastewater treatment within food processing sector. Besides the important market associated to the treatment of these effluents, some of their specific characteristics imply important challenges in the treatment step, such as high DQO levels. Moreover, the presence of a large variety of natural extracts from food processing converts the effluents into a very attractive source of antioxidants, proteins and other value-added additives typically used in the development of food and cosmetic products.

In this frame, the H2020 AFTERLIFE project (Advanced filtration technologies for the recovery and later conversion of relevant fractions from wastewater) proposes a flexible, cots- and resource-efficient wastewater treatment process with the simultaneous recovery of compounds of interest and the conversion of the rest of the organic matter into a high-volume added value plastic biopolymer (polyhydroxyalkanoates) with the use of a promising technology for the wastewater
The wastewater is pretreated to remove large size solids and emulsions and enters the filtration unit where is processed through consecutive cross-flow micro- (MF), ultra- (UF), nano-filtration (NF)/reverse osmosis (RO). The process ultimately originates concentrates and ultrapure water. The latter is used to supply water in all the relevant operations such as membrane and other equipment washing and bacterial digestion medium preparation, to minimize the fresh water consumption in the process and thus the impact on resources consumption. High value-added extracts and metabolites are recovered on the basis of molecular size exclusion in the different concentrated streams. The rest of the organic matter is converted into polyhydroxyalkanoates through a two-stage process: first, production of volatile fatty acids through an acidogenic fermentation and, then, the conversion into the biopolymer in an aerobic bacterial process.

The first results in the project have shown the potential of the technology to treat streams from different sources. Effluents from three types of food industry (cheese manufacturing, fruit processing and sweets manufacturing) have been characterised, pretreated and gone through the filtration step for the production of high pure water and maximize the recovery of organic compounds. Currently, the work for the purification of the recovered compounds is on-going to produce purified extracts, which will be used for the development of enriched products, through the use of advanced extraction and purification techniques. The fermentation of the rest of the recovered organic matter for polyhydroxyalkanoates production is also being optimised at lab scale for the subsequent upscaling in an integrated pilot of the process.

The AFTERLIFE project aims to deliver a substantial positive impact on the progress of wastewater treatment technologies and relevant fractions recovery. The upscaling of the process at pilot scale during the project will allow the demonstration of the technology with real effluents from the food industry and will pave the way to spread out its application to other sectors.

![Diagram to AFTERLIFE process](image)

**ACKNOWLEDGMENTS** AFTERLIFE has received funding from the Bio-Based Industries Joint Undertaking under the European Union’s Horizon 2020 research and innovation program under grant agreement No. 745737.

**REFERENCES**
CoRe Water: from WWTP to a Sustainable Water and Resource Factory

K. Roest 1*a, J. Muñoz Sierra 2a, L. van Dijk 3b, A. Polman 4b, H. Ramaekers 5c, A. Hendriks 6c, E. Cornelissen 7a

1aKWR Watercycle Research Institute, Groningenhaven 7, 3430BB, Nieuwegein, The Netherlands
2aBLUE-tec, Industrieweg 16, 6871 KA, Renkum, The Netherlands
3bRoyal HaskoningDHV, P.O. Box 1132, 3800 BC, Amersfoort, The Netherlands
*aCorresponding author’s email: kees.roest@kwrwater.nl; Telephone: +31 30 606 9531

Abstract: How does wastewater treatment in the future look like? In the CoRe Water concept wastewater treatment will be fundamentally different from current practice. This innovative treatment concept consists of two steps. In the first step the wastewater is concentrated by a factor of twenty or more by means of membrane filtration. Subsequently the valuable components in the concentrated stream (one of the twenty parts) are recovered in several steps, the remaining nineteen parts can be reused as pure water after further treatment. The CoRe Water concept represents a highly innovative and disruptive approach of the treatment of wastewater, and aims to (1) bring about the reuse of water and valuable raw materials, (2) reduce greenhouse gas emissions, (3) significantly reduce the emissions of organic micro-pollutants like pharmaceuticals and (4) stimulate a compact and modular construction in wastewater treatment. In this presentation the current progress of our CoRe project, including applied pilot research at an existing sewage treatment plant, will be presented.

Keywords: Concentrate; Resource recovery; Reuse

BACKGROUND The transition to how we deal with our wastewater in the future is shaped by a number of developments aimed at improving effluent quality, reduction of greenhouse gas emissions, recovery of valuable raw materials and energy, and the preference for a modular and adaptive purification concept. The challenge in this project is to work on sustainability and cost-effectiveness of sewage treatment and on better effluent quality (specifically the removal of organic micro-pollutants (OMP; including pharmaceuticals), nitrogen and phosphate) at the same time. To achieve these goals the innovative wastewater treatment concept CoRe Water (Concentrate, Recovery & Reuse) is developed. In this concept wastewater is first concentrated before it is further treated. In this way, sewage water can be efficiently and effectively treated achieving a higher removal efficiency of nitrogen, phosphorus and OMP. Likewise, an optimal recovery of resources such as nutrients, energy and especially water can be achieved/obtained: from wastewater treatment plant to sustainable water and resource factory. In this way, optimal recovery of resources such as nutrients, energy and especially water is obtained turning the wastewater treatment plant into a sustainable water factory (van Leeuwen et al. 2018). The pre-concentration of wastewater is done using forward osmosis (FO) technology due to its high rejection capacity and low fouling propensity (Lutchmiah et al. 2014). Scarcity of water is a key driver for reuse of wastewater in many places around the world. Meanwhile, current wastewater practice is challenged to improve on reduction of greenhouse gas emissions.
emissions, removal of organic micro-pollutants and on recovery potential of valuable compounds. This is where the CoRe Water concept comes in: Concentrate, Recovery and Reuse. The diluted draw solution and clean water are recovered, and the concentrate stream is further treated (Lutchmiah et al. 2011). Due to substantial flow and quality variations, municipal wastewater is a challenging application for FO technology. Worldwide, FO is already applied and in operation for treatment of specific industrial wastewaters (Haupt and Lerch 2018) at capacities higher than 25 m³/h¹, but not yet to sewage.

OBJECTIVES In order to investigate the technology of FO itself there are three subprojects which combine pilot research and adjoining laboratory research on different scale sizes for the extraction of water, energy and raw materials. Here there is also attention paid to the anaerobic treatment of the concentrate, the recovery of nutrients and the removal of OMP. The possible application of the raw materials is also included in the study. The aim is to obtain sufficient information about the technical and economic potential of the CoRe Water concept in order to assess whether it is a fully-fledged new alternative for the treatment of sewer wastewater and to have sufficient insight into both the overall energy balance and the economic feasibility of the concept. We also obtain insight into the possibilities for pure water reuse from the membrane treatment, and energy production and the application of recovered raw materials from the concentrate of the FO.

METHODOLOGY Concentrating of wastewater is achieved with a technology based on the principle of Forward Osmosis (FO). This is the key step in the production of clean water without nutrients, (pathogenic) micro-organisms and OMP and a concentrated wastewater stream that can be treated more energy-efficiently and from which valuable resources are easier to recover. FO is already applied to industrial wastewater, but not yet to municipal wastewater. The principle of FO is based on a general part of natural biological systems. In our engineered FO process a semi-permeable membrane is placed between the pre-clarified wastewater and the ‘draw solution’ (typically a concentrated salt solution). The osmotic gradient between the two flows generates a water flow through the membrane, resulting in a concentrated feed stream and a diluted draw solution. Afterwards, the diluted draw solution together with the clean water are recovered, and the concentrate stream is further treated. Due to substantial flow and quality variations, municipal wastewater is a challenging application for FO technology. Currently we are scaling up the FO process for concentrating pre-clarified wastewater. Worldwide, full-scale FO plants are already in operation for the treatment of specific industrial wastewaters with capacities greater than 25 m³/h.

RESULTS AND DISCUSSION CoRe Water stands for an innovative concept: ‘Concentrate, Recovery and Reuse’. As a first step, municipal wastewater is concentrated by a factor of 20 or more by applying FO. The concentrated stream is then biologically treated – first anaerobically, then aerobically. In this way the maximum amount of energy and valuable components is recovered, while making the removal of OMP manageable. Potentially also huge steps towards limiting greenhouse gas emissions are taken. Considering all the existing and new challenges imposed on the treatment process of municipal wastewater, there are convincing arguments for the need/importance of rethinking the system. A key element is concentrating wastewater early in the process.
CONCLUSIONS What are the reasons for concentrating wastewater first?

- As a general rule in water technology, the more concentrated the liquid stream, the more efficient treatment processes are.
- The concentrate can be economically treated anaerobically, which converts organics into methane.
- Recovery of valuable compounds (e.g. nutrients) and energy from the concentrate are favored.
- Organic micro-pollutants, like pharmaceuticals, are managed more efficiently.
- The emission of greenhouse gases (esp. N₂O) is potentially significantly reduced.
- And last but not least: the clean water flow can be reused in high-end applications.

The extracted water from the original wastewater is released as pure water of deminwater quality, which is suitable for reuse in a number of applications. With CoRe Water we are now truly making the step from WWTP to a water and resource factory!

ACKNOWLEDGEMENT The CoRe Water project is a collaboration by Waterschapsbedrijf Limburg, water boards Vallei & Veluwe and Rijn & IJssel, companies BLUE-tec and Royal HaskoningDHV and knowledge institute KWR Watercycle Research Institute. This activity is co-financed with PPS-funding from the Topconsortia for Knowledge & Innovation (TKI’s) of the Dutch Ministry of Economic Affairs and Climate.

REFERENCES
Chemically Enhanced Primary Treatment: Shall We Pay More Attention to Bio-Sourced Coagulants to Maximize CH₄ Production?


* IRSTEA, UR REVERSAAL, 5 Rue de la Doua, 69100 Villeurbanne, France
** IRSTEA, UR RiverLy, 5 Rue de la Doua, 69100 Villeurbanne, France
*** INSA, DEEP, 20 av. Albert Einstein, 69621 Villeurbanne, France
**** SAUR, R&D, 2 Rue de la Bresle, 78310 Maurepas, France

Keywords: CEPT; Bio-based coagulants; anaerobic digestion

INTRODUCTION
Developing wastewater treatment plant of the future leads to an increasing interest in shifting from energy consuming activated sludge processes to Water Resource Recovery Facility that significantly improves their energy balance. One way to advance proceed towards an energy efficient wastewater treatment plants is to maximize the capture of organic matter further valorized through anaerobic digestion, rather than oxidation or extensive bioconversion processes. The chemically enhanced primary treatment (CEPT) represents a well-known technology enabling to redirect as much as 40% of inlet carbon as biomethane (Wan et al., 2016). Although CEPT process with metallic coagulants is well known, 3 main drawbacks are generally associated with their use: i) they can reduce primary sludge biodegradability and therefore CH₄ production (Diamantis et al., 2013), ii) the environmental footprint of their production is quite high (Norgate et al., 2007), and iii) metals in digested sludge generally represents an environmental issue for disposal (Sotero-Santos et al., 2007).

In this context, the main objective of this study is to evaluate the efficiency of new chemical and bio-sourced organic coagulants compared to the conventional FeCl₃ focusing on removal mechanisms, their impact on carbon capture performances and bio-methane production.

MATERIAL AND METHODS
Experiments were performed in 3 steps using raw urban wastewater and comparing different coagulants including FeCl₃, chemical and bio-sourced organic coagulants. First step, isotherms sorption curves were drawn by means of jar test experiments (ASTM D2035, 2013) to select the best performing coagulant among 60 different ones provided by 4 major coagulant suppliers in France. Concentrations were increased over a range of 5 mg/L to 120 mg/L. Second step, isosettling curves were drawn by means of static settling column experiments(40 L) performed on the 4 best coagulants (Metcalf et al., 2003). Third step, continuous experiments using a pilot primary settler were performed with the 4 best coagulants on a primary settler at 0.1 m³/h flowrate. Performances of the 3 experiments were evaluated by measuring the removal of TSS, COD, sCOD, BOD₅, turbidity and punctually TP, P-PO₄ measured according to standard methods. Biodegradability was
estimated by BOD$_{u}$ltimate and BMP tests on sludge produced in the column experiments and in the pilot experiment. Removal mechanisms were investigated in column experiments by measuring colloidal matter content (total colloids, protein, and sugar) and performing high performance size exclusion chromatography with UV detection (HPSEC-UV) on obtained supernatants.

**RESULTS AND DISCUSSION** A decision matrix was developed to select the best performing coagulants based on their removal efficiency (jar test), biodegradability, and price. The selected coagulants were PolyDADMAC and Polyamine, Starch and Tannin (bio-sourced). Jar test results showed that the selected coagulants enabled to reach overall performances similar to FeCl$_3$. Preliminary results from the column tests confirmed the removal efficiencies of the selected products, with similar settling velocities for PolyDADMAC, Tannin and FeCl$_3$ (respectively in m/h 1.48, 1.60 and 1.50) compared to primary settling (0.3 m/h). Although the action of coagulants and FeCl$_3$ were similar on the overall TSS and COD removal, differences were observed in colloid matter removals. When comparing supernatant fractions before / after treatment, better efficiencies were observed for protein removal with tannin compared to FeCl$_3$ for example with 31 and 23 % respectively, confirming literature results (Kooijman et al., 2017). Daily fluctuation of raw wastewater composition due to rain events led to large differences in terms of CEPT results, with FeCl$_3$ (at fixed dose), working better than other coagulants with low inlet COD concentrations (< 200 mg/L). Regarding HPSEC-UV analysis at 227 nm, preliminary results show that FeCl$_3$ and Tannin have different actions on molecules according to their molecular masses, investigations are ongoing to better understand the removal mechanisms associated to each coagulant.

**Table 1.1** Average removal efficiencies observed in jar test, HP-sec preliminary results at 227 nm.

<table>
<thead>
<tr>
<th>Coagulant</th>
<th>Average removal efficiencies %</th>
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<tbody>
<tr>
<td></td>
<td>Dose (mg/L)</td>
</tr>
<tr>
<td>I Settling</td>
<td>-</td>
</tr>
<tr>
<td>Polydadmac</td>
<td>25</td>
</tr>
<tr>
<td>Tannin</td>
<td>45</td>
</tr>
<tr>
<td>FeCl$_3$</td>
<td>45</td>
</tr>
</tbody>
</table>

Several experiments are ongoing, including: continuous flow tests with the best 4 coagulants, BMP and BOD$_a$ investigations on produced sludge. Complementary analysis regarding colloid fractions and overall mass balance of CEPT are also ongoing and results will be presented with a focus on carbon capture and CH$_4$ production. Finally, considering the positive impact of FeCl$_3$ on H$_2$S control on CEPT digested sludge processes, several tests will be performed by combining coagulants and iron salts.

**REFERENCES**


Diamantis, v. et al. sewage pre-concentration for maximum recovery and reuse at decentralized level. water science and technology, v. 67, n. 6, p. 1188-1193, 2013.

Kooijman, G.; de Kreuk, M.K.; van Lier, J.B., 2017. influence of chemically enhanced primary treatment on anaerobic digestion and dewaterability of waste sludge. water science and technology, 6, 1629-1639.


Norgate, t. e.; jahanshahi, s.; rankin, w. j. assessing the environmental impact of metal production processes. journal of cleaner production, v. 15, n. 8, p. 838-848,

Sotero-santos, r. b.; rocha, o.; pavinelli, j. toxicity of ferric chloride sludge to aquatic organisms. chemosphere, v. 68, n. 4, p. 628-636,

Water Recovery and Reuse, Between Opportunities and Barriers: The Fusina Integrated Project (PIF)

P. Ragazzo*, C. Franzoi**, A. Razzini***

*Veritas S.p.A. - R&D, EU projects–Integrated Water Service –Venice, Italy
p.ragazzo@gruppoveritas.it
** SIFA S.c.p.a., Mestre-Venice, Italy
***Veritas S.p.A. – General Direction, Venice, Italy

Abstract: Venice (Italy) and related lagoon zones are sensitive areas and due to intensive human activities (industrial, commercial, touristic...) the environmental equilibrium of this area has been at risk over the years and required continuous and intensive safeguarding and maintenance efforts. From these needs and the regional “2000 Director Plan” addressing actions for the lagoon protection, the Fusina Integrated Project (PIF) has been conceived; a multifunctional treatment pole which approaches the environmental issues of this habitat by adopting a system of integrated technologies and NBS solutions; at the same time by fostering municipal waste water industrial reuse. Thus constituting one of the basic infrastructures for the transformation of the National Interest Site “SIN - Porto Marghera” into an area of ecological interest, with services connected to the needs of reclamation and requalification of the areas.

Keywords: Wastewater reuse; industrial site reclaiming; nature based solutions

THE VENICE LAGOON Located between the mouth of two important rivers (Piave to the north and Brenta to the south), it is a complex eco-system in which natural balances and human needs must coexist. It represents one of the most complex hydraulic systems in the world (550 km² occupied by water and salt marshes (76%), fishing valleys (16%) and land (shorelines, reclamation banks, islands) and to this area belong the 117 islands on which Venice rises.

In this environment, a passage between mainland and sea, in the last century the Porto Marghera industrial area and the commercial and touristic port of Venice have been built. If on one side this allowed important socio-economic development, on the other hand it implied a relevant environmental impact and progressive increase in resources withdrawal and polluting loads released into the lagoon (over 2,000 km² of urbanized drainage basin, 108 municipalities and over 1,000,000 inhabitants).

It is in this framework that in the early 1970's, the first Special Law for safeguarding Venice was issued (Law 171/73), to organically address the different problems of city and lagoon preservation. However, it was in the early 2000s that the environmental policy issued an articulate "regulatory framework" strongly addressed to preserving this land-water delicate environment while at the same time safeguarding the model of economic development of the Venetian mainland. So was born “2000 Director Plan" the regional plan for actions addressing the Venice Lagoon
protection and draining basin reclaiming-management; and from this plan arose the Fusina Integrated Project (PIF).

**THE FUSINA INTEGRATED PROJECT (PIF)** The P.I.F has been realized by means of Project Financing (started from the Veneto Region through a European tender procedure) and it represents a fundamental tool to approach environmental management issues in the lagoon habitat. At its base there were three original objectives: i) contributing to the reduction of pollution generated in the Venice Lagoon drainage basin, by drastically limiting discharges, even previously treated; ii) the reclaiming of the polluted Porto Marghera sites, for which it represents a key element for the waters cycle (restoration and reuse); iii) the optimization of water resources management by implementing extensive reuse of water intended for industrial reuse.

The project included concentrating and treating wastewater in a multi-functional platform: i) urban discharges of Mestre and its surroundings (*wastewater type A-more than 100,000 m³/day*); ii) both the Porto Marghera industrial discharges (*type B1*) and site polluted groundwater (*type B3*), in addition to run-off water of the potentially polluted sites (*type B2; wastewater type B-around 50,000 m³/day*). For type A wastewater, three blocks of post-treatments to support water reuses were identified. One of them is represented by the requalification of an artificial island, created in the early 1960s (*by using sludge from the canals’ excavation*) to support the potential third industrial Porto Marghera area, never developed due to the socio-economic changings happened. Exploiting a re-naturalization process, which occurred over the years, this island has been transformed into an artificial wetland (*Nature Based Treatment*), to refine effluent before being sent to dual/industrial reuse as well as to be a reservoir for significant rainfall events.

An underwater pipeline allows treated water to be discharged to the open sea, 10 kms from the Lido coast. To give an idea of the dimensions: the length of main network pipe is almost 30 km (*network for both type B and water ready for reuse*).

With the exclusion of storage volumes (50,000 m³ for type A and 75,000 m³ for type B), the block diagram of Figure 1 and Table 1 report the main project treatment sections and flow rates.

For **type A - wastewater**, primary and secondary treatments were implemented/adapted and three blocks of post-treatments to enable water reuse for industrial purposes were realized:

**Block 1** - Pre-filtration followed by UV disinfection;

**Block 2** - Artificial Wetland treatment consisting in100 hectares organized in 6 basins working both in series and in parallel, in their turn constituted by 70% of superficial lands (0.3-0.6 m depth), 30% of deep areas (less than 2 m depth) and 1% of emerged islands;

**Block 3** – A further refining treatment with sand filtration followed by UV disinfection.

For **type B1+B2 - wastewater**, the following post-treatments were implemented in order to guarantee a wide flexibility and modularity:

- Clariflocculation followed by lamellar sedimentation
- Sand filtration
- Denitrification (*type-post*) in a biological activated filter to treat industrial effluents
with high nitrate concentration;

- UV Disinfection

**Type B3 - wastewater** together with type "A" wastewater, downstream primary treatments, were supposed to be treated by MBR to enable their industrial reuse.

![Diagram of wastewater treatment process](image)

**Figure 1** Sections and flows block diagram of PIF Executive Project (2006) and Integration Act (2010)

| Table 1 Design flow rates - PIF executive project (2006) |
|---------------------------------|-----------------|-----------------|
| **Project flowrates (m³/h)**    | **Average**     | **Max**         |
| **Line A** - Municipal wastewater | Primary and secondary Treatment | 4,600 | 12,000 |
|                                 | Post Treatments block 1 | 4,600 | 7,750 |
|                                 | Post Treatments blocks 2 and 3 | 3,125 | 4,000 |

<table>
<thead>
<tr>
<th><strong>Line B</strong></th>
<th><strong>Average</strong></th>
<th><strong>Summer</strong></th>
<th><strong>Winter</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 - pretreated industrial discharges</td>
<td>2,620</td>
<td>1,835</td>
<td></td>
</tr>
<tr>
<td>B2 - rainwater run off - polluted site</td>
<td>380</td>
<td>957</td>
<td></td>
</tr>
<tr>
<td>B3 - polluted groundwater</td>
<td>208</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The original project has undergone some variations with the aim of taking into account the main socio-economic and legislative evolutions. Up until today, most of the infrastructures have already been completed, but to attain target goals of reuse other efforts should be done.

**REFERENCES**


Enabling Next Generation Resource Recovery


*Jacobs, 13113 Melrose St., Overland Park, KS 66213, USA.
E-mail: julian.sandino@jacobs.com
** Hazen and Sawyer, Raleigh, NC, 27701. USA
*** Associate Professor, Civil & Environmental Engineering, Bucknell University, Lewisburg, PA, 17837, USA

Abstract: This paper reports the findings of a Water Environment & Research Foundation (WE&RF) – funded project (Khunjar, et al., 2017) examining the next generation resource recovery form wastewater. Four product groups were investigated: volatile fatty acids (VFAs), polyhydroxyalkanoates (PHA), alcohols, hydrogen peroxide, and sodium hydroxide. VFAs are used for the production of PHAs, hydrogen peroxide, and sodium hydroxide. Therefore, evaluation of and improvements to VFA production serve as a gateway to recovery of higher value products. The value of hydrogen peroxide and caustic solution make both products appear attractive. This work is important for three reasons: (1) It provides water resource recovery facilities (WRRFs) the full menu of options for carbon management; (2) It continues to shift the perception of wastewater from a liability to a resource; and (3) It identifies technological and/or economic barriers, which are likely to spur future research efforts.

Keywords: Fermentation; volatile fatty acids (VFA); carbon management

BACKGROUND AND RELEVANCE Population growth, rapid urbanization, and linear resource consumption are causing climate change, rising energy demand, and resource depletion. To cope with the practical realities of the 21st century and beyond, a truly circular economy must be established based on the premise that carbon is not a pollutant that must be eliminated but a resource that can be recovered. The water resource recovery facility (WRRF) of the future will have several options for using carbon. The focus of this WE&RF study (Khunjar, et al 2017) is the next generation carbon management with emphasis on nutrient removal and resource recovery.

RESULTS Although historically, WRRFs have implemented biosolids land application, there is a need to consider alternative products and processes to sustainably meet modern society's resource requirements. The main objectives of the WE&RF project are: (1) Develop an inventory of technologies capable of recovering the next generation resources; (2) Identify market potential and financial climate for selected commodity products; and (3) Prioritize commodities based on their current and potential future market value.

Four product groups were identified as the most promising candidates: VFAs, PHAs, alcohols, hydrogen peroxide and sodium hydroxide. For each group, Table 1 provides production considerations and potential uses.
Table 1.1 Overview of Recoverable Product Groups, Production Considerations, and Potential Uses.

<table>
<thead>
<tr>
<th>Product Group</th>
<th>Production Considerations</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>VFAs</td>
<td>End product of fermentation of primary sludge, waste activated sludge, and other high strength wastes such as food wastes</td>
<td>Offset supplemental carbon demand for nutrient removal, Feedstock for higher value commodity production, Feedstock for methane production, Ubiquitous industrial precursor chemicals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHAs</td>
<td>Internal storage product in biomass (e.g. phosphorus accumulating organisms), Produced through cyclical process environments</td>
<td>Precursor to biodegradable plastics with thermomechanical properties similar to traditional polyethylene (PE) derived from petroleum</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alcohols</td>
<td>Product of Gas-to-Liquid (GTL) synthesis, or end product of certain types of fermentation</td>
<td>Offset supplemental carbon demand for nutrient removal, Ubiquitous industrial precursor chemicals</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEC Products</td>
<td>Hydrogen peroxide, Caustic (sodium hydroxide), End product of electrochemical processes</td>
<td>Cleaning and bleaching applications (peroxide), pH control and supplemental alkalinity (caustic)</td>
</tr>
</tbody>
</table>

**VFAs:** Volatile fatty acids can serve as a carbon source for nutrient removal/recovery and product generation processes and are uniquely suited as a gateway product. Municipal wastewater is too dilute for mainstream fermentation. Fermentation of primary sludge will maximize VFA production.

**PHAs:** It is possible to harvest PHA-rich biomass when stored polymer is at its peak. However, such processes are not anticipated to be viable with low-strength municipal wastewaters (van Loosdrecht, 2014). We conclude that the most likely approach for commodity-scale PHA production would involve fermentation of primary sludge to generate VFAs followed by PHA-rich biomass generation.

**Methanol and other alcohols:** The study concluded that the most likely commodity alcohol from municipal wastewater is methanol, via methanogenesis followed by the conventional reforming/F-T process (Havran et al. 2011). The relatively low polysaccharide content of municipal wastewater makes it an unsuitable substrate for butanol production.

**Peroxide and Caustic:** Production of peroxide and/or caustic solutions at concentrations sufficient for in-plant use is possible via microbial electrolytic cells (MECs). In-plant uses such as membrane cleaning and alkalinity could offset the purchase of bulk-chemical. VFAs are a suitable feedstock for MECs.

**Commodity Product Yields**

All yields (Table 2) were calculated based on the following assumptions: 3,785 cubic meter per day (m³/d) of municipal wastewater at 400 mg/L chemical oxygen demand (COD); and methanol yield from biogas of 1 barrel (0.16 m³ or 2 US gal) per 453 m³ (16,000 ft³) of natural gas (Weiss, 2000). Due to its complexity, PHA production is not expected to be economically feasible. The value of hydrogen peroxide and caustic solution make both products appear attractive. While caustic solution has been produced from wastewater at concentrations near 1M, which are suitable for practical application, peroxide, has only been produced at concentrations up to 1%, which would likely be better suited for in-plant use rather than external sale. A WRRF would have to find use
for 6,200 liters per million gallons (per 3.785 m³) treated, if the solution were 3% by weight; an unlikely scenario.

<table>
<thead>
<tr>
<th>Process and Product</th>
<th>Product Yield, per million US gallon (MG)</th>
<th>Potential product value, $USD per MG of treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic digestion of PS/WAS to methane for electricity</td>
<td>730 kWh</td>
<td>$73</td>
</tr>
<tr>
<td>Anaerobic digestion of PS/WAS to methane for steam/heat</td>
<td>8,800 ft³ of natural gas equivalent</td>
<td>$50</td>
</tr>
<tr>
<td>Methane to methanol via steam reformation &amp; F-T</td>
<td>1.1 bbl</td>
<td>$66</td>
</tr>
<tr>
<td>Acidogenesis of PS/WAS to mixed VFA</td>
<td>256 kg VFA as COD</td>
<td>$48</td>
</tr>
<tr>
<td>Conversion to biopolymer (PHA)</td>
<td>14.1 kg PHA</td>
<td>$14</td>
</tr>
<tr>
<td>Electrochemical production of hydrogen peroxide</td>
<td>205 kg H₂O₂</td>
<td>$103</td>
</tr>
<tr>
<td>Electrochemical production of caustic solution</td>
<td>330 kg NaOH</td>
<td>$109</td>
</tr>
</tbody>
</table>

1 barrel = 0.16 m³; 1 million US gallon = 3,785 m³; 1 ft³ = 0.03 m³

Table 1 assumptions are too numerous and will be presented in the manuscript.

REFERENCES


Upgrading of a Wastewater Treatment Plant to Resource Recovery

D. Thornberg*, N. Ahrensberg*, J. Agertved**

*BIOFOS. Refhalevej 250, 1432 København K, Denmark. dt@biofos.dk
**EnviDan. Fuglebækvej 1, 2770 Kastrup DK. jam@envidan.dk

Abstract: The shift from conventional wastewater treatment towards resource recovery facilities has become a priority focus in Denmark. In Copenhagen BIOFOS is heading a project that will introduce a multitude of activities towards a resource recovery facility at Avedøre wwtp (350,000 PE). A lighthouse project called VARGA is paving the way to more energy production, reduction of greenhouse gasses and recovery of phosphorus and concrete material from sewage sludge ashes.

Keywords: Prefiltration, nitrous oxide, phosphorus recovery, fertiliser

BIOFOS is Denmark’s largest waste water utility operating three large wastewater treatment plants for 1,2 mill. people in the Greater Copenhagen Area, Denmark. In the last 5 years it has been a part of BIOFOS strategy to become energy positive and to recover the resources from the wastewater that makes sense. The focus points are

- Production and export of biogas and heat
- Phosphorus recovery
- Reduction of greenhouse gasses

ENERGY BALANCE

BIOFOS has been sending more energy to the grids outside than the consumption for the last 3 years. In table 1, a comparison with the reference year is shown. The energy input is the sum of power, fossil fuels and heat, whereas the output is the sum of biogas, power and heat. The district heat grid in Copenhagen is receiving a large part of the MWh’s. The heat is mainly generated by sludge incineration.

Table 1: Key figures for BIOFOS energy. Ref. year 2005/2007

<table>
<thead>
<tr>
<th>BIOFOS Key figures for energy</th>
<th>Reference year MWh</th>
<th>2017 MWh</th>
<th>Change MWh</th>
<th>Reduction in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy input</td>
<td>75.408</td>
<td>56.576</td>
<td>-18.832</td>
<td>-24</td>
</tr>
<tr>
<td>Energy output</td>
<td>41.661</td>
<td>82.139</td>
<td>+40.478</td>
<td>+97</td>
</tr>
<tr>
<td>Net energy consumption</td>
<td>-33.747</td>
<td>+25.564</td>
<td>+59.311</td>
<td>-</td>
</tr>
<tr>
<td>Energy self-sufficiency in %</td>
<td>55.2</td>
<td>145.2</td>
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</table>

The biogas from the largest WWTP is exported as is to the town-gas grid as it is. The biogas from the second largest plant is upgraded to pure methane and exported to the national natural gas grid. The third plant is utilizing the biogas in a CHP unit to produce power and heat.

THE VARGA PROJECT

The Danish EPA has launched a series of so-called lighthouse projects to promote Danish environmental knowhow and to act as showcases. BIOFOS is the lead in a new lighthouse project called VARGA. This is short for the Danish words for ‘Water Resource Recovery Facility’
Other partners are EnviDan, Unisense, A.R.C, and the Danish Technical University. The scope is to transform the WWTP Avedøre (350,000 p.e.) into a WRRF with the latest technologies. The project period is from 2017 to 2020 with a final demonstration at the next IWA world water conference in Copenhagen 2020.

The six technical focus areas are illustrated in Figure 1.1 (WP1-6) together with the link to circular economy of the city resources.

The six areas are

1. Carbon harvest,

   The maximum controlled amount of organic matter is removed in the primary step to maximize the biogas production, and save aeration energy. A full scale test line of 80,000 PE with prefiltration and following activated sludge is constructed in 2019.

2. Nitrous Oxide mapping and reduction,

   On-line measurements of dissolved N2O has been conducted since 2018, a continuous climate footprint estimation is performed, as contribution to the total CO2 footprint calculation.

3. Value chain of food waste,

   Investigations into the regulation, value chain and market for the application of food waste digestate as fertilizer on organic farmland.

4. Recovery of phosphate and residual sand

   Testing of an Electrodialytic method in pilot scale. Investigating ways to market.

5. Large scale digestion of food waste,

   Changing an existing sludge digester to food waste digestion.

6. Food waste digestion

   Pilot experiments with food waste digestion. Biogas production and fertilizer that will be evaluated in agriculture field tests (cf. 3).

The positive effects of changing a WWTP into a WRRF with the above-mentioned steps will be evaluated in a LCA and eco-efficiency analysis. The midway results from the projects will be presented in Venice.

REFERENCES

Homepage: https://projekt-varga.dk/en/front/

Using Monte Carlo Based Simulation Optimization for the Design and Optimization of Wastewater Resource Recovery Facilities

R. Al, C.R. Behera, G. Sin*,

*Process and Systems Engineering Center (PROSYS), Dept. of Chemical and Biochemical Engineering, Technical University of Denmark, Kgs. Lyngby, 2800 Denmark, Email: gsi@kt.dtu.dk

Abstract: Available treatment and separation technologies for wastewater are steadily expanding as the industry is undergoing a major paradigm shift toward a strengthened interest in resource recovery in the forms of both scarce materials and energy with tighter environmental regulations gradually put in place for allowable effluent discharge limits. Therefore, the problem of how to synthesize a wastewater resource recovery facility (WRRF) for a given influent has become more challenging than ever. With the purpose of addressing this problem with more systematic approaches borrowed from process systems engineering discipline, we proposed a novel Monte Carlo simulation-based superstructure optimization framework, which guides decision-makers to systematically synthesize and design plant layouts for WRRFs given influent pollutant loadings and desired design objectives. Provided by its in-house developed simulation-based optimization solver coupled with Monte Carlo simulations, the framework also enables engineers to optimize the design and operational decisions under uncertainty considerations using arbitrarily complex non-linear mechanistic process models. Finally, the framework also provides parallelization workflows to speed-up the required computational times and insightful data visualizations to assist decision-makers.

Keywords: Simulation optimization; design under uncertainty; Monte Carlo simulation

INTRODUCTION As the recovery of materials and energy from wastewater streams is gaining traction in many countries, new ways of handling such streams are paying the way for innovative technologies. Therefore, the design of next-generation wastewater resource recovery facilities requires systematic approaches to exploring design and operational trade-offs in order to meet more and more stringent legislation regarding allowable effluent quality limits. To that end, multiple frameworks are proposed to assist decision-makers to incorporate various alternative treatment technologies into the early-stage design decision-making process (Bozkurt et al., 2014; Castillo et al., 2016). In order to find the optimal design for a given influent, these frameworks traditionally resorted to mathematical programming, which required to have an algebraic formulation of an optimization objective as a function of decision variables. However, the returned solutions are sensitive to input data and simulation of bioprocesses are refined to linear expressions. In order to address these shortcomings of this approach, we propose a Monte Carlo simulation-based superstructure optimization framework, which makes use of advanced machine learning algorithms as part of its solution algorithms along with well-established first principle mechanistic models used in wastewater. The remainder of this paper
describes the methodological contributions and presents results followed by a discussion.

**METHODOLOGY** A framework consisting of 3 phases is proposed to address the process design challenges, and depicted in Figure 1.1. First, a superstructure of available treatment technologies is postulated and in a unified modelling platform and alternative plant configurations are generated using expert knowledge and combinatorial synthesis. Secondly, Monte Carlo simulations are performed to explore the design spaces of each different layout. Technical performance constraints are introduced to identify feasibility regions and plant performance indicators (KPI) are calculated to identify promising layouts, which holds most feasible designs. More details of this framework steps can also be found in (Al et al., 2019). Global sensitivity analysis of select design objectives to design and operational parameters is also performed using surrogate models, such polynomial chaos expansion, in order to find key decision variables that are influential with respect to the chosen plant KPI, before proceeding with optimization.

![Figure 1.1](image)

**Figure 1.1** The proposed framework to process synthesis and design of WRRFs divides the problem into 3 distinct phases; process synthesis, process design, and optimization under uncertainty.

At the third phase of the framework, a rigorous optimization allowing for detailed formulation of optimization objective/constraints by making use of state-of-the-art simulation technologies is proposed. As the uncertainty is playing a key role in decision making of wastewater networks, a simulation optimization solver, which can systematically integrate various sources of uncertainty during the optimization of design spaces of promising layouts, has been developed. The solver allows for definition of input uncertainty such as influent concentration, and propagates these to the plant KPIs using Monte Carlo simulations. These results are analysed and used to fit stochastic Kriging type surrogate models for the mean and variance of the objective and the constraints. An infill criterion utilizing these models to maximize expected improvement of the objective under multiple stochastic constraints is defined and optimized to find better design points in the design space. The returned near-optimal solutions are validated with simulations and the corresponding design spaces are returned.

**RESULTS AND DISCUSSION** A superstructure consisting of three primary, two mainline, and one sludge treatment technologies is postulated as shown in Figure 1.2 (A). This resulted in six different plant configurations, all of which are explored for their design and operational parameters using Monte Carlo based design space
exploration. Optimization objective is set to minimizing operational cost index (OCI), more details of which can be found in (Gernaey et al., 2014). Figure 1.2 (B) shows the sensitivity of OCI to different design and operational parameters for each different configuration. Finally, optimization of OCI is performed with respect to the most influential design parameters under the uncertainty defined in influent fractionation parameters, as studied in (Sin et al., 2009). Figure 1.2 (C) shows the convergence to near-optimal design space in optimization of BSM2 layout. Results obtained shows that the framework can effectively work with complex simulation models to do optimization, while providing hedge against the existing uncertainty. Future work will focus on extending the superstructure to include more process models.

**Figure 1.2** The superstructure considered in this study is shown in (A). The results of global sensitivity analysis using polynomial chaos expansion is shown in (B). The progress of the optimization solver for minimizing the OCI of BSM2 layout under stochastic effluent quality constraints is shown in (C).

**REFERENCES**


Hydrothermal Carbonization as a Suitable Process for Resource Recovery and Enhancement of Biogas Production from Sewage Sludge

G. Mannarino*, M. Puccini, A. Salimbeni, M. Aiello, S. Caffaz, R. Gori**

*Department of Civil and Environmental Engineering, University of Florence, via di S. Marta, 3, 50139 Florence, Italy (E-mail: gemma.mannarino@unifi.it)

** Department of Civil and Environmental Engineering, University of Florence, via di S. Marta, 3, 50139 Florence, Italy (E-mail: riccardo.gori@unifi.it)

Abstract: Hydrothermal carbonization is a relatively new alternative for sewage sludge management. The aim of this work was to study the integration of HTC and wastewater treatment plants. The San Colombano plant (Florence, Italy) was selected as case study. Anaerobic digestion is here proposed to recovery of energy from the liquid fraction, obtained as a by-product of sewage treatment using HTC. For this objective, the process water from carbonization tests carried out on San Colombano plant’s secondary sludge was firstly chemically characterized. Then, the San Colombano plant was modelled, considering the process water as a new input in AD. The model resulted in an enhancement of biogas production, indicating anaerobic digestion as a suitable process to increase the sustainability of HTC process for sewage sludge treatment.

Keywords: Energy recovery; hydrothermal carbonization; sewage sludge

In EU sewage sludge (SS), generated as a by-product of wastewater treatment plants (WWTPs), is expected to exceed 13 Mtons/y on dry basis in 2020 (Kelessidis and Stasinakis, 2012). For different reasons (such as environmental concerns, social acceptability, costs, and legal constraints), each major route for sludge handling (agriculture, composting, incineration) is becoming complex to deal with. Thus, it is increasingly important to give SS its value in the circular economy, developing sustainable processes to recover valuable products embedded in SS.

Among suitable technologies for SS treatment, hydrothermal carbonization (HTC) is gaining attention as it is an effective process for converting wet biomass at mild temperatures (up to 220°C), under autogenous pressure (up to 20 bar), within a short time (in the order of 3-10 h) in a slurry containing: a solid coal-like material (named hydrochar), a liquid phase (process water) and a small gaseous fraction (mainly CO₂) (Libra et al., 2011).

Hydrochar, whose market value is in the range 60-80 €/ton, is a carbonaceous matrix that may find valorisation as combustible, soil ameliorant and fertilizer, adsorbent material (Libra et al., 2011), and source of phosphorous (Huang and Tang, 2015). Process water is very rich in nutrients (nitrogen, potassium, calcium) and organic matter and may be reused for agriculture. Before that process water could be treated with anaerobic digestion (AD) for energy recovery (Wirth et al., 2015) thus increasing the sustainability of the process without reducing nutrients content.
This study was developed within the project SLUDGE4.0 which has the goal to integrate the SS HTC treatment in the Tuscany water service framework. The project aims to analyse optimal integration of WWTPs and HTC. In this study the San Colombano plant (managed by Pubblicacqua SpA, Florence, IT) was selected as case study. The worst-case scenario of liquid supernatant recirculation in the wastewater treatment line (instead, while its reuse in agriculture) is analysed.

San Colombano WWTP is a conventional MLE activated sludge process treating urban wastewaters. HTC tests were conducted on secondary sludge before AD (solid concentration (TS) equal to 5 wt%) with a maximum temperature of 208 °C and a reaction time of 2 hours. The slurry was separated by centrifugation, and the process water was characterized in terms of: COD (total and soluble), nitrogen (total and ammonium), and phosphorous (total and orto-phosphate). The COD resulted remarkably high (18 g L\(^{-1}\)) and in a good balance with TN. The biodegradable COD (bCOD) of process water was determined using Oxitop\(^\text{®}\) Control system, and BOD tests resulted in a high percentage of bCOD (83.9 %).

The integration of San Colombano WWTP and HTC was investigated using a modelling approach. The WWTP was simulated with an ASM No. 3 model using the software WEST (DHI). The model was first calibrated and validated using a 1-year real data. Later, the present configuration of WWTP and a modified one with HTC process in the sludge treatment line were simulated and compared with different values of sludge retention time (SRT) in the range 9-28 d, considering the analysed process water as a new input in AD. The introduction of HTC in the sludge treatment line is responsible for an increase of aeration energy between 5% and 28% (the higher is the SRT the lower is the increase) mostly due to the recycling of ammonia nitrogen. At the same time biogas production with HTC is reduced at high value of SRTs (-14% at 28d) but doubled at the lower value of SRT (9 d) (Table 1.1).

Thus, this study indicated that HTC, which is a promising technology to manage SS, while recovering organic matter and nutrients, can be also a suitable process to enhance biogas production in WWTPs via DA thus increasing energy recovery embedded in SS.

![Table 1.1 Results of simulations of integration between San Colombano WWTP and HTC process.](image)

**REFERENCES**


Micro-sieving of Municipal Wastewater Improves Effluent Quality, Energy Balance and Clarification Capacity of WWTPs

N. Derlon*, K. Lüdin*, M. Behl**, B. Maissen***, T. Kraft****, S. Bützer****, A. Fumasoli****

* Eawag, überlandstrasse 133, 8600 Dübendorf, Switzerland. ** Picatech Huber AG, Winkelstrasse 12, 6048 Horw. *** Sihtal WWTP, Bruchstrasse 250, 8041 Zürich. **** Hunziker-Betatech AG, Bellariastrasse 7, 8002 Zürich. Nicolas.Derlon@eawag.ch, Ken.Ludin@eawag.ch, Markus.Behl@picatech.ch Info@arasihltal.ch Tobias.Kraft@hunziker-betatech.ch Simone.Buetzer@hunziker-betatech.ch, Alexandra.Fumasoli@hunziker-betatech.ch

Abstract: We evaluated the recovery of organic carbon from municipal WW using a drum screen, and its conversion into energy. The performances of the drum screen, the quality of the treated WW and the net energy balance were evaluated for two parallel treatment lines on a full-scale WWTP: without primary settler (control line) and with drum screen (experimental line). Solids removal of 67 ± 18% and 88 ± 7% were achieved with the drum screen alone or combined with flocculant, respectively. Energy consumption could be reduced by 13% while energy production could be increased by 70% with a drum screen alone. Also, the use of flocculant would help reducing the energy consumption by 25% while increasing the energy production by 125%. Effluent quality in terms of organic compound was improved, but deteriorated in terms of nitrates/ortho-phosphates, thus requiring adaptation of the operating conditions (recirculation rate). Clarification capacity was augmented due to the reduced biomass concentration and despite deterioration of the sludge settling properties. Overall, our study provides relevant insights about the full-scale implementation of drum screen for carbon recovery/conversion, and its implications on the whole treatment line.

Keywords: drum screen; organic carbon capture, net energy balance, biogas

INTRODUCTION Municipal wastewaters (WW) are usually treated using aerobic biological processes, which produces CO2 (a useless end-product) and excess biomass. Excess biomass production is normally reduced via anaerobic digestion but the disposal of residual solids remains a major issue. The overall balance of such systems in terms of energy production/recovery of valuable products is ultimately quite negative. One relevant approach towards the development of more sustainable WWTPs consists in capturing the organic carbon contained in the WW for further conversion into methane. Micro-sieves such as drum screens help capturing significant amounts of the organic carbon. But our practical experience of WW micro-sieving and of its influence on the overall plant performances remains limited. The current study thus focused on evaluating the performances of a full-scale WWTP with/without WW micro-sieving. The influence of WW micro-sieving on (1) the quality of the treated WW, (2) the net energy balance (aeration savings and methane production) and on (3) the sludge settleability was evaluated. Tests were also performed with combined flocculation/drum-screen. The composition and biogas production potential of the sieved materials were also analysed.
MATERIAL AND METHODS A drum screen (LIQUID, Huber, Germany) with a 200 µm mesh-size was installed between June 2018 and February 2019 at the WWTP of Sihltal (Zürich, Switzerland). The plant consists of 3 separated parallel lines (33’000 EH) and is designed for BOD and nitrogen removal (nitrification/denitrification). Sihltal WWTP is not equipped with primary clarification and loading will increase of 30% by 2040. Anaerobic digestion is applied to convert excess sludge into methane for further energy generation. Performances of the drum screen was evaluated over long-term, with or w/o chemical pre-treatment. The effluent quality, sludge properties and energy balance of the different lines (with or w/o micro-sieving) were monitored. Characterisation of the sieved materials and anaerobic digestion tests were also performed to confirm the methane production potential.

RESULTS The drum screen alone helped removing more than 67 ± 18 % of the solids (measured as TSS), 38 ± 7 % of the COD and 18 ± 6 % of the total phosphorus while almost no nitrogen removal was observed (8 ± 6%). An increasing influent TSS concentration resulted in the formation of a denser cake at the mesh surface, which in turn increased the solids retention: an increasing TSS concentration from 200 to 1000 mgTSS/L help increasing the TSS removal efficiency from 30 to almost 80%. When combined with flocculant, 88 ± 7 % solids capture, 68 ± 11 % COD capture, 50 ± 10% phosphorus removal and 19 ± 12 % nitrogen removal were achieved. In terms of effluent quality, application of the drum screen helped reducing the COD effluent concentration due to the reduced organic load. However, increased nitrates and ortho-phosphates concentrations were measured in the treated WW due to the reduced biomass production (i.e., increased N-load to nitrify and then denitrify). Operating conditions (recirculation rates, chemical precipitation of phosphorus) must thus be adapted to maintain high TN and TP removal when capturing organic substrate.

The sludge concentration in the aerobic tank decreased proportionally to the reduction of the organic load, from around 3 to 2 gTSS/L. No variation of the sludge volume index (SVI) was observed between the line with/without micro-sieve. Overall, the clarification capacities of the secondary settler could be significantly increased, thanks to the reduced sludge concentration and constant SVI.

![Figure 1.1 Energy production/consumption of the WWTP for the cases: (1) no drum-screen, (2) drum-screen alone and (3) drum-screen+flocculant.](image)

Aeration could be reduced by -20% with the sieve alone, and by -37% when combining the sieve with flocculant. Simultaneously, the energy production could be increased by +70% and by +125% with the sieve alone or with sieve+flocculant, respectively. Overall, the net energy balance could be reduced by -33% and -39% for those two scenarios.

CONCLUSIONS Micro-sieving of municipal wastewater represents a relevant alternative to primary clarification. WW micro-sieving helps increases the energetic performances and the treatment/clarification capacities of WWTPs. High effluent quality could be achieved but however requires adapting the operating conditions (e.g., internal recirculation to maintain high denitrification rates).
Wednesday, 11th September 2019

Session 13

SMART PLANT SESSION
Recovery and Valorisation of Cellulose from Waste Water – The Road to Circularity

P. Marcelis, C. Wessels

CirTec B.V., Nijverheidsweg 26, 1442 LD Purmerend, The Netherlands

Abstract: Cellulose is one of the materials that can be recovered from sewage water, next to for example Phosphate and Ammonium. Cellulose is recovered by physical separation of cellulosic screenings from the influent of treatment plants with rotating belt filters (RBF). The cellulose is recovered more efficiently with a RBF than with primary clarifiers. Compared to the sludge from a primary clarifier, the cellulose content of the cellulosic screenings from a RBF contains twice the concentration of cellulose. The removal of cellulose from the influent does not only produce a material that can be used in biocomposites and construction, but also reduces the sludge production and energy consumption of a treatment plant.

Keywords: Three keywords separated by; semi-colons

INTRODUCTION The shift from sewage treatment plant or wastewater treatment works, to water reclamation plant, water factory or energy and resource factory, has changed the way water authorities and companies view sewage water treatment and how the processes for treatment are designed. Technologies which can recover materials, for example cellulose, from wastewater are preferred over the old technologies, as they are not designed for resource recovery. In the Netherlands, the target set by the Raw materials and energy factory is to recover 25% of all the cellulose from the Dutch sewage water in 10 years (Pinkse, et al., 2018). During the past years, a lot of research has been done in the use of RBF as primary treatment, the influence of RBF on the downstream process and the valorisation of the RBF cellulosic screenings (Ahmed, et al., 2018), (Giaccherini, et al., 2018), (Roest, et al., 2018), (Reijken, 2014), (Ruiken, Klaversma, Breuer, & Neef, 2010).

An important question is how the recovered cellulose can be applied as a biobased resource. The application of recovered cellulose, with or without additional treatment, has been researched for various applications (de Vegt & Winters, 2012), (Winters, Pijlman, Maathuis, & Dinkla, 2013), (Pijlman, et al., 2017). These processes include the application in asphalt (Pijlman, et al., 2017), the possibility to convert the cellulose to PLA, anaerobic digestion of the cellulosic screenings to produce biomethane (Ghasimi, 2016) and the application of dried recovered cellulose in biocomposites. A market analysis has shown that there is large interest from the market for cellulose that is recovered from sewage and that can be used as a sustainable product.

METHODOLOGY Most of the research regarding the impact on downstream processes in the Netherlands has been performed at three treatment plants: STP Beemster, STP Aarle-Rixtel and STP Blaricum. At these STP’s one or multiple RBF
have been placed for the treatment of the influent. The treatment capacity of the STP range from 97 l/s (350 m³/h) to 695 l/s (2,500 m³/h) dry weather flow and range from 144 l/s (518 m³/h) to 1,008 l/s (3,680 m³/h) at full flow. On these sites the influent is filtered with a CellCap RBF, after which the influent flows through to the aeration basin (in two cases a Carrousel type aeration tank and in the other case a m-UCT type aeration tank).

During the research at STP Aarle-Rixtel, which consists of two identical m-UCT treatment trains, one train received CellCap RBF pre-treated water for over a year, while the other train received the untreated influent. The differences between the trains were monitored during the research. Research at STP Beemster showed that the average treatment capacity increased with approximately 20% after installation of the CellCap RBF. In other research, the application of the recovered material is taken into account. This research, that aims to provide a standard material specification for specific applications and the need for additional pre- or post-treatment, is still ongoing.

At all locations the efficiency for TSS was measured and the cellulose content of the product was measured. The TSS was measured according to a couple of different methods. This makes a direct comparison difficult, however, the results are comparable.

Research on the extraction of pure cellulose from cellulosic screenings as a marketable product (ReCell®) is part of the Horizon2020 project SMART-Plant. The operational aspects and impact of return flow from the Cellvation process (the process to extract cellulose) are determined at the demonstration installation at the STP Geestmerambacht. At STP Beemster, an inventory is made of the reduction in CO₂ emissions, in case cellulosic screenings are digested and in the case that cellulose is used as a raw material. The CO₂ reduction is related to a reference STP with a carousel-type active sludge system without pre-sedimentation having a size of 100,000 PE.

**RESULTS AND DISCUSSION**

The research at STP’s Aarle-Rixtel and Beemster show a TSS efficiency of 20-30% (when measured with 1.2μm filters) or a TSS efficiency of 36-60% (when measured with 12-25μm filters). The filters have a higher efficiency (>50%) when there is more TSS in the influent (>300 mg/l) (Reijken, 2014). With a CellCap RBF, cellulose is removed very efficiently. The cellulose removal efficiency was 80%, even in cases where the TSS removal efficiency was only 25% (1.2μm filter) (Ahmed, et al., 2018).

The removal of TSS reduces the energy consumption in the aeration tank with 10-15%, because the bacteria have to convert less COD to CO₂ and water. The amount of sludge produced is also 10-15% lower than compared to untreated influent.

The biological removal of nitrogen and phosphate are unaffected in both STP Beemster and STP Aarle- Rixtel. The recovered cellulosic screenings, without any further treatment/upgrading to Recell®, consists for 67% of fibres (Roest, et al., 2018). Of the 67%, 55% is cellulose, 5% is lignin and 7% is hemicellulose.

For the application of recovered cellulose in asphalt or concrete, it is required that the material is dry (>90% DM) and has loose fibres. For the use of the material in digestion only dewatering is needed. When the cellulosic screenings are digested, the biogas potential (600 Nm³/tdm) is higher than the biogas potential of secondary sludge (300 Nm³/tdm), measured over a period of 30 days.

The CO₂ reductions are based on the following scenarios in a WWTP for 100,000 PE:
- A: Production of Glucose from the cellulosic sludge with digestion of the residual product. The digestate will be dewatered and incinerated

- B: Directly digesting the cellulosic sludge, followed by dewatering and incineration of the digestate.

These two scenarios are compared to a WWTP without a RBF for cellulose recovery. In the reference scenario the sludge from the WWTP is dried and incinerated afterwards. Due to a lot of uncertainties in the process of converting the cellulosic screenings to glucose, the A route was estimated at an average reduction of 100 ton CO2-eq per year. The uncertainties in this route result in a variation between an increase of 320 ton CO2-eq per year to a reduction of 500 ton CO2-eq. The B route is a well known process, with less uncertainties. This route leads to a reduction of 730 ton CO2-eq per year. For both routes the reduction of CO2-eq in the WWTP where the RBF are installed (without the post treatment for the cellulosic screenings, but including the drying and incineration of the sludge) is 360 ton CO2-eq per year. (Odegard & Broeren, 2018)

CONCLUSION

There are a lot of potential markets for cellulose recovered from waste water, ranging from co-digestion for additional biogas production to the application in building materials such as asphalt, biocomposites and concrete. In these markets the recovered cellulose has a positive value and is considered a valuable product. The versatility in applications enables the water authority or owner of a STP to choose different processing routes. Since valorisation of resources is not the core task of a water authority, this can be outsourced to an external specialised party. The use of CellCap RBF as primary treatment, in addition to the benefits of the cellulose production, reduces the power consumption in the aeration tank by 10-15% and reduces the secondary sludge production by 10-15%. In case cellulosic screenings are separated with an RBF and the cellulose is applied as resource, the total climate impact on the Water Reclamation Plant is 360 tonnes CO2-eq/year, this is excluding the post treatment of the cellulosic screenings.

REFERENCES


vapacity increases by 10% with fine-screen technology. Clean Enviro Summit Singapore 2018. Singapore.


Exploring the Integration of EBPR at Low SRT and DO in an A-stage System for COD and P Removal

C. Scalia*, C.C. Zhang*, G. Mannina**, A. Guisasola*, J.A. Baeza*

*GENOCOV, Departament d’Enginyeria Química Biológica i Ambiental, Escola d’Enginyeria, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, 08193 Barcelona, Spain (claudio-scalia@live.it, albert.guisasola@uab.cat, juanantonio.baeza@uab.cat).
**Department of Engineering, Palermo University, Viale delle Scienze, ed. 8, 90128 Palermo, ITALY (giorgio.mannina@unipa.it).

Abstract: A novel high-rate A-stage WWTP configuration is proposed combining enhanced biological phosphorus removal (EBPR) and short SRT operation for the treatment of urban wastewater. The objective of an A-stage is removing as much COD as possible to redirect it to biogas production, while N is removed by a posterior B-stage with autotrophic processes. Considering our experience studying EBPR at low SRT, this work explores the possibility to integrate EBPR in an A-stage with an anaerobic/aerobic continuous configuration. Main key operational points for the success of this configuration are working at enough SRT and DO to maintain PAO activity while avoiding nitrification. Long-term operation data indicate that the operation is possible although the appearance of sporadic nitrification can compromise the stability of the system due to some nitrate leakage to the anaerobic reactor.

Keywords: A-stage, DO, EBPR.

The two-stage A/B-WWTP is a configuration proposed for biological N and organic matter removal with low energy-demand or even with a net energy generation. Resource recovery in the two-stage A/B-WWTP has been focused until now on COD removal in the A-stage and autotrophic N removal in the B-stage. The A-stage is applied as an alternative process for carbon redirection that allows less COD oxidation in the biological reactors as in the high-rate activated sludge (HRAS) system proposed by Jimenez et al. (2015). However, no biological P removal has been reported in the literature for the A-stage. On the other hand, previous works have proved the feasibility of operating enhanced biological phosphorus removal (EBPR) at solid retention time (SRT) below 5 days (Chan et al., 2017; Ge et al., 2013). An anaerobic/aerobic continuous configuration is here proposed to include EBPR in the A-stage operating at low SRT. The final aim is to obtain a more efficient WWTP in terms of effluent quality, resource recovery and energy consumption in a more environmental sustainable perspective.

In order to verify the feasibility of the proposal, a pilot WWTP consisting on anaerobic and aerobic total mixed reactors in series (A/O configuration) and a settler was thoroughly monitored for 4 months under different operational conditions. At 3 days SRT, average dissolved oxygen (DO) of 0.7 mgO₂/l and T = 22°C, good polyphosphate accumulating organisms (PAO) activity was observed with satisfactory COD (Figure 1) and P removal (Figure 2) and low ammonium oxidation. Nevertheless, EBPR results were unsteady and sensible to environmental conditions
changes (temperature, wastewater quality, DO). Operation at very low DO (average of 0.4 mgO₂/l) to limit nitrification led to bad biomass flocculation and biomass washout, avoiding also PAO activity. In the last phase of the experimental period, the system was bio-augmented with sludge from an A²/O pilot plant with PAO and nitrifiers, to understand in which SRT and DO condition nitrification was avoided. Unexpectedly, despite SRT was gradually reduced from 4.5 to 3.5 days, and DO from 3.0 to 0.7 mgO₂/L, nitrification limitation was not observed, resulting in a deterioration of EBPR due to the lack of an anaerobic phase. Throughout the experimental period, high COD removal was reached (89.3±5.6%) with most of the organic carbon depleted in the anaerobic phase (more than 60% of total COD removed) ensuring an oxygen saving.

The observations suggest that the co-presence of nitrifying biomass with PAO in the sludge culture at very low SRT in A/O treatment system is the main barrier towards maintaining an optimal EBPR. However, the results of the first experimental period suggest that the integration of EBPR in the A-stage is feasible. Therefore, further research is currently being conducted to find the optimal conditions to reach a satisfactory EBPR with very low nitrifying activity.

![Figure 1.1](image1.png)

**Figure 1.1** Evolution of COD (mgO₂/L) in the feed wastewater (●), anaerobic reactor (○) and aerobic reactor (▼).

![Figure 1.2](image2.png)

**Figure 1.2** Percentage of phosphorus removal

**REFERENCES**


Nitrogen Removal via Nitrite from Thermally Hydrolysed and Digested Reject Water

E. Statiris*, C. Noutsopoulos, D. Mamais, N. Petalas, S. Malamis

*School of Civil Engineering, National Technical University of Athens
5 Iroon Polytechniou St, Zografou Campus, 15780, Athens Greece

Abstract: A pilot-scale SBR was applied in order to treat reject water produced after dewatering of hydrolyzed and digested sludge. The system operated by implementing the nitritation/denitritation process achieving 88.6±6.2% and 71.0±19% NH₄-N and TN removal respectively during the period with the higher nitrogen loading rate. During the examined period the SBR biomass was used in ex-situ tests in order to investigate the FNA inhibition on ammonia oxidation rates. These tests unveiled 50% inhibition at pH 7, 7.5 and 8 for FNA concentrations equal to 0.05, 0.04 and 0.035 mg HNO₂ L⁻¹ respectively. Similar experiments in a non-acclimated in FNA biomass showed that significantly lower concentrations of FNA (0.04, 0.017, 0.010 mg HNO₂ L⁻¹) can decrease the ammonia oxidation rates for 50%.

Keywords: Reject water; nitritation; FNA

INTRODUCTION

The nitritation/denitrification process seems to fit for the treatment of sludge reject water and other wastewater effluents as it offers 25% less oxygen demand and a significant reduction of external carbon source requirements during denitrification (Ge et al., 2015). During the nitritation process, the accumulation of nitrite can lead to significant concentrations of free nitrous acid (FNA) which can cause severe inhibition in nitrification processes (Anthonisen et al., 1976). This work aims to investigate the efficiency of a pilot-scale SBR unit applied to treat sludge reject water via the nitritation/denitrification process. The effect of FNA concentration on ammonia oxidation rates (AUR) was also investigated. Moreover, the inhibition caused by FNA on the SBR biomass was compared with the corresponding inhibition on a typical biomass taken from Psyttalia WWTP.

MATERIAL AND METHODS

A 9 m³ pilot-scale SBR was operated for the treatment of reject water produced after dewatering of thermally hydrolyzed and digested sludge by using the short-cut nitrification/denitrification process (SCND). The SBR system operated for about 180 d before the three examined periods which lasted about 310 days, implementing stable short-cut nitrification/denitrification.

The batch assays were conducted to the SBR biomass in order to examine the inhibition of FNA on ammonia oxidation rates of an acclimated (in significant FNA concentrations) biomass. The AUR tests were also conducted to a typical nitrifying (non-acclimated to FNA) biomass of the Psyttalia WWTP.

RESULTS AND CONCLUSIONS

The SBR operated for approximately 310 days under stable conditions treating the reject water of a WWTP which was produced after the dewatering of thermally hydrolyzed and digested sludge. Table 1 presents an
overview of the SBR performance during a period of stable nitritation process with the NOB bacteria suppressed. Nitrates were only occasionally observed and at very low concentrations.

Table 1.1 Pilot plant operating conditions, kinetics and effluent values

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1st period (183-258 d)</th>
<th>2nd period (258-400 d)</th>
<th>3rd period (400-491 d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLVSS (mg L(^{-1}))</td>
<td>5287±1038</td>
<td>5689±509</td>
<td>3890±1280</td>
</tr>
<tr>
<td>NLR_TKN (kg N m(^{-3}) d(^{-1}))</td>
<td>0.36±0.09</td>
<td>0.51±0.08</td>
<td>0.32±0.13</td>
</tr>
<tr>
<td>NH(<em>4)-N(</em>{effluent}) (mg L(^{-1}))</td>
<td>97.5±43.3</td>
<td>150±74</td>
<td>31±25</td>
</tr>
<tr>
<td>NO(<em>2)-N(</em>{effluent}) (mg L(^{-1}))</td>
<td>211±201</td>
<td>280±132</td>
<td>55±25</td>
</tr>
<tr>
<td>AUR (mgNO(_2)-N/g VSS h(^{-1}))</td>
<td>4.2±0.6</td>
<td>7.6±0.7</td>
<td>7.5±2.2</td>
</tr>
<tr>
<td>NUR (mgNO(_2)-N/g VSS h(^{-1}))</td>
<td>9.4±5.5</td>
<td>8.3±0.4</td>
<td>11.7±1.9</td>
</tr>
<tr>
<td>TN removal (%)</td>
<td>73.4±11.2</td>
<td>71±19</td>
<td>92.2±10.8</td>
</tr>
<tr>
<td>NH(_4)-N removal (%)</td>
<td>91.3±4.3</td>
<td>88.6±6.2</td>
<td>98±1.9</td>
</tr>
</tbody>
</table>

The higher NLR in terms of TKN was equal to 0.51±0.08 kgNm\(^{-3}\)d\(^{-1}\) during the 2nd period while the SBR achieved 88.6±6.2% NH\(_4\)-N removal via nitrite and 71.0±19% TN removal respectively. As shown in Figure 1.1, the FNA inhibition on AUR was investigated for 3 different pH values.

![Figure 1.1](image)

Figure 1.1 Investigation of FNA inhibition on ammonia oxidation rates of an acclimated biomass

Using increasing concentrations of FNA the higher inhibition was calculated at pH=8 (75.8% for 0.08 mg L\(^{-1}\) FNA) while at the same FNA concentration and pH 7 the inhibition was 55%. This reveals that nitrite is also an inhibitory factor for ammonia oxidation. For the SBR biomass, the 50% of the AUR inhibition emerged at concentrations of FNA equal to 0.05, 0.04 and 0.035 mg HNO\(_2\) L\(^{-1}\) for pH of 7, 7.5 and 8 respectively. The 50% inhibition of the ammonia oxidation rates on the non-acclimated biomass were measured at lower FNA concentrations, equal to 0.04, 0.017 and 0.010 mg HNO\(_2\) L\(^{-1}\) respectively at the same pH. As expected, the acclimated biomass showed a better tolerance against FNA compared to the non-acclimated biomass.

ACKNOWLEDGMENTS This work was carried out thanks to the funding from the European Union’s Horizon 2020 research and innovation programme under the SMART-Plant Innovation Action (www.smart-plant.eu grant agreement No 690323).

REFERENCES


Modelling of a Novel Side-Stream Technology Combining Short-Cut Nitrogen Removal and Bioplastic Recovery


* UCIBIO-REQUIMTE, Department of Chemistry, Faculty of Sciences and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal, jmds.ribeiro@campus.fct.unl.pt
**Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy, vincenzo.conca@univr.it
1Instituto de Biologia Experimental e Tecnologia, 2780-157 Oeiras, Portugal,
2School of Chemical Engineering, University of Queensland, Brisbane, QLD, 4072, Australia

Abstract: This work focusses on extending the ASM3 model towards the description of short-cut nitrogen removal and simultaneous polyhydroxyalkanoate (PHA) recovery and the subsequent model application to describe this process currently operated at the pilot-scale in Carbonera, Italy. Results indicated that the calibrated and validated model could describe well the nitritation process, coupled with the aerobic feast/anoxic famine process for the selection of PHA producing organisms. The model will also be applied to test alternative operational strategies designed to maximise PHA recovery.

Keywords: Extended ASM3 model; Nitrite pathway; Short-Cut nitrogen removal and PHA Recovery technology

INTRODUCTION

A novel side-stream technology combining short-cut nitrogen removal coupled with the selection and accumulation of PHA producing biomass is being operated at pilot-scale in the wastewater treatment plant (WWTP) of Carbonera, Italy. It consists of an aerobic nitritation sequential batch reactor (SBR) coupled with an aerobic feast/anoxic famine SBR for PHA-biomass selection and denitritation. This PHA-producing biomass will then be used in a subsequent accumulation stage for achieving PHA recovery as bioplastics. Readers are referred to Basset et al., 2016 for more details about the technology.

Mathematical models are useful tools for the optimisation and design of novel wastewater treatment technologies and their integration for resource recovery. The most used models in practice are the activated sludge models (ASM). This work aims to calibrate and validate an extended version of the ASM3 model by applying the model to the operation of this novel technology. It also intends to use the model to predict and optimise the recovery of PHA.

MODEL DESCRIPTION

An extended version of the ASM3 model (Kaelin et al., 2009) was implemented in AQUASIM (Riechert, 1994). This model describes the simultaneous removal of COD and N, as well as the production of PHAs. The following modifications were incorporated in the model: two-step nitrification/denitrification was implemented, where the state variable S\textsubscript{NOx} is separated into S\textsubscript{NO2} and S\textsubscript{NO3} and the state variable X\textsubscript{AUT} is separated into X\textsubscript{AOB} and X\textsubscript{NOB}.

MODEL CALIBRATION AND VALIDATION

The influents of the nitritation SBR and PHA-biomass selection SBR were characterized through a week-long sampling campaign. The calibration of the extended ASM3 model was performed by
adjusting the kinetic parameters of heterotrophic and autotrophic organisms through simulating the experimental results obtained from each process. The model for the nitritation SBR was validated through simulating the recorded measurements from the effluent. The validation of the model in the PHA-biomass selection SBR and PHA accumulation stage is ongoing.

**TAKE-HOME MESSAGES** The model was successfully calibrated by adjusting only 3 parameters in the nitritation SBR and 8 parameters in the PHA-biomass selection SBR (see Table 1.1 and Figure 1.1). Figure 1.2 shows that the calibrated model was able to describe the long-term operation of the nitritation SBR without any further adjustment of model parameters. This study shows that the extended ASM3 model is a useful tool for the design, optimisation and prediction of PHA production under feast/famine conditions, as well as oxidation of NH$_4$ in NO$_2$.

**Table 1.1** Calibrated parameters for PHA-biomass selection SBR and the nitritation SBR.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
<th>Default values from ASM3+BioP</th>
<th>Calibrated for PHA-biomass selection SBR</th>
<th>Calibrated for nitritation SBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_{AOB}$</td>
<td>Decay rate for AOBs</td>
<td>0.15</td>
<td>-</td>
<td>0.25</td>
</tr>
<tr>
<td>$\mu_{AOB}$</td>
<td>Growth rate for AOBs</td>
<td>0.80</td>
<td>-</td>
<td>0.50</td>
</tr>
<tr>
<td>$Y_{AOB}$</td>
<td>Yield coeff. for growth</td>
<td>0.18</td>
<td>-</td>
<td>0.24</td>
</tr>
<tr>
<td>$b_{O_2}$</td>
<td>Decay rate for OHOS</td>
<td>0.30</td>
<td>0.01</td>
<td>-</td>
</tr>
<tr>
<td>$b_{STO_O_2}$</td>
<td>Endog. rate for OHOs</td>
<td>0.30</td>
<td>0.08</td>
<td>-</td>
</tr>
<tr>
<td>$\eta_{H_NO_2}$</td>
<td>Red. factor for denitrif.</td>
<td>0.15</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>$k_{STO}$</td>
<td>Max. storage rate</td>
<td>12.00</td>
<td>0.26</td>
<td>-</td>
</tr>
<tr>
<td>$\mu_{H}$</td>
<td>Growth rate for OHOS</td>
<td>3.00</td>
<td>0.10</td>
<td>-</td>
</tr>
<tr>
<td>$Y_{H_O_2}$</td>
<td>Yield coeff. for growth</td>
<td>0.80</td>
<td>0.90</td>
<td>-</td>
</tr>
<tr>
<td>$Y_{H_NO_2}$</td>
<td>Yield coeff. for growth</td>
<td>0.60</td>
<td>0.25</td>
<td>-</td>
</tr>
<tr>
<td>$Y_{STO_O_2}$</td>
<td>Yield coeff. for storage</td>
<td>0.80</td>
<td>0.90</td>
<td>-</td>
</tr>
</tbody>
</table>

**Figure 1.1** Calibration of the nitritation SBR (left) and the PHA-biomass selection SBR (right).

**ACKNOWLEDGMENT** This work was supported by ‘SMART-Plant’ Innovation Action that has received funding from the Europe Union’s Horizon 2020 research and innovation programme under grant agreement No 690323.
REFERENCES


Abstract: The goal of the study was to assess the dynamic environmental performance of implementing full-scale side-stream nitritation-denitritation treatment of anaerobic supernatant at a real municipal WWTP in Italy. The trade-offs between process efficiency, energy consumption and greenhouse gas (GHG) emissions under different operational conditions were investigated. Changepoint detection and timeseries outlier detection techniques were applied to link operational conditions with elevated dissolved N2O concentration and energy consumption. Abnormal behaviour of the system was linked with low availability of carbon source and anaerobic supernatant. This methodology can be used to assist researchers and operators to track and limit GHG emissions and energy consumption at wastewater treatment processes, integrating crucial environmental variables into process monitoring.

Keywords: Full-scale short-cut enhanced nutrients abatement - SCENA; long-term dissolved N2O and energy consumption monitoring, multivariate statistical analysis

INTRODUCTION Environmental sustainability metrics (i.e. energy consumption, greenhouse gas emissions (GHG)) have gained increased attention towards the evaluation of the performance of wastewater treatment plants (WWTPs) (Arnell et al., 2017). Recent life cycle assessment (LCA) studies have shown that integration of Short-Cut Enhanced Nutrient Abatement (SCENA) process in the sidestream treatment line, is linked with reduced energy and chemical consumption and GHG emissions (mainly related with energy consumption) (Longo et al., 2017). However, the direct nitrous oxide (N2O) emissions have not been investigated long-term.

The goal of the study was to assess the dynamic environmental performance of implementing full-scale side-stream nitritation-denitritation treatment of anaerobic supernatant in a real municipal WWTP in Italu. Multivariate statistical techniques were applied to the online data collected from long-term energy consumption and dissolved N2O monitoring campaigns in the system in order to i) link the environmental performance of the system with operational conditions, ii) identify disturbances in the operation of the process and their effect on energy consumption and N2O and iii) visualize the range of the operating parameters that optimize the environmental performance of the system.
MATERIALS AND METHODS The system under investigation consists of a full-scale sequence batch reactor (maximal working volume equal to 70 m³) for the treatment of anaerobic supernatant via nitrite enhanced phosphorus removal associated with nitritation-denitrification. P-rich sludge is recovered from the system. Features characterising the variables monitored online in the SCENA system were used in the analysis (i.e. mean, variance, autocorrelation), together with features characterising the batch (i.e. batch and phase duration). Timeseries anomaly detection techniques (Chen and Liu, 1993) were applied to identify unusual patterns, short-term spikes and temporary changes in the profiles of the parameters monitored online and isolate abnormal cycles. Timeseries changepoint detection techniques were applied to the features extracted, to identify changes in the behaviour variables monitored online in the system. Dissolved N₂O concentrations and energy consumption were investigated under different operational and environmental conditions and carbon source.

RESULTS AND DISCUSSION The short-cut SBR treats around 40 kg of N/day from anaerobic supernatant. N₂O emissions exhibit significant variability ranging from 0.16 kg N₂O-N/batch (1.5% of NH₄-N load) to 1.9 kg N₂O-N/batch (18% of NH₄-N load). In total, ~35% of the batches were characterised with abnormal behaviour of the operational variables monitored online. Abnormal batches were isolated and investigated separately. Main reasons for significant deviations in the profile of the N₂O, electricity consumption, pH and oxidation reduction potential (ORP) were due to limitation of anaerobic supernatant during weekends and extension of aerobic phase length in the SBR. Additionally, abnormal batches were also linked with low availability of carbon source. Different operational conditions during the monitoring period were identified and linked with the characteristics of the carbon source and major works at the WWTP. Figure 1.1 shows an example of change in the energy consumption of SCENA, linked with the upgrade of the primary clarifier.

![Figure 1.1: Aerobic energy consumption timeseries (blue line) showing the sub-periods identified (red dotted lines: changepoints identified by the algorithm)](image)

CONCLUSIONS This work investigated the trade-offs between process efficiency, energy consumption and GHGs emissions under different operational conditions of high nitrogenous wastewater in a full-scale scale SCENA process. Changepoint and timeseries outlier detection techniques were applied to link operational conditions with elevated dissolved N₂O concentration and energy consumption. This methodology can be used to assist researchers and operators to track and limit GHG emissions and energy consumption at wastewater treatment processes, integrating crucial environmental variables into process monitoring.

REFERENCES
Environmental Technology Verification of the Full Scale Short-Cut Enhanced Nutrients Abatement (SCENA) Process


*Department of Biotechnology, University of Verona, Strada Le Grazie 15, I-37134, Verona – Italy
**Alto Trevigiano Servizi Srl, Ufficio Ottimizzazione Processi depurativi, Via Schiavonesca Priula 86, 31044 Montebelluna, Italy.
***Department of Science and Engineering of Materials, Environment and Urban Planning-SIMAU, Marche Polytechnic University, Breccia Bianche St., 60131, Ancona, Italy (VE) – Italy.

Abstract: This work reports the long-term operation of the Short-Cut Enhanced Nutrients Abatement (SCENA) for the treatment of anaerobic reject water. SCENA process adopted the via-nitrite pathway for an efficient nitrogen removal combined with the on-site VFAs production through acidogenic fermentation of sewage sludge. The system was operated for more than 450 days, where the applied vNLRT was maintained between 0.50 to 0.66 kgN/m³ day, while the average removal efficiency was stable at around 82% (average). Currently, the energy consumption for nitrogen removal (kWh/kgN removed) and related N₂O emissions (gN₂O-N/kgN removed) are the performance claims target under evaluation to achieve the Environmental Technology Verification (ETV), which will establish the environmental added value of the process through independent assessment.

Keywords: Environmental technology verification; short-cut enhanced nutrient abatement (SCENA); external carbon source; SBR; Horizon 2020 – Smart-Plant

During the last decade, the environmental regulations are increasingly stringent, so the wastewater treatment plant (WWTP) should improve the effluent quality at affordable cost. In WWTPs, the sidestream treatment of the reject water from the sewage sludge digestion represents a suitable option to meet efficiently the effluent standard limits for nitrogen and phosphorus. The aerobic reject water can increase the nitrogen load to the mainstream biological treatment by 20-25 %, which may lead to an increase in air supply, and thus the energy demand. To minimize these negative economic and environmental impacts, the reject water from anaerobic digester should be treated with proper technology separately before it is recycled to the headworks of the WWTPs. On the other hand, the penetration of innovative technologies into the market could be helped by standard assessment of the environmental performance claims through Environmental Technology Verification (ETV pilot program, 2018). Within the EU framework program Horizon 2020, the Smart-Plant project (https://www.smart-plant.eu/) aims the development, implementation and validation through the ETV of the first full scale Short-Cut Enhance Nutrients Abatement (SCENA, Renzi et al., 2015) in Carbonera WWTP (Treviso, North of Italy) for the via-nitrite treatment of anaerobic reject water. Specifically, the system adopted the on-site production Volatile Fatty Acids (VFAs) as carbon source by controlled fermentation of sewage sludge (Longo et al., 2015; Frison et al., 2016).

In this work, the long-term operation of the SCENA system and the monitoring period to evaluate the performance claims for the ETV are described. SCENA process operated continuously for around 450 days and 3 different periods were identified and described below (Table 1.1):
Table 1.1 Description of the periods during the operation

<table>
<thead>
<tr>
<th>Period</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1</td>
<td>Start-up of the process (first 20 days) and achieving the design operating</td>
</tr>
<tr>
<td></td>
<td>conditions;</td>
</tr>
<tr>
<td>Days 233-282</td>
<td>Interruption of the sludge line due to not ordinary maintenance.</td>
</tr>
<tr>
<td></td>
<td>During these days, the anaerobic reject water was not available;</td>
</tr>
<tr>
<td>Period 2</td>
<td>Recovered of the design operating conditions after the interruption of the</td>
</tr>
<tr>
<td></td>
<td>sludge line;</td>
</tr>
<tr>
<td>Period 3</td>
<td>Monitoring of the energy consumption and N₂O for the evaluation of the</td>
</tr>
<tr>
<td></td>
<td>performance claims valid for the Environmental Technology Verification</td>
</tr>
</tbody>
</table>

Briefly, the fermented sludge is dewatered by a screw-press and the liquid stored in 20 m³ of tank, while the anaerobic reject water is stored into a storage tank of 90 m³ and then used as feeding for the SBR. The latter has a working volume of 70 m³ and it was designed to treat up to 42 kgN/day. The aerobic conditions were accomplished by a volumetric blower (power installed 11 kW) combined with porous membrane disk in the bottom for fine bubbles distribution. During the anaerobic/anoxic conditions the biomass was kept suspended by a mixer having 1.5 kW of installed power. The length of the aeration phase and the carbon source dosage were controlled by conductivity real-time measurements, while the length of the anoxic phase was set on a timely basis. The typical cycles of the SBR consisted on the following ranges: feeding: 8-10 min; anaerobic: 60-90 min; aerobic: 180-260 min; anoxic: 50-60 min.

Figure 1.1 Performances under long-term period of the SCENA process.

In the steady conditions, according with the nitrogen content in the reject water, the vNLR varied between 0.50 to 0.66 (kgN/m³ day) with an average nitrogen removal efficiency of 82%. On the other hand, in period 1 the vNLR increased up to 0.73 kgN/m³ day without significantly affecting the nitrogen removal efficiency. Preliminary assessment during the ETV monitoring period (Period 3) resulted that the observed energy consumption for nitrogen removal (including the VFAs production) accounted for 5-6 kWh/kgN removed. The latter was mainly affected by the nitrogen concentration of the reject water. On the other hand, the analysed N₂O emitted during the aerobic phase (data not shown) was quantified around 15 gN₂O-N/kgN removed.

REFERENCES


Polymer Grade Succinic Acid Production from Organic Waste: The PERCAL Project Pipeline

K. Rabaey*,**, C. Pateraki***, J.C. Arroyo*,**, V. Essman****, C.S.K. Lin***** , D. Ladakis***, A. Koutinas***

* Center for Microbial Ecology and Technology (CMET), Ghent University, Belgium
Korneel.rabaey@ugent.be
** CAPTURE, www.capture-resources.be
*** Department of Food Science and Human Nutrition, Agricultural University of Athens, Greece
**** New Technologies, Covestro Deutschland AG, Leverkusen, Germany
***** School of Energy and Environment, City University of Hong Kong, Hong Kong

Abstract: Production processes from side streams such as the organic fraction of municipal solid waste (OFMSW) or stillage generally lead to impure products limiting use for e.g. polymer products. In the Horizon 2020 project PERCAL a pipeline was developed to produce succinic acid in which fermentation was coupled to membrane electrolysis to achieve minimal chemical dosing during production while enabling a pure acidified product stream. The polysaccharide content of OFMSW was enzymatically hydrolysed using a commercial enzymatic cocktail, the resulting aqueous stream contained >70 g/L of C5 and C6 sugars with glucose being the predominant one (over 80%). This hydrolysate was fermented using an engineered *Yarrowia lipolytica* yeast strain at a yield of 0.26 g/g and a productivity of 0.53 g/L/h. The succinic acid was extracted using membrane electrolysis, at more than 70% coulombic efficiency for succinic acid extraction which increased the production efficiency of the succinic acid, decreased the need for pH control with caustic soda and delivered an acid rich product stream. The resulting stream contained 66.5 g/L succinic acid, it was evaporated to extract volatile organic acids and cooled down to below 4 °C to crystallize out the succinic acid. After subsequent washing, the resulting product was used to produce polyester polyols as precursor for production of polyurethane dispersions. The product achieved a quality comparable to commercially available bio-based succinic acid, showing that it is feasible to produce high quality products from low value substrates. Moreover, preliminary life cycle assessment showed that provided renewable energy is used as driver for the production process, the environmental impact is considerably improved, notably if the productivity of succinic acid production is increased.

Keywords: Bioproduction; side stream; organic waste; polymer production, polyurethanes

REFERENCES

Purple phototrophic bacteria – biofilm technology for microbial protein production

Tim Hülsen*, Samuel Stegman*, Paul Jensen, Damien, J., Batstone
*t.huelsen@awmc.uq.edu.au
**s.stegman@awmc.uq.edu.au

Abstract: Purple phototrophic bacteria (PPB) can be enriched as concentrated biofilm on submerged, infrared illuminated surfaces, to mediate organics and nutrient removal and recovery as protein-rich biomass. Laboratory and field reactors were designed using either artificial or natural illuminate. The reactors were used to assess biomass production and consistency during separate treatment of piggery effluent, poultry effluent and red meat processing wastewater. In all cases, PPB growth was successful; however, COD conversion and biomass yields were variable. Growth consistency and product quality ultimately determines the applicability of PPB biomass as microbial protein and its value for the manufacturer. This is crucially important for the advancement of PPB mediated technology as photobioreactors are both, capital and operationally expensive and the costs need to be balanced with a high-quality, consistent product to generate a revenue stream.

Keywords: Purple phototrophic bacteria; biofilm; microbial protein

Introduction

Microbial protein (MP) has been proposed as an alternative to effectively upgrade and recycle nutrients from waste streams. However, despite decades of research, MP production is still at least a factor 6 - 30 more expensive compared to conventional agricultural protein sources (e.g., 0.39 $ kg⁻¹ for soybean vs. 5 - 24 $ kg⁻¹ for microalgae (Enzing et al., 2014)). To reduce the overall production costs and enable widespread MP production and application, several authors proposed the use of wastewater instead of defined or synthetic growth medium. Using wastewater would reduce the substrate costs to virtually zero (water, organics and nutrients) (Jin et al., 1999; Pikaar et al., 2018) while also offsetting current waste treatment costs. However, maintaining axenic cultures in non-sterile, complex, variable matrices such as wastewater is challenging. Poorly controlled mixed cultures can emerge, where target organisms are substantially diluted or outcompeted (Hülsen et al., 2018).

In addition, wastewater contains components such as inert particles, non-protein solids and heavy metals that are not desired constituents of the MP product, but are difficult to separate from a suspended culture. Impacts may include MP products with inconsistent composition and quality or products that do not meet safety guidelines for use.

Major costs associated with the production of MP include harvesting, drying and sterilization costs. Emerging strategies to reduce these costs include biofilms e.g. as attached films on submerged surfaces (Gao et al., 2015), as biological aggregates (granules) (Tiron et al., 2017) as well as through immobilisation methods e.g. in alginate or carrageen (Vasilieva et al., 2016), all of which have the potential to...
substantially reduce the harvesting costs. To date, biofilm approaches have not been systematically developed or applied to purple phototrophic bacteria.

**Material and methods**

This work describes recent developments and the transition from lab-scale suspended growth PPB cultures using artificial light, towards pilot-sale biofilm technology utilising filtered natural light (Figure 1.1). The work has been conducted over a period of 6 years using multiple waste sources and extends the knowledge of suspended culture to attached, biofilm systems (unpublished data).

![Figure 1.1: PPB growth systems in (A) 160 mL serum flasks (B), 2 L continuous photo anaerobic membrane bioreactors (PAnMBR), (C) on-site 1000L biofilm photobioreactor (BPBR) and (D) on-site outdoors BPBRs (~500L)](image)

**Results and discussion**

Removals of chemical oxygen demand (COD), N and P varied between 50 – 95%, 30-95% and 30-90%, respectively depending on the wastewater source (Figure 1.2).

![Figure 1.2: COD, TN and TP removal performance and the VC (COD) of mixed culture PPB in different reactor configurations.](image)

Biomass yields were generally >between 0.8 - 1.0 gCOD gCOD⁻¹ and areal productivities in outdoor, naturally illuminated biofilm systems were around 10 g m⁻² d⁻¹, which is lower compared to suspended systems. The same applies to the volumetric conversion (VC) of COD. However, attached growth PPB biomass was characterised by consistently high crude protein and amino acid contents (0.64 and 0.55 g gVS⁻¹), high VS/TS (>96%) and lower heavy metal constituents compared to suspended biomass. The concentration of attached growth PPB biomass averaged 12% TS during harvest, and was significantly more concentrated than suspended growth PPB.

**Conclusion**

The PPB technology enables COD, N and P from various agri-industrial wastewaters, while attached PPB growth in biofilms also produces a consistent MP product over time, almost independently from the wastewater composition. This is crucial to balance the operational costs and might bring the embryonic PPB technology a step forward.
Acknowledgments

This work was funded by Australian Pork Limited and the Department of Agriculture and Forestry, Australia (Project No: 2014/534.05) as part of its Rural R&D for Profit Programme and the Commonwealth of Australia through the Cooperative Research Centre Programme for Water Sensitive Cities (CRCWSC project C2.1).

REFERENCES

Economic Potential of Brewery Effluent Treatment with Maximized Heterotrophic Microbial Protein Production

G. Papini*, M. Muys, M. Spiller, F.A. Meerburg, S.E. Vlaeminck

*Research Group of Sustainable Energy, Air and Water Technology, University of Antwerp, Belgium. 
gustavo.gomesdesousa@uantwerpen.be

Abstract: Endangered food security demands the formulation of alternative ways for protein production in high quantity, quality and with low footprints. Microbial protein has great potential and dried aerobic heterotrophic bacteria (AHB) biomass is highly attractive as it can be grown on secondary resources. Using high-rate activated sludge as core technology and brewery effluent as substrate, 12 scenarios were tested for AHB production. Obtained data were used to calculate total annual cost and economic indicators to compare with a conventional treatment system. Soybean and fish meal market prices were used to estimate lowest and highest selling prices of AHB biomass. Scenarios with high-rate conventional activated sludge and anaerobic fermentation reached the highest economic output. Net present value and payback period ranged between 4-15M€ and 3.5-10.8 years, respectively. Economic results confirm the potential for AHB protein production on brewery effluents.

Keywords: Microbial protein; industrial wastewater treatment; resource recovery

Food security is endangered and scientists are in the quest to find alternative ways to produce enough protein for an expanding population while reducing its inherent environmental impacts. Microbial protein (MP) has been pointed as a potential protein source to replace traditional products (i.e. soybean and fishmeal) as it can provide similar nutritional quality with smaller footprint than conventional systems (Pikaar et al. 2017). Aerobic Heterotrophic Bacteria (AHB) grown on secondary resources, such as brewery effluents, can offer several benefits as it allows high protein productivity with minimal water and surface area requirement while promoting the recovery of nutrients locally and stimulating circular economy. For the proposed application, high-rate activated sludge (HRAS) is envisaged as the core technology to maximize protein production due its higher yields and biomass generation compared with traditional activated sludge (AS).

In order to assess the protein productivity of HRAS on brewery wastewater and the potential future applicability of the technology, 12 scenarios were tested. Reactors (2 L) were operated as sequencing batch reactors (SBR) at 20°C, pH 7.0±0.4 and dissolved oxygen above 2 mg L⁻¹. Synthetic medium was used to mimic brewery effluent. A cycle of 2 h was used: feed and react (100 min), settle (15 min), withdraw (4 min) and idle (1 min) and, when a applied, contact to stabilization ratio was 0.38. The main characteristics and results are shown in Table 1. Based in the obtained data, an economic evaluation was done aiming to: i) identify most promising scenarios for further optimization; ii) obtain a preliminary economic feasibility of the process.
Table 1.1 Parameters and performance of the runs and results obtained at steady state. Results as mean ± standard error, n.a. not applicable. Abbreviations: High-rate contact stabilization (HiCS), high-rate conventional activated sludge (HiCAS), volume exchange ratio (VER) and sludge loading rate (SLR) and observed yield (Yobs).

<table>
<thead>
<tr>
<th>N°</th>
<th>Type of influent</th>
<th>Operated as</th>
<th>SRT (d)</th>
<th>VER</th>
<th>Total CODinfluent (g COD L⁻¹)</th>
<th>SLR (g COD g⁻¹ VSS d⁻¹)</th>
<th>Biomass (g VSS L⁻¹)</th>
<th>Yobs (g VSS g⁻¹ CODremoved)</th>
<th>VSS/TSS</th>
<th>Protein productivity (g L⁻¹ d⁻¹)</th>
<th>COD removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Raw HiCS</td>
<td>0.23 ± 0.01</td>
<td>45%</td>
<td>3.13 ± 0.36 14.4 ± 1.7</td>
<td>1.54 ± 0.36 0.66 ± 0.11</td>
<td>0.91 ± 0.03 2.57 ± 0.63</td>
<td>45 ± 8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Raw HiCS</td>
<td>0.49 ± 0.03</td>
<td>49%</td>
<td>3.55 ± 0.28 7.4 ± 1.1</td>
<td>3.32 ± 0.44 0.53 ± 0.12</td>
<td>0.87 ± 0.05 2.70 ± 0.52</td>
<td>60 ± 8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Raw HiCS</td>
<td>1.12 ± 0.07</td>
<td>41%</td>
<td>3.67 ± 0.41 3.1 ± 0.6</td>
<td>6.09 ± 0.67 0.52 ± 0.16</td>
<td>0.89 ± 0.03 2.22 ± 0.19</td>
<td>70 ± 10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Raw HiCAS</td>
<td>0.22 ± 0.01</td>
<td>45%</td>
<td>2.76 ± 0.16 13.1 ± 1.2</td>
<td>1.39 ± 0.18 0.71 ± 0.13</td>
<td>0.87 ± 0.03 2.08 ± 0.32</td>
<td>34 ± 9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Raw HiCAS</td>
<td>0.50 ± 0.02</td>
<td>34%</td>
<td>3.67 ± 0.38 4.5 ± 0.4</td>
<td>3.48 ± 0.35 0.57 ± 0.10</td>
<td>0.90 ± 0.02 2.91 ± 0.34</td>
<td>95 ± 1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Raw HiCAS</td>
<td>0.87 ± 0.12</td>
<td>34%</td>
<td>3.52 ± 0.24 2.7 ± 0.5</td>
<td>5.30 ± 0.60 0.52 ± 0.09</td>
<td>0.86 ± 0.03 2.00 ± 0.36</td>
<td>71 ± 9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Fermented HiCS</td>
<td>0.24 ± 0.01</td>
<td>45%</td>
<td>2.67 ± 0.39 14.1 ± 3.4</td>
<td>1.33 ± 0.27 0.64 ± 0.21</td>
<td>0.87 ± 0.04 2.63 ± 0.48</td>
<td>50 ± 12%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fermented HiCS</td>
<td>0.48 ± 0.03</td>
<td>49%</td>
<td>3.04 ± 0.33 7.5 ± 1.9</td>
<td>2.78 ± 0.61 0.59 ± 0.17</td>
<td>0.88 ± 0.04 2.49 ± 0.43</td>
<td>60 ± 17%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Fermented HiCS</td>
<td>1.09 ± 0.13</td>
<td>41%</td>
<td>2.75 ± 0.94 3.6 ± 0.9</td>
<td>4.21 ± 0.55 0.48 ± 0.13</td>
<td>0.88 ± 0.05 1.62 ± 0.17</td>
<td>69 ± 11%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Fermented HiCAS</td>
<td>0.24 ± 0.01</td>
<td>45%</td>
<td>2.59 ± 0.10 11.2 ± 2.3</td>
<td>1.35 ± 0.38 0.62 ± 0.14</td>
<td>0.87 ± 0.05 2.89 ± 0.74</td>
<td>64 ± 16%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Fermented HiCAS</td>
<td>0.5 ± 0.02</td>
<td>34%</td>
<td>3.16 ± 0.30 5.3 ± 0.8</td>
<td>2.67 ± 0.24 0.47 ± 0.08</td>
<td>0.88 ± 0.03 2.52 ± 0.38</td>
<td>92 ± 1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Fermented HiCAS</td>
<td>1.17 ± 0.1</td>
<td>34%</td>
<td>3.17 ± 0.13 2.7 ± 0.3</td>
<td>4.68 ± 0.33 0.41 ± 0.05</td>
<td>0.85 ± 0.05 1.89 ± 0.31</td>
<td>90 ± 4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A large size brewery with influent flow of 4,800 m³/day was considered. Scenarios were compared against typical brewery wastewater treatment (baseline: anaerobic treatment + AS) which was designed assuming data from literature and obtained in Flemish breweries. In order to reach discharge limits (Flanders, Belgium), it was considered for all alternative scenarios the presence of a second SBR, if necessary. Harvested biomass assumed to be centrifuged and dried to 95% total solids, with 5% losses. Annual CAPEX and OPEX were estimated and a differential cash flow analysis (Damodaran 2010) was performed between the baseline and each tested scenario in order to obtain the individual net present value (NPV) for mutually exclusive projects with equal lives (20 years, discount rate 5%). Market soybean meal (317.03 €/ton) and fishmeal prices (1,301.68 €/ton) from January 2019 were used.

Figure 1.1 a) Estimated cost and revenue of the treatment scenarios. ATC = annual CAPEX + annual OPEX. Baseline system: Upflow Sludge Blanket (UASB) + AS with sludge centrifugation and final disposal. b) NPV and minimum payback period. Minimum and maximum values correspond to biomass sold at soybean meal and fishmeal price respectively. *systems without a second SBR for polishing (COD effluent below discharge limit).

Systems operating with fermented influent reached higher economic results mainly due the higher protein content and productivity. HiCAS overperformed HiCS. Scenario n°10 obtained highest net present value (15M€) and minimal payback period (3.5 years) and deserve attention for further optimization. Results confirm the high potential for AHB protein production on brewery effluents.

REFERENCES


Power-to-Protein: Next Step Towards Consumable Single Cell Proteins from Waste Water and Renewable Hydrogen

F.I.H.M. Oesterholt*, L. Palmen**, W. Verstraete***, J. Boere****

*KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, the Netherlands.
**Center for Microbial Ecology and Technology (CMET), Ghent University, Coupure Links 653, 9000 Gent, Belgium
***Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium
****Allied Waters, Groningenhaven 7, 3433 PE Nieuwegein, The Netherlands

Abstract In the Power-to-Protein concept lithotrophic hydrogen oxidizing bacteria reassemble carbon dioxide and ammonium-nitrogen from sewage treatment to single cell protein (SCP) while using hydrogen as energy source. The concept was demonstrated at two sewage treatment plants (STPs) in The Netherlands. Parallel to the Power-to-Protein pilot an ammonia recovery pilot was tested for removal efficiency of pathogens while producing ammonia sulphate from reject water of the sludge digestion. Special attention was given to the quality aspects of the SCP that was produced especially with regard to crude protein content, amino acid sequence and in vitro digestibility. A Life Cycle Analysis was performed to compare the production of SCP with traditional protein sources.

Keywords: Resource recovery; single cell protein; ammonia reuse; LCA

INTRODUCTION The concept “power-to-protein” (PtP-concept) was first introduced by Ghent University, and is about the production of high-value protein through biosynthesis using hydrogen, oxygen and carbon dioxide (see figure 1.1). Nitrogen, as ammonia, is required as main building block of the protein, and can be retrieved directly from the waste water matrix, e.g. from the liquid fraction of anaerobic digestion (reject water). The biosynthesis of single cell protein (SCP) is performed by a mixed culture enriched in hydrogen-oxidizing bacteria (HOB microbiome) (Matassa et al., 2015a). The technical feasibility of the concept was demonstrated by Avecom in their laboratory in Gent by producing autotrophic hydrogen-oxidizing bacteria at 5 L scale. After harvesting the amino acids profile of the produced edible microbial protein was analysed, indicating a high quality product that could replace conventional feed sources such as fishmeal or soybean meal. For the economic feasibility of the concept a desk study was performed using actual data from the biological sludge digestion system of the two STPs in the city of Amsterdam. The results, showing a good economic potential, were presented at the IWA 2016 World Water Congress & Exhibition in Brisbane (Oesterholt, 2016).

MATERIAL AND METHODS The work was continued in recent years by designing and building a pilot plant reactor with an intended production capacity of about 1 kg SCP per day. The pilot plant was used to demonstrate the production of SCP and to monitor the production process at two STPs in The Netherlands. To feed the power-to-protein pilot with recovered ammonia an existing pilot scale ammonia
recovery system (NAR-pilot) was used based on air stripping at elevated temperatures and pH followed by absorption of the stripped ammonia in a sulphuric acid solution. On both locations, the reject water of the sludge digestion plants was used as source for the ammonia recovery step. The different steps within the NAR-pilot were closely monitored, particularly in terms of pathogens transfer from the reject water to the final ammonium sulphate solution produced. For this purpose, challenge tests were performed with three indicator microorganisms to prove sufficient virus, bacteria and protozoa removal. The biomass produced in the PtP-pilot was analysed for protein content, amino acids composition and in-vitro digestibility. The environmental impact of SCP was evaluated by performing a Life Cycle Analysis using SimaPro software and the EcoInvent 3.0 database.

RESULTS AND CONCLUSIONS Ammonia recovery using air stripping turns out to be technically and economically feasible. The total costs of € 2.18 per kgN can be further reduced to € 1.54 per kgN when waste heat is available on location. Challenge test results show high removal efficiencies for indicator organisms (see table 1.1.) indicating that transfer of faecal pathogens from the reject water to the recovered ammonia sulphate is very unlikely. LCA results indicate that – due to the amount of electricity necessary for the hydrogen (and oxygen) production - the source of electricity is the determining factor in the case of environmental impact of SCP. So the “greener” the power source the lower the impact. In figure 1.2 a comparison is made between SCP and conventional protein sources per kg crude product for “off shore wind’ as a common power source in the future. With the interpretation of these data it is important to understand that the crude protein content of SCP is substantial higher than that of meat. Pilot results in general indicate insufficient hydrogen transfer efficiency in the pilot reactor resulting in direct loss of hydrogen and a relatively low specific SCP production capacity. So optimisation of the reactor concept in general and the hydrogen transfer in particular are crucial for the continuation of the PtP-concept.

Table 1.1 Results of two challenge tests with indicator organisms in the ammonia recovery pilot

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>Salmonella senftenberg</th>
<th>SSRC</th>
<th>Coliphages phiX174</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>°C</td>
<td>MPN/l</td>
<td>CFU/l</td>
<td>PFU/l</td>
</tr>
<tr>
<td><strong>Test 1 June 30 2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influent + inoculate</td>
<td>24.2</td>
<td>&gt; 3.7 *10⁴</td>
<td>4.2 * 10⁷</td>
<td>1.9*10⁷</td>
</tr>
<tr>
<td>(NH₄)SO₄ from scrubber</td>
<td>60.1</td>
<td>&lt; 0.6</td>
<td>5.8 * 10³</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Overall log removal</td>
<td>&gt; 6.4</td>
<td>5.5</td>
<td>&gt; 6.9</td>
<td></td>
</tr>
<tr>
<td><strong>Test 2 August 7 2017</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Influent + inoculate</td>
<td>24.2</td>
<td>7.8 *10⁷</td>
<td>8.4 * 10⁶</td>
<td>7.7*10⁶</td>
</tr>
<tr>
<td>(NH₄)SO₄ from scrubber</td>
<td>60.1</td>
<td>&lt; 0.6</td>
<td>1.7 * 10⁴</td>
<td>&lt; 100</td>
</tr>
<tr>
<td>Overall log removal</td>
<td>&gt; 10.1</td>
<td>5.7</td>
<td>&gt; 6.9</td>
<td></td>
</tr>
</tbody>
</table>
ACKNOWLEDGEMENTS This project is a collaboration of AEB, Avecom, Barentz/Agri Nutrition, Waternet, Waterkracht (cooperation of four water boards in the east of The Netherlands), KWR Watercycle Research Institute and Allied Waters. This activity is co-financed with PPS-funding from the Topconsortia for Knowledge & Innovation (TKI’s) of the Dutch Ministry of Economic Affairs and Climate.

REFERENCES
Biological Upgrading of Biogas and Production of Single Cell Proteins


*EnviDan A/S, Fuglebækvej 1A, 2770 Kastrup, Denmark, jam@envidan.dk
**DTU Environment, Bygning 115, Bygningstorvet, 2800 Kongens Lyngby, Denmark
***BIOFOS, Refhalevej 250, 1432 København K, Denmark

Abstract The Danish utility company BIOFOS is leading a large development project called VARGA introducing several technologies transforming WWTP Avedøre (350,000 PE) into a Water Resource Recovery Facility. A pilot plant has been running for one year and results from anaerobic digestion of biowaste shows methane yields of ~360 Nm³ CH₄/ton VS at relatively stable operation. The produced biogas is being biologically upgraded using methanogenic microorganisms to natural gas quality. In a new spin-off project called FUBAF, led by the consultant company EnviDan, the upgraded biogas is converted to Single Cell Proteins. Production of nutrients using a novel Electrochemical System (ES) is a key element in the overall FUBAF concept, which is evaluated in terms of environmental sustainability.

Keywords: Upgrading of biogas, single cell proteins, nutrient recovery, food production, resource recovery, bioeconomy.

The largest wastewater utility in Denmark, BIOFOS, is leading a large development project in which a traditional Wastewater Treatment Plant (WWTP) is transferred into a Water Resource Recovery Facility (WRRF). The project, called VARGA, is taking place at Avedøre WWTP. VARGA is getting financial support from the Ecoinnovation fund through the Ministry of Environment and Food in Denmark.

One of the work packages in VARGA cover separate anaerobic digestion of source-separated organic waste from households in the Copenhagen area. The generated biogas is being biologically upgraded using methanogenic microorganisms to natural gas quality and bioaugmentation experiments are performed to be able to cope with possible ammonia inhibition. The high quality digestate produced will be applied in organic farming through field trials in Spring 2019 to test the fertilizer characteristics. Organic fertilizers are in high demand in the Eastern part of Denmark, so the digestate is expected to have a good market potential. All experiments have been performed in laboratory scale at the Technical University of Denmark, DTU (e.g. Khoshnevisan et al., 2018) before going to pilot scale.

A pilot plant has been in operation since January 2018 at Avedøre WWTP with very stable process conditions. The methane yield has been expectedly high at ~360 Nm³ CH₄/ton VS and there have been no signs of ammonia inhibition (manuscript under preparation). Biological upgrading of the biogas has successfully been performed in the laboratory using ceramic membranes (manufactured by silicon carbide or aluminium oxide) with different pore sizes for hydrogen dispersion (see Figure 1.1, manuscript under preparation). All membranes are performing well (>90% CH₄) at gas retention times (GRT) of 10 hours with H₂ and CO₂ utilization efficiency more than 95%. The efficiency decreases at lower GRT as seen in Figure 1.1. The
experiments are still been performed in the laboratory with focus on process efficiency and choice of membrane / material. An upgrading unit is under construction and will be tested in pilot scale in 2019.

A newly started development project (January 2019) is a spin-off from VARGA and will further examine production of high value end-product from biogas. The project is called FUBAF and the main aim is to produce Single Cell Proteins (SCP) from biologically upgraded biogas. Up to now, the concept of producing SCPs using methane oxidizing bacteria (MOB) has been demonstrated at industrial scale using natural gas and synthetic media. As an example, The Danish company, Unibio, has commissioned a commercial scale methane to protein plant using their novel U-Loop technology (Petersen et al., 2017).

A novel technology for nutrient recovery from both digestate from anaerobic digestion of source-separated organic waste from households and reject water from sludge dewatering is demonstrated in this project. It is a Electrochemical System (ES) and it is described in Zhang & Angelidaki (2015a and 2015b). The efficiency of the system is depending on various parameters as for example, substrate characteristics (i.e. total solids and ammonia content), applied current density and type of electrode. The technology has been patented by the Technical University of Denmark and further optimization and upscaling is now taking place.

This 2nd generation production concept where both recovered nutrients and upgraded biogas streams from anaerobic digestion of urban biowastes is used for production of SCPs has not yet been developed. The sustainability of the concept will be evaluated using circular economy principles.

ACKNOWLEDGMENTS BIOFOS, EnviDan, DTU Environment and ARC are partners in VARGA. In addition, LiqTech, Unibio, Aarhus Vand and VandCenter Syd are partners in FUBAF.

REFERENCES


Towards a More Sustainable Food Chain: Microbial Protein Production from Catalytically or Biologically Fixed CO₂

M. Sakarika*, P. Candry*, R. Ganigué*, K. Rabaey*

*Center for Microbial Ecology and Technology (CMET), Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000, Gent, Belgium.
myrsini.sakarika@ugent.be; pieter.candry@ugent.be; ramon.ganique@ugent.be; korneel.rabaey@ugent.be

Circumvent mass transfer limitations caused by the direct use of gaseous CO₂. Experiments showed that formate and acetate can be used as carbon sources for growth of several pure and mixed cultures, producing MP. Specifically, we established key kinetic, stoichiometric as well as nutritional parameters, proving the feasibility of this concept. This approach can further decrease the environmental footprint of MP, paving the way for a more sustainable food chain.

Keywords: Single cell protein; nutrient recovery; nutritional quality

It is now recognized that meeting the future food demands of the increasing population is one of the major future challenges (Charles et al., 2015). The intensification of current agricultural practices threaten global stability, causing nitrogen pollution, greenhouse gas emissions, deforestation and biodiversity loss (Pikaar et al., 2018). Hence, drastic changes are needed in order to sustainably meet the growing food demands. To this end, microbial protein (MP) can alleviate the stress on the food chain and environment by providing a more sustainable protein source. Specifically, predictions show that substitution of crop-based animal feed (10-19%) with MP can reduce the nitrogen losses (8%), agricultural greenhouse gas emissions (7%) and cropland expansion (6%) compared to the conventional soybean meal-based scenario (Pikaar et al., 2018).

Current production of MP relies on the use of sugars - using edible substances - or methane - causing food-fuel competition - and therefore more sustainable approaches are needed. A widely abundant source of carbon is CO₂, with more than 330 Gtons emitted in EU-28 during 2016 (Ritchie and Roser, 2017). This CO₂ can be converted to formate and acetate through catalysis and gas fermentation respectively, and serve as carbon sources for microbial growth. Using these CO₂-sourced substrates, rather than gaseous CO₂, can enable higher productivities by eliminating mass transfer limitations.

This study evaluated the use of formate as a feedstock for MP production, and compared it with the use of acetate. To this end, a selection of microorganisms (i.e. bacteria, yeasts) were grown on these substrates to assess the growth, yields and nutritional quality of the selected microorganisms.

MATERIALS AND METHODS The microorganisms selected for these tests were: Cupriavidus necator LMG 1199, Methylbacterium extorquens DSM 1338, Corynebacterium glutamicum DSM 20300, Yarrowia lipolytica ATCC 20362, Komagataella phaffii (previously known as Pichia pastoris) ATCC 76273 as well as a mixed microbial community (original culture obtained from ValProMic). First, growth curve experiments were performed in 96-well plate (96-WP). Each organism was grown in ammonium mineral salts (AMS) medium, with acetate or formate levels ranging between 5 and 174 mM, at pH 6 and 7. The Richards equation was fitted to the log-
transformed optical density data using the nls.lm optimisation algorithm from the minpack.lm package in R (Elzhov et al., 2015). Parameters were estimated in Python, using the pyIDEAS package (Van Deel et al., 2015), using the Nelder-Mead algorithm for parameter optimization. Finally, flask experiments were performed using AMS medium, with non-inhibiting acetate or formate levels (derived from the 96-WP experiments), at pH 7, with the aim to derive the yields and protein contents.

RESULTS The results illustrated in Table 1.1 and Figure 1.1 show the results obtained with *C. necator* as an example case. It can be seen that pH has a strong effect on the performance of the strain, with pH 6 resulting in lower growth rates and inhibition at lower concentrations. Furthermore, the carbon yields are 2 times lower during the use of formate compared to acetate. Finally, protein analysis revealed that the protein content ranges between 27% and 58% (in dry weight) depending on the growth stage and carbon source.

**Figure 1.1:** Experimental data and model prediction of *Cupriavidus necator* growth rate in respect to carbon source concentration, on formate (left) and acetate (right) at pH 7 and 6.

**Table 1.1:** Kinetic and stoichiometric parameters of *Cupriavidus necator* grown on acetate and formate at pH 7 and 6. Mean values ± 95% confidence intervals (n≥3) are presented for the parameters $\mu_{\text{max}}$, $K_s$ and $K_I$ while mean values ± standard deviation (n=3) are shown for $Y_{x/s}$. Abbreviations: CDW = cell dry weight; COD = chemical oxygen demand.

<table>
<thead>
<tr>
<th>pH</th>
<th>$\mu_{\text{max}}$ (h$^{-1}$)</th>
<th>$K_s$ (mM)</th>
<th>$K_I$ (mM)</th>
<th>$Y_{x/s}$ (gCDW biomass/gCOD consumed)*</th>
<th>$\mu_{\text{max}}$ (h$^{-1}$)</th>
<th>$K_s$ (mM)</th>
<th>$K_I$ (mM)</th>
<th>$Y_{x/s}$ (gCDW biomass/gCOD consumed)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>0.29 ± 0.02</td>
<td>2.5 ± 1.0</td>
<td>146 ± 23</td>
<td>0.29 ± 0.03</td>
<td>0.41 ± 0.02</td>
<td>0.48 ± 0.30</td>
<td>50 ± 4</td>
<td>0.48 ± 0.08</td>
</tr>
<tr>
<td>6</td>
<td>0.22 ± 0.09</td>
<td>4.7 ± 5.0</td>
<td>44 ± 16</td>
<td>-</td>
<td>0.14 ± 0.01</td>
<td>-**</td>
<td>52 ± 12</td>
<td>-</td>
</tr>
</tbody>
</table>

*values derived from flask experiments; **$K_s$ below the tested range

ACKNOWLEDGEMENTS This work was performed in the framework of the Catalisti cluster SBO project CO2PERATE (“All renewable CCU based on formic acid integrated in an industrial microgrid”), with the financial support of VLAIO (Flemish Agency for Innovation and Entrepreneurship).

REFERENCES


Wednesday, 11th September 2019

Session 15

GOVERNANCE AND REGULATION
Barriers and Opportunities for a Circular Economy of Phosphorus in the Baltic Sea Region

K. Barquet, L. Järnberg, B. Macura, A. Rosmarin

The Stockholm Environment Institute (SEI)
karina.barquet@sei.org, linn.jarberg@sei.org, biljana.macura@sei.org

Abstract: This paper sheds light on the market and governance barriers and opportunities affecting the development, choice and implementation of innovations for phosphorus (P) reuse in the agriculture and wastewater treatment sectors. Lack of appropriate policy steering and insufficient knowledge on the performance of technologies for reuse are key obstacles for closing the P loop. Structural opportunities presented by the new EU Fertiliser Regulations are likely to improve market opportunities for recovered P. However, the system is currently characterized by a narrow focus on a few innovations for P recovery and reuse which can lead to a new lock-in. Solutions need to address users’ acceptability of recovered products while the vision of a circular economy needs to be better articulated in regulations that capture environmental externalities. The paper highlights knowledge gaps, and recommendations for policy and research.

Keywords: Circular economy; innovation; nutrient recovery and reuse

Phosphorus (P) is one of the crucial elements needed for global food security. However, the phosphate life cycle is currently predominantly linear, from P rock mining to fertiliser production, agriculture, and food consumption, with the P excess ending up in soil and runoff (Haas et al. 2015). In the Baltic Sea Region (BSR), home to over 90 million people (Swain 2017), eutrophication is affecting more than 90% of the region due to past and present excessive inputs of nitrogen (N) and P (HELCOM 2018). As a result, the BSR suffers from algal blooms, reduced water clarity, changes in species composition, and reduced oxygen concentrations in bottom waters (Svanbäck and McCrackin 2016). Eutrophication coupled with limited global commercial P reserves (Schröder et al. 2011) call for increased efforts towards creating a circular economy for P in the Baltic Sea region.

Despite technological advancements for recovering nutrients, large-scale implementation of these technologies remains scattered, with only a few successful examples of full commercialization (Ohtake and Tsuneda 2019). Thus, the question this paper addresses is What is needed to accelerate the transition toward a circular P economy in the Baltic Sea Region? We adapt a multi-dimensional analytical framework that merges an innovation systems perspective (Weber and Rohracher 2012) with elements of socio-technical transitions (Geels 2011) to explore market and governance barriers and opportunities affecting the development, choice and implementation of innovations for P reuse, including technologies and practices in the agriculture and wastewater treatment sectors. The framework consists of seven analytical dimensions designed to capture different aspects affecting the development and uptake of innovative technologies for P reuse, including 1) structure i.e. any type of physical, financial, or institutional infrastructures; 2) coordination of processes and

This study is part of BONUS RETURN, an ongoing project exploring circular innovations for recovering and reusing nutrients in the Baltic Sea Region. BONUS RETURN has received funding from BONUS (Art 185), funded jointly by the EU and Swedish Foundation for Strategic Environmental Research FORMAS, Sweden’s innovation agency VINNOVA, Academy of Finland and National Centre for Research and Development in Poland.
system components; 3) interactions between actors via exchange of information and resources; 4) system’s directionality and a common vision; 5) actor’s capabilities to monitor, learn and act upon knowledge; 6) their values and worldviews; 7) system’s ability to clearly articulate problems or opportunities, anticipate and act upon them. To collect data on different barriers and opportunities for technological innovations in the field of P reuse, we have searched for literature on Web of Science Core Collections and Google Scholar. We have applied predefined eligibility criteria and screened literature at three stages: title, abstract and full text. This has been complemented with 10 key-informant interviews to corroborate literature review findings. Data from interviews and the review has been extracted in the form of quotes and summaries. We have thereafter created a set of themes within each analytical dimension in the framework, identifying different barriers and opportunities.

Results show several structural barriers for operationalizing a circular flow of nutrients, including aspects related to technology development for producing nutrient-rich material, policies and infrastructures to enable reuse, and the market structures that define profitability of innovative techniques for recovery and reuse. Apart from policies, a major challenge for recovery and reuse technologies is related to the costs of the industrial recovery process and the lack of inclusion of environmental externalities in price-setting and in regulatory forcing, which has created an uneven playing field between conventional and waste-derived fertilisers. Furthermore, findings suggest there is a need to increase policy steering towards P reuse (and not just towards reducing eutrophication), without closing promising systemic solutions. One barrier for the development of solutions is the lack of capabilities due to limited knowledge on the performance and cost-benefits of technologies. From the few technologies that have progressed to commercial implementation we have learnt about the difficulty of navigating value chains, and the type of policies that can favour innovation development. The drawback is that current policy and technology development have favoured the development and implementation of certain types of technologies potentially directing the system into a new lock-in. To improve the articulation of a circular economy of P, more contextualized solutions that consider the size of cities, the tax-payer base, the values of users and consumers, the interactions between wastewater and agriculture, the allocations of responsibilities and ownership across sectors and between actors, as well as the lack of coordination within agriculture with regards to manure supply and demand, and the agencies that will be responsible for monitoring and evaluating the new processes stemming from the reuse of P, are necessary.

REFERENCES
The politics of a Transition Towards a Circular Economy in the Dutch Wastewater System

K. Ampe, E. Paredis, L. Asveld, P. Osseweijer, T. Block

Recently, environmental and societal problems have increased the calls for a ‘transition’ or ‘paradigm shift’ towards resource recovery and the circular economy (CE) in the Dutch wastewater sector. Already in 2012, the sector developed a relatively broad ‘Wastewater Management Roadmap towards 2030’ (Dutch Water Authorities & Association of Netherlands municipalities, 2012). By 2017, the sectors’ joint initiative the ‘Energy & Resource Factory’ (ERF) had translated the Roadmap into the development of business cases for a top 5 of resources that can be recovered from wastewater (ERF, 2017).

The ERF’s translation has considerably narrowed down the interpretation of a transition. This provokes us to ask questions about the political rationales and power struggles that drive the ERF-process: how is a transition interpreted? How and why did the interpretation evolve? And what does this imply for the nature of this so-called transition? These questions were explored by analysing twenty-seven interviews, (participatory) observation and documents through the lens of a power framework that focuses on relational, dispositional and structural power to understand change and stability in transitions (Grin, 2010).

From a theoretical perspective, we conclude that the ERF’s (CE) discourse led to stability and, at most, incremental changes (i.e. optimisation and market development) in the Dutch wastewater system, particularly because their innovative activities struggled with a variety of mechanisms such as resistance of the incumbent actors; the established, large-scale treatment infrastructure; cost-benefit strategies; win-win discourse; and organisational silos. Our findings thus suggest a lock-in in the current Dutch wastewater system (e.g. Klitkou, Bolwig, Hansen, & Wessberg, 2015) although continuous incremental changes may lead to a fundamental shift to sustainability (e.g. Geels & Schot, 2007). Further questions can be raised about the influence of new discourses on socio-technical systems characterised by stability and large-scale infrastructure (e.g. Sovacool, Lovell, & Ting, 2018). From an empirical point of view, and in line with recent research on the CE (e.g. Hofmann, 2019; Korhonen, Honkasalo, & Seppälä, 2018; Lazarevic & Valve, 2017), we argue that there are political choices to be made about a transition towards a CE. As such, it is not surprising that the ERF’s interpretation of a transition excludes societal and stakeholder perspectives such as water recovery, decentralised treatment systems, citizen involvement and non-competitive projects.
REFERENCES


HOUSEFUL - Innovative Water, Energy, Material and Nutrient Cycles for the Housing Sector

M. Wirth*, G. Bertino**, J. Kisser***, R. Grünner****

*alchemia-nova GmbH, Baumgartenstraße 93, 1140 Vienna, Austria, +Presenting author
*maria.wirth@alchemia-nova.net, **gaetano.bertino@alchemia-nova.net, ***jk@alchemia-nova.net,
****roman.grunner@alchemia-nova.net

Abstract  The housing sector is a major contributor to environment and climate challenges in the EU. The lock-in to linear models of resource management are causing adverse impacts throughout a building’s life cycle, spanning resource extraction, manufacturing, construction, use and building waste. While the transition towards a circular economy has advanced in industries, this has not yet reached the housing sector. The EU-funded HOUSEFUL project aims to accelerate the transition towards a more circular housing sector, by demonstrating integrated systems of on-site technical solutions for circular management of energy, water, materials and waste in four demo sites in Austria and Spain, covering different socio-cultural contexts and building archetypes. The innovations include water and nutrient recovery from household wastewater by treating the liquid fraction in novel green wall constructed wetlands and processing solids in a household-scale biogas unit and compost cultivator.

Keywords: circular economy; housing; nature-based solutions; resource recovery; wastewater

The housing sector accounts for 50% of all extracted materials, 50% of energy use, one-third of water consumption and one-third of all waste produced in the EU (European Commission, 2014). This makes it a major contributor to resource depletion, environmental and climate challenges as well as an important target area for circular management of energy, water, materials and waste. So far, efforts have mainly focused on circular economy in industries, or on single housing dimensions. When water is reclaimed, it usually comes from communal wastewater treatment plants with inefficiencies due to distance from water users and risk of industrial pollutants, while also removing nutrients in a way that they cannot be recovered. In the EU, 70% of the phosphorus in sewage sludge and biodegradable solid waste are lost (WEF, 2016) amid high dependency on fertiliser imports (Fertilizers Europe, 2016). Nature-based solutions for water and nutrient recovery exist, but they have not been integrated with other building dimensions, or across the building life cycle. Succeeding in the transition towards a circular economy requires a redesign of current business models, co-creation with wide user groups and transferability to different contexts.

HOUSEFUL has developed a way to integrate circular management and efficient use of water, energy, material and waste into single buildings. The solutions are adapted to different climate conditions, types of residential construction (‘60s and ‘70s social housing, a centenary building and new social housing from 2017), socio-cultural attributes and regulatory frameworks, demonstrated in four use cases in Austria and Spain. HOUSEFUL solutions include new processes for construction/refurbishment and
demolition, sustainable material use and improved energy efficiency of buildings as well as an integration of recovery and reuse processes for water, energy and nutrients. Efficient, nature-based treatment of wastewater and kitchen waste enable internal reuse of water and nutrients, and on-site production of biogas and compost, shown in figure 1. HOUSEFUL has developed two integrated solutions for water and nutrient cycles:

(i) Household greywater and blackwater are separated and greywater treated in multi-level green walls indoor or outdoor (façade or roof) for >90% water reuse together with rainwater in toilets or irrigation. Blackwater and shredded bio-waste are fed into a novel building-scale anaerobic membrane bioreactor (AnMBR) producing biogas. The blackwater is treated by UV disinfection for reuse.

(ii) Unsegregated household wastewater (greywater and blackwater) is combined with shredded bio-waste. It is separated into liquid and solid fractions, where the liquid fraction is treated with odour-free green solutions for indoor, façade or roof, achieving >95% wastewater reuse together with rainwater for toilet flushing, or irrigation. The solid fraction is processed to biogas and digestate using dry anaerobic digestion (dAD), being adapted to temperate climates. Depending on the building size, the biogas unit can be combined with a Combined Heat and Power (CHP) co-generator to produce electricity and heat for the building or even the neighbourhood.

The indoor water treatment unit is a horizontal subsurface flow (HSSF) constructed wetland in a vertical set up, adapted to treat the liquid fraction of unsegregated household wastewater. In the indoor and outdoor setups, the constructed wetland units converge into production of edible plants. Outdoors, a greenhouse allows for an extended cultivation season. Conveyance systems to transfer wastewater and separated fractions to the treatment units are designed for integration into the building in a way that both user friendliness and technical requirements are met. High-quality compost is produced from digestate and plant clippings in a closed-vessel compost cultivator. The recovery of over 95% of household food waste and 95% of organic matter from blackwater will be achieved by anaerobic digestion to biogas. Energy-efficient building techniques and biogas valorisation will contribute to the achievement of near-Zero Energy Buildings (nZEB).

HOUSEFUL is targeting both technical and social barriers, including shifting attitudes to enable on-site water and resource loops. By developing solutions fit for urban contexts, HOUSEFUL contributes to a change in the role of cities from consumers and polluters towards centres for resource recovery and reuse.

REFERENCES


Time to Stop Flushing Potable Water with Our Faeces & Urine – A National Water Strategy based on Resource Recovery from Re-Engineered Toilets

J.N. Bhagwan*, V. Naidoo*, S. Pillay*
*Water Research Commission, 4 Daventry Road, Lynnwood Bridge Office Park, Pretoria, South Africa. Email: sudhirp@wrc.org.za

Abstract: Current technical options used in sanitation, primary full flush with reticulated sewerage and on-site sanitation, are limited and cannot be sustainably scaled to meet Sustainable Development Goals (SDGs). New approaches are required that combine the benefits of both approaches, namely, eliminating need for sewers, point-of-use treatment and resource use efficiency and recovery. Under conditions of increasing climatic variability, the norm of flushing potable water with faeces and urine needs to change. Droughts experienced in Cape Town and Eastern Cape of Southern Africa highlighted the illogical approach of potable water flushing. A plethora of re-engineered toilets have been developed nationally and internationally with the aim of recovering up to 30% potable water supply. These re-engineered toilets offer water-saving coupled with organic and nutrient recovery processes to enable commercial possibilities linked to service provision but require policy-enablers to facilitate uptake of RDI.

Keywords: Re-engineered toilet, resource recovery

INTRODUCTION The full flush toilet connected to a sewer remains the “gold” standard in terms of sanitation technologies. The cistern flush and the P-trap design, which has its origin in the U.K, has not significantly changed over the last 150-years. Recent climatic episodes of droughts experienced in South Africa have shown us that flushing 6-12 litres of potable water with your faeces and/or urine is not the most water efficient engineering process. A new sanitation paradigm is required that requires a re-engineering of the standard flush toilet design into one that incorporates water-saving and resource recovery. This paper will present the strategic progress that South Africa has made to re-engineering the toilet and developing the enabling framework to facilitate uptake of novel sanitation solutions as part of larger water security strategy.

BACKGROUND South Africa, like many other Sub-Saharan African countries, is characterised by a binary sanitation engineering paradigm of full flush toilets with sewers and on-site sanitation systems, such as latrines and septic tanks. The historical inequalities created through apartheid spatial planning has resulted in reticulated sewerage infrastructure located in mainly urbanised areas with on-site technologies implemented outside the sewered boundaries in typical rural and peri-urban areas.

South Africa is a water-scarce country with demand expected to exceed supply by 2030. Full flush toilets connected to wastewater works is not technically feasible for the entire country. Estimates from eThekwini Municipality indicated that the cost of
full flush sewerage would be ZAR 6 billion. This was only for capex related costs and is beyond the financial reach of most municipalities. This is scenario experienced in Africa and Asia (WSUP, 2008). For this reason, indigent populations outside the sewered network have been provided with government-sponsored waterless on-site sanitation alternatives. Approximately 1 million Ventilated Improved Pit (VIP) latrines have been implemented by the South African government to resolve sanitation backlogs.

However, on-site systems have their own set unique challenges. While water-saving compared to full flush reticulated sewerage, on-site sanitation systems are associated with poor user experience, malodours and the management of the sludges that accumulate in them is notoriously difficult (Bhagwan et al., 2008). Faecal sludge has been shown to highly concentrated with pollutants, such as pathogens and nutrients, while the sludge is “wiper” (toilet paper using) communities has shown to have low biodegradability and therefore not suited for digestion processes using this feedstock alone (Tunde, 2012). A new approach to sanitation is required – one that encompasses the benefits of a flush toilet (easy to clean, limits odours, “flush-and-forget”) and on-site systems (quicker implementation, water-saving features) with possibilities to recover carbon (in various forms) and nutrients as part of circular economy principles.

RE-ENGINEERING THE TOILET

Front-end pedestal design

In urban settings, toilet use between 9 to 12 litres using syphon-flush mechanism or 6 litres in newer models. In South Africa, potable water tends to be used for flushing. The Water Research Commission (WRC, South Africa), a national organisation dedicated to strategically funding solutions to South Africa’s water and sanitation challenges, initiated research aimed at developing low flush toilet pedestals (lower than current 6-litre modern flush toilets used) (Fig.1). Two low-flush pedestals were developed from research funding and tested to international flushing protocols. This includes the WRC Low / Pour Flush technology and the Arumloo. The former is designed as a low-flush (3-litre flush) alternative to VIP latrines and can be connected to a leach pit or septic tank and can handle newspaper that is used for anal-cleansing. Over 1,000 units of the former have been successfully implemented. The latter is a low flush (2 litre) pedestal aimed at urban, environmentally conscientious customers. This paper will present how the bowls were developed to become more efficient through R&D and creation of vortex flushes using biomimicry design principles.
Point-of-use treatment and resource recovery
The second part of the paper will focus on the development, piloting and engineering field-testing of new sanitation approaches that require little or no external flush water and recovers resources from faeces and urine. Solutions presented are those developed from funding through the WRC and the Bill & Melinda Gates Foundation and are at various levels of technology readiness (TRL). The paper will provide an overview of the development of selected re-engineered solutions (including the scientific principles and validation of process in laboratory), products recovered and the context in which certain technologies are currently being field-tested through partnerships between municipalities, private companies and universities.

Enabling environment for re-engineering solutions
As water is part of our national risk registry, the Department of Trade and Industry (DTI, South Africa) launched the Industrial Pathway Action Plan (IPAP) 2017: Water and Sanitation. The purpose of the investment strategy is to invest in mechanisms to facilitate uptake of water-saving technologies. A similar IPAP strategy for LCD televisions saw significant local production at reduced costs compared to imports coupled with the job creation and significant market share. It is envisaged that a similar investment strategy will allow the entry of re-engineered solutions in the market that is being backed by standards development, including ISO standards for process performance of re-engineered toilets, and the comparison of sanitation-derived products to market-related products. A new Sanitation Policy (2017) provides motivation for water-saving and beneficiation of waste streams.

REFERENCES


Impact and Opportunities for the Urban Water Cycle of the ‘Fully Circular in 2050’ Target of the Netherlands - Circular Water 2050

K. Roest*, L. Snip**, L. Palmen***, A. Segrave****, H.J. van Alphen*****

* KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, kees.roest@kwrwater.nl
** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, laura.snip@kwrwater.nl
*** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, luc.palmen@kwrwater.nl
**** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, andrew.segrave@kwrwater.nl
***** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, henk-jan.van.alphen@kwrwater.nl

Abstract: The project’s aim is to develop a vision and roadmap(s) for the water sector, with a view to the national ‘A Circular Economy in the Netherlands by 2050’ programme. This involves the raw material efficiency in the urban water cycle, including the extraction and reuse of raw materials. The incoming and outgoing substance flows of the current water chain in the Netherlands have been mapped. The material flows are presented in the form of Sankey diagrams. An overview of possible conceptual and technological innovations that can be relevant for the water cycle in 2050 has been produced. Finally a circular system integration is needed. We investigated, described, discussed, defined and established what is meant in the water cycle with fully circular in 2050.

Keywords: Circular economy, resource recovery, water cycle

BACKGROUND A circular economy revolves around an efficient management of raw materials, including energy and water. Materials are given a second life through upgrading into renewable raw materials or through their reuse. The water sector translates this quest by cutting its use of the usual raw materials and by seeking alternatives for them through joint, practice-oriented research. The sector also works on the recovery and reuse of raw materials in the urban water cycle, which should reduce the emission of substances into the environment (Van Leeuwen et al. 2018). In the project we determine the different impacts and opportunities that the ‘fully circular in 2050’ target involves for the water sector. Drawing on different scenarios, one or more roadmaps are being produced charting the possibilities and opportunities for raw material efficiency, including energy and water. Starting from the situation today, the map(s) will assist in the realisation of a circular urban water cycle by the stated deadline. The programme’s added value, besides its substantive component, lies in the reinforcement of the collaboration between the different organisations, both within and outside of the urban water cycle.

OBJECTIVES The project’s aim is to develop a vision and roadmap(s) for the water sector, with a view to the national ‘A Circular Economy in the Netherlands by 2050’ programme. The project involves the raw material efficiency in the urban water cycle,
including the extraction and reuse of raw materials. We generate insights into where action is needed to bring about, or increase, circularity, and what the consequences might be.

In achieving our objective, we engage in a variety of activities:
- we reveal the nature of all the current incoming and outgoing material streams in the urban water cycle,
- we concretise the spot on the horizon: What does ‘fully circular in 2050’ mean for the urban water cycle?,
- we clarify the short- and long-term implications, opportunities, obstacles and risks related to achieving a fully circular urban water cycle in 2050, and the measures and actions required to get there.

**METHODOLOGY** In order to clarify which measures can be taken to achieve the fully circular water chain in 2050, insight is needed into which substance streams are currently used in the water chain and which leave the chain. By substance flows is meant here all raw materials and auxiliary materials, but also materials and energy that are used in the regular operations in the chain, or leave the chain as a residual flow. Opportunities are identified and created for circular applications for the water sector. Think of possibilities to use less primary raw materials and to close / shorten circles and to use residual flows of the one as raw material for the other, or to make process adjustments to make this (better) possible.

**RESULTS AND DISCUSSION** The incoming and outgoing substance flows of the current water chain in the Netherlands have been mapped. The material flows are presented in the form of Sankey diagrams. Characteristic of a Sankey diagram is that the width of the arrow, which represents the relevant energy or material flow, is proportional to the size of that flow. A list of possible conceptual and technological innovations that can be relevant for the water cycle in 2050 has been produced. Different definitions / descriptions are used for what should be understood under 'completely circular'. Does this mean, for example, that a residual material will have to be reused in the same process as an auxiliary substance or is 100% reuse of a residual in another process also to be regarded as completely circular? We investigated, described, discussed, defined and established what is meant in the water cycle with fully circular in 2050.

**CONCLUSIONS** The Circular Water 2050 project generates insights into where action is needed in the urban water cycle to bring about, or increase, circularity, and what impact and opportunities are involved. This give us a greater understanding of the nature of different incoming and outgoing material streams in the water sector, but also of the links with adjacent sectors like agriculture and industry. Knowledge and expertise will provide the basis for the organisation of circular chains, through the reuse of recovered raw materials or through their combination. The reduction in raw material consumption should also be underpinned and quantified. Moreover, citizens’ awareness will also be needed, so that they see the need for a circular urban water cycle and actively participate in its promotion. Ours is a broad-based commitment to a circular system integration.

This publication is produced within the Circular Water 2050 project, as part of the Joint Research Programme’s ‘Water in the Circular Economy’ initiative; carried out by KWR, STOWA/EFGF and AquaMinerals.

**REFERENCES**
Decentralised Water and Waste Treatment in View of Resource Recovery

S.W.H. Van Hulle*

*LIWET, Department of Green Chemistry and Technology, Ghent University Campus Kortrijk, B-8500 Kortrijk, Belgium

Abstract: The application of decentralised systems offers the benefit that transport of water, energy and nutrients is largely reduced. In order to demonstrate the potential of different techniques that can be used for decentralised treatment several pilot test are being conducted. Efficient water treatment for discharge, potable water production from secondary effluent and nutrient and energy recovery are demonstrated in Flanders and The Netherlands.

Keywords: Decentralised water treatment; resource recovery; pilot scale tests

In many parts of the world, including Flanders and the Netherlands, there will be many challenges in the coming years to build and/or upgrade water and waste treatment plants. Centralized systems can be used in case of high population density, but the continued growth and the lack of water treatment systems in peripheral zones increases the demand for use of decentralized systems. As this involves large investments, it is necessary to investigate which new, innovative and energy efficient systems can offer a sustainable solution that incorporate e.g. reuse of (rain)water and nutrients. The application of decentralised systems offers the benefit that transport of water, energy and nutrients is largely reduced (Libralato et al., 2012). In order to demonstrate the potential of different techniques that can be used for decentralised treatment several pilot test are being conducted. Efficient water treatment for discharge, potable water production from secondary effluent and nutrient and energy recovery are demonstrated.

A first case study consists of operating a temporary and mobile waste water treatment system at (music) festivals. Such multi-day events lay a heavy burden on the surrounding environment, especially in terms of (waste) water. As such, efficient water treatment is necessary. The system that was operated consists of a typical vertical flow wetland suited in a 15 m³ container. This container is filled with a gravel bed with plants on top. The grey water that needs treatment percolates through the filter material and is finally collected by a drainage network at the base of the container. The mobile system was operated at different music festivals during the 2017 and 2018 summer festival season. The obtained results indicate toward a good removal of COD, BOD, suspended solids and detergents. Discharge limits for BOD and suspended solids (the only parameters regulated for decentralised waste water systems in Flanders) were met. Through nitrification in the system, also ammonium is removed, but no full denitrification was obtained (as such, nitrate remains in the effluent). No phosphate removal was obtained. In Figure 1 the removal of different
parameters is demonstrated (76 m³ was treated in total). In the future (2019 edition) coupling with an off-grid drinking water production system is foreseen.

In a second case study, phosphate and nitrogen removal from goat milk company waste water effluent through low cost natural and commercial substrates was investigated. The wastewater in this case was already treated by a constructed wetland with lava rock substrate, but nutrient (especially phosphate) removal was insufficient to meet discharge limits. A column-adsorption system was built and tested with the various substrates to evaluate the adsorption capacity at equivalent hydraulic loading rate. The results of the experiments showed that iron oxides coated granules are both performing very well in removing phosphate. Remarkable about these substrates is that they are waste materials themselves, originating from the iron removal step during drinking water treatment (Vandermoere et al., 2018). As such waste material is used as resource for water treatment. A third case study deals with the separate treatment of grey, yellow and black water originating from an outdoor sports center in view of maximal recuperation. In total, about 350 litre per week of yellow water can be collected. This yellow water is ozonated for stabilisation and disinfection prior to application as fertiliser. The black water (+/- 17 m³ per week) will be treated in an MBR system, while the grey water (+/- 38 m³ per week) will be treated in a new type of aerated constructed wetland (with activated carbon and expanded clay as substrate), incorporated in the parking lot (www.rietland.com). A fourth case study deals with restaurant waste water treatment and re-use. A restaurant located in an area were no drinking water distribution and no sewer system is present (which is rather rare in Flanders) will be equipped with a 50 m² constructed wetland treating 3,5 m³ per day of waste water. This water will be treated further by a BOSAQ membrane filtration system (www.bosaq.com), producing about 2,4 m³ per day of potable water by membrane (UF-RO) filtration for the restaurant visitors. This amount is sufficient to supply all the potable water necessary for the restaurant (cooking, drinking, toilet flushing, …).

REFERENCES
Libralato, G., Ghirardini, A. V., & Avezzù, F. 2012. To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management. J. Environ Manage, 94(1), 61-68.

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Session 16

METALS RECOVERY
Membrane Electrolysis for Separation of Cobalt from Terephthalic Acid in Industrial Wastewater

R. Gao*, X. Dominguez-Benetton**, J. Varia, B. Mees, G. Du Laing, K. Rabaey

*Center for Microbial Ecology & Technology (CMET), Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Gent, Belgium, rui.gao@ugent.be
**Separation and Conversion Technologies, Flemish Institute for Technological Research (VITO), 8 Boeretang 200, 2400, Mol, Belgium, xochitl.dominguez@vito.be

Abstract: Recovery of valuable metals from wastewaters containing both metals and organics is challenging with current technologies, in part due to their interactions. Typical approaches are chemical intensive. Here, we developed a membrane electrolysis system coupled to an acidic and alkaline crystallizer to enable separate precipitation of the organics and metals without additional chemicals. The target industrial wastewater contained mainly terephthalic acid (TPA), benzoic acid (BA), p-Toluic acid (PA), cobalt (Co), and manganese (Mn). We examined the recovery efficiency of cobalt from two types of synthetic stream and the real process stream using several configurations. The alkaline crystallizer achieved a cobalt recovery efficiency of 94.51 ± 0.21 % (pH 11.37 ± 0.21) in batch tests of the simple synthetic stream (TPA and Co). Then, the system was operated continuously with complex synthetic stream (TPA, BA, PA, Co and Mn). The alkaline crystallizer achieved a cobalt recovery efficiency of 97.78 ± 0.02 % at pH 11.68 ± 0.02. A real stream was tested over 5 h runs in batch showing 82.92 ± 0.22 % cobalt recovery at pH 8.07 ± 0.02.

Keywords: metals organics separation; metal recovery; organics recovery

Modern industrial chemical production leads to more than 70,000 unique products. In many cases, metallic catalysts such as cobalt, silver and gold are used to enable conversion of organic compounds in chemical processing (Formalczyn, 2012). However, metals recovery from the waste streams is challenging due to interactions between residue metals and organics. Available treatment technologies such as ion-exchange resin, electrodialysis and electrocoagulation combined with electro Fenton are chemical intensive (Qiu et al., 2010; Kabdaşlı et al., 2010; Banasiak and Schäfer, 2009). In this work, we developed a novel membrane electrolysis system coupled to an acidic and an alkaline crystallizer (Figure 1) to enable simultaneous separation of organics and metals without the addition of chemicals.

Towards this goal, we work with a model stream, which is discharged by a chemical industry producing purified terephthalic acid (TPA) at high temperatures (80, 100 and 120°C), containing mainly terephthalic acid (TPA), benzoic acid, p-Toluic acid, cobalt and manganese. We evaluated the removal efficiency of cobalt from two types of synthetic stream and real stream. The cobalt was recovered as a brownish precipitate at pH 11.37 ± 0.21 with recovery efficiency of 94.51 ± 0.21 %. The concentration of cobalt in the effluent was only 1.71 ± 0.03 mg L⁻¹. The concentration of TPA in the effluent was 3.64 ± 0.64 mg L⁻¹ indicating the acidic crystallizer achieved a removal efficiency of 98.74 ± 0.22 % of TPA at pH 3.03 ± 0.18 in batch tests.

In a second phase, the system was operated continuously with a more complex synthetic stream containing multiple ions (TPA, benzoic acid, p-Toluic acid, cobalt and manganese). The cobalt was recovered as a dark brown precipitate in alkaline crystallizer at pH 11.68 ± 0.02 with a recovery efficiency of 97.78 ± 0.02%. The concentration of remained cobalt in the effluent was 0.62 ± 0.14 mg L⁻¹ over 144 h. The removal efficiency of TPA decreased to 61.18 ± 0.03 % (pH 3.71 ± 0.03). The concentration of remained TPA in the effluent was 74.51 ± 0.44 mg L⁻¹. In a third phase, the system was operated with real wastewater. The concentration of TPA in the real stream was 240 mg L⁻¹, which...
was higher than 200 mg L$^{-1}$ in the synthetic stream. However, the concentration of cobalt in the real stream was lower than synthetic stream, which was only 10 mg L$^{-1}$. Real stream was tested over 5 h runs showing decreased removal and recovery efficiency of TPA and cobalt with 31.08 ± 1.01% (pH 2.71 ± 0.12) and 82.92 ± 0.22% (pH 8.07 ± 0.02), respectively.

In our research, a membrane electrolysis system with an acidic and alkaline crystallizer system was developed and tested. We introduce a novel system design resulted in the simultaneous separation of TPA and cobalt without additional chemicals or adsorption materials. The system achieved an excellent recovery efficiency of cobalt from the stream with or without multiple ions is 94.51 ± 0.21% and 97.78 ± 0.02%, respectively. Also, the removal efficiency of TPA 98.74 ± 0.23% in a simple stream a lower efficiency of 61.18 ± 0.03% with multiple ions. However, the system with the real process stream achieved a low removal efficiency of TPA at 31.08 ± 1.01%. The cobalt in the process stream is hard to be precipitate into valuable forms. Therefore, the system still needs further development to deal with matrix effects.

![Figure 1.1 Schematic of membrane electrolysis system (two compartment cell with an acidic and alkaline crystallizer)](image)

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**REFERENCES**


Detection, Removal and Recovery of Metals from Water, Sludge and Fly Ash

K. Roest*, E. de Buijzer**, L. Palmen***, J. Muñoz Sierra****

* KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, kees.roest@kwrwater.nl
** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, edwin.de.buijzer@kwrwater.nl
*** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, luc.palmen@kwrwater.nl
**** KWR Watercycle Research Institute, Post Box 1072, 3430 BB Nieuwegein, The Netherlands, julian.munoz@kwrwater.nl

Abstract: The focus of water treatment is increasingly shifting to the recovery of raw materials, partly stimulated by the quest for a circular economy. Drinking water companies, Water Authorities and sludge final-processors are particularly concerned with the recovery and useful reuse of residuals. Besides water, phosphorus and cellulose there are also opportunities for the recovery of (rare) heavy metals and earth metals, including copper, zinc, cobalt, silver, gold and palladium. Apart from the benefits of recovering metal/metals, the removal of metals improves effluent quality, sludge quality and residual ash, and therefore opens alternative disposal possibilities.

Keywords: Metal detection; metal recovery; water cycle

INTRODUCTION AND RESEARCH DESCRIPTION
Metals are used in many processes, but heavy metals and rare earth metals are becoming more scarce, while demand is increasing (Binnemans et al. 2013). There are predictions that some metals, such as antimony, indium, silver, copper, titanium and tantalum, cannot be mined any more within less than 50 years (Swain et al 2012). Mining is associated with substantial costs and environmental degradation and with some ore grades currently as low as 1-2g/t there is a need to look for other sources of these metals. Research focused on recovery of metals or secondary raw materials is promoting a shift in perspective from environmental impacts to circular economy (Quina et al. 2018). The water sector also works on the recovery and reuse of raw materials in the urban water cycle, which should reduce the emission of substances into the environment and facilitate beneficial reuse (Van Leeuwen et al. 2018). At the start of this research, knowledge about the load and concentration, in combination with the speciation (appearance) of metals in the water and sludge processing cycle was insufficient to provide the basis for selection of a suitable applicable metal recovery technology. Phase 1 of this project started with the development of a method for sample pretreatment and validation of a metal-concentration measurement based on inductively coupled plasma mass spectrometry (ICP-MS). ICP-MS was used for the detection of 66 elements, metals and several non-metals, in principle at concentrations as low as one part in 1015 (part per quadrillion, ppq) on non-interfered low-background isotopes. On the basis of this method, we researched what concentrations and speciation (i.e., total, dissolved/colloidal, residual) of heavy and rare (earth) metals,
occur in different streams in drinking water, wastewater treatment and sludge final-processing (Figure 1.1). These monitoring results have been used to assess the potential of various technologies (new and newly-applied) for the removal and/or recovery of selected metal(s) from water – i.e., (sources of) drinking water, membrane concentrate, WWTP influent and effluent – wastewater treatment sludge and fly ash of incinerated surplus sludge. In Phase 2 of the project the effectiveness of the selected technologies has been tested on a small scale for selected streams with the aim to test its feasibility. This research focused on the application of ion exchange and selective metal precipitation from wastewater and leached fly ash. Special attention was paid to the metals copper, zinc, cobalt, iron, lithium, titanium, wolfram, palladium, silver and gold.

DISCUSSION AND CONCLUSIONS Metals from different sources, such as medicines, auto catalysts and (industrial) processes, end up in the water cycle. We still have a lot to learn about the load and concentration of metals in the water cycle, in combination with speciation (appearance), which provides the basis for the development of a suitable recovery technology. In this study we analysed the concentrations of 66 elements in the water cycle. In the Netherlands, yearly individual loads above 1,000 kg have been measured for copper, cerium, chromium, lanthanum, lead, nickel, gallium, tin and tungsten. In comparison to some ores, several metals are present in relatively high concentration in ash from incinerated sludge. Especially in combination with intended phosphorus recovery from this ash, there is potential for recovery of (scarce) heavy metals and rare earth metals, including copper, zinc, gold and palladium. The effectiveness of ion exchange and precipitation was tested on a small scale for removal and possible specific recovery of selected metals like copper, zinc, cobalt, iron, lithium, titanium, wolfram, palladium, silver and gold (Figure 1.2.). Moreover, removing these metals improves the quality of the water, sludge and residual ash, and thereby opens easier disposal possibilities for these residuals as well. The predictions that some metals such as antimony, indium, silver, copper, titanium and tantalum cannot be mined anymore in the near future, further strengthens the potential to recover scarce metals from the water cycle.

Figure 1.1 Sampled and analysed streams in the water cycle and surplus sludge processing.
Figure 1.2 Experimental results with wastewater treatment plant influent and sludge fly-ash applying precipitation, ion-exchange for removal and possible specific recovery of selected metals.

ACKNOWLEDGEMENTS This project is a collaboration of Waterschapsbedrijf Limburg, Waterschap Vallei en Veluwe, Waterschap Rijn en IJssel, Oasen, HVC, GMB, Hoogheemraadschap van Delfland, Hoogheemraadschap van Rijnland, Hoogheemraadschap van Schieland en de Krimpenerwaard, Waterschap Hollandse Delta, Waterschap Rivierenland and KWR Watercycle Research Institute. This activity is co-financed with PPS-funding from the Topconsortia for Knowledge & Innovation (TKI’s) of the Dutch Ministry of Economic Affairs and Climate.

REFERENCES
Towards Lithium Selective Membranes: Crownether Containing Poly-electrolyte Multilayer Membranes

M. Kazemabad*, A. Verliefde**, E.R. Cornelissen***, A. D’Haese****

*Particle and Interfacial Technologies group, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000, Ghent, Belgium, Mohammad.kazemabad@ugent.be
** Particle and Interfacial Technologies group, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000, Ghent, Belgium, Arne.verliefde@ugent.be
*** KWR Water Cycle Research Institute, Groningenhaven 7, 3433 PE, Nieuwegein, the Netherlands, Emile.Cornelissen@kwrwater.nl
**** Particle and Interfacial Technologies group, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000, Ghent, Belgium, Arnout.dhaese@ugent.be

Abstract: The growing need of industries in lithium can be answered with alternative sources. However, most of these sources contain high amounts of chemically and physically similar Na, K and Mg. Achieving monovalent cation selectivity in membranes can have a major impact in introducing them to lithium mining industry. In this study, we have embedded 15-crown-5 ether, a cation selective moiety in the Polyethylenimine (PEI) chain, which was used to prepare polyelectrolyte multilayer membranes. The resulting membranes were characterized in terms of stability, thickness and water and solute permeability. It was shown that manufactured membranes showed Li/K selectivity for a period of 90 minutes, and increased salt rejection properties. Moreover, stability of the membranes at high salinities was evaluated.

Keywords: Lithium selectivity; crown ethers; polyelectrolyte multilayer membranes

RESULTS AND DISCUSSIONS A derivative of 15-crown-5 was synthesized and covalently attached as a pendant group to the PEI chain. The synthesized modified PEI was characterized by the help of HNMR and purity and crownether/monomer ratio of 1:44.2 was determined.
The modified PEI was then used as poly cation in combination with poly styrene sulfonate (PSS) as poly anion to prepare a PEMM. The performance of the membranes from modified and unmodified polymers were studied and compared. In agreement with the literature, PEMMs manufactured from unmodified PEI, showed a non-selective monovalent salt rejection behaviour in the range of loose NF membranes. In contrast, modified PEMMs showed an initial preference for the transport of potassium and hindering of lithium. This initial selectivity was gradually lost after a period of around 90 minutes. It is hypothesized that all crownether moieties are saturated at this point. Therefore, two zones could be differentiated in the modified membranes’ performance: a transient (grey zone in the Figure 1.1) and a steady state. Salt and water permeability of the membrane in both of these states (Table 1.1) is discussed.

PEMMs are known to be sensitive to high salinity and extreme pH. Since one of the possible alternative lithium resources is the brine from RO desalination plants, it was crucial to study stability of the membranes in high salinities. To do this, quartz crystal microbalance with dissipation (QCM-D) was used to track loss of the active layer of the polyelectrolyte films. It was established that modified membranes experience a 20% loss of their active layer at the first contact with the saline solutions, but remain stable thereafter until a concentration of 4.75M NaCl. Unmodified PEI/PSS multilayers were stable and didn’t show observable active layer loss.

**IMPACT** Cation selectivity of the PEMM membranes with crownether moieties in their structure is proven in this study. As such, this study not only reports on a monovalent selective membrane, but also functions as a proof of concept and provides suggestions for preparing membranes with selectivity for other metals. The authors postulate that replacing the chosen crownether with other ligands of this family results in membranes with different selectivities. It should be noted that the synthesis route of the crown ether moiety is not exclusive to the 15-crown-5. Different crown ethers can be synthesized via the same route by changing the ether precursor (here bis[2-(2-chloroethoxy)ethyl]ether). The presented synthesis procedure can thus be used for other cation/crown ether pairs as well.

**Figure 1.1** Lithium-Potassium selectivity as a function of time for modified and unmodified membranes. The grey zone indicates the transient zone where membranes are selective.

**Table 1.1** Water permeability (A) and cation permeability (B) of the modified and unmodified membranes.

<table>
<thead>
<tr>
<th>Membrane</th>
<th>A (m⁻²·bar⁻¹)</th>
<th>B_Li (m/s)</th>
<th>B_K (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unmodified PEI/PSS</td>
<td>4.53 ± 0.49 E-7</td>
<td>7.01 ± 0.03 E-8</td>
<td>6.83 ± 2.36 E-8</td>
</tr>
<tr>
<td>modified PEI/PSS</td>
<td>1.26 ± 0.08 E-7</td>
<td>1.40 ± 0.10 E-8</td>
<td>8.87 ± 2.57 E-9</td>
</tr>
</tbody>
</table>
REFERENCES


Yang, S., Zhang, F. & Ding, H., 2018 Lithium extraction from seawater. *Joule* 9, 1648-1651.
An Integrated Approach for HCl and Metals Recovery from Waste Pickling Solutions: Pilot Plant Design and Operations


*Dipartimento di Ingegneria Chimica, Gestionale, Informatica, Meccanica, Università di Palermo – Viale delle Scienze ed.6, 90128 Palermo, Italy, rosa.gueccia@unipa.it
Fraunhofer Institute for Solar Energy Systems ISE Heidenhofstraße 2, 79110 Freiburg, Germany, Daniel.Winter@ise.fraunhofer.de

Abstract: Continuous regeneration of industrial pickling solutions and recovery of valuable materials are implemented in a pilot-scale plant including diffusion dialysis, membrane distillation and reactive precipitation units. The main results of the preliminary assessment of on site operation are presented. Different hydrochloric acid concentration and metals composition were investigated and the performance of the system were analysed in terms of quality of recovered compounds, energy efficiency and environmental footprint.

Keywords: industrial wastewater; acid recovery; membrane technologies

Pickling is one of the key steps in the hot-dip galvanizing process, where HCl solutions are largely used thus generating spent waste liquors containing acids and metals in high concentration. Disposal of the industrial pickling waste dramatically affects the hot-dip galvanizing process economics and environmental footprint. Thus, reducing acid waste disposal is one of the most beneficial steps to enhance the process sustainability.

Continuous regeneration of pickling solutions enhances pickling rate and process performance, but also minimises industrial wastewater disposal and chemicals consumption. The recovery and recycling process of valuable substances (e.g. acid, metals and aqueous streams) can be accomplished by coupling two important cutting-edge membrane technologies: diffusion dialysis (DD) and membrane distillation (MD) (Tomaszewksa et al., 2001, J. Luo et al., 2011). A demonstration pilot-scale plant was purposely designed and build as a final outcome of 2 years modeling and experimental activities carried out within the EU-H2020 funded ReWaCEM project (Randazzo et al., 2018, Rewacem Project). The Demo plant consists of a DD unit, where HCl is recovered, an MD unit, where HCl is concentrated and fresh water recovered, and a reactive precipitation unit, where Fe, trapped in the outlet solution from the diffusion dialysis, is recovered as iron hydroxide, which is a valuable product. As a by-product, also an ammonium hydroxide/zinc chloride solution is produced, useful in the fluxing bath of the hot-dip galvanizing plant. A schematic of the developed process is reported in Fig. 1.

The pilot unit is able to operate in stationary mode and guarantee the continuous regeneration of the pickling solution at the optimal conditions in terms of HCl and Fe concentration (Randazzo et al., 2018). Moreover, also a recovery of waste heat
(necessary for the MD operation) is performed, thus contributing to enhance process sustainability.

In the present work, the results of the first assessment of the on site operation of the pilot plant are presented. Several experiments were carried out to test the Demo operation and assess its performances in terms of materials recovery and energy efficiency, aiming at dramatically reducing spent pickling solution disposal and recover valuable materials.

Acknowledgments

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REFERENCES


Rewacem Project, www.rewacem.eu
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Session 17

MICROALGAE-BASED PROCESSES
Application of Microalgae for Wastewater Treatment and Recovery of Bioenergy and High-Value Bioproducts


*GEMMA - Environmental Engineering and Microbiology Research Group, Universitat Politècnica de Catalunya, c/ Jordi Girona 1-3, Building D1, E-08034 Barcelona, Spain, larissa.arashiro@upc.edu

**Department of Green Chemistry and Technology, Ghent University Campus Kortrijk, Graaf Karel de Goedelaan 5, 8500 Kortrijk, Belgium

Abstract: Resources recovery from wastewater has been addressed as a key element towards a circular economy within the water cycle. Microalgae-based systems are widely used for algal biomass growth but also as efficient systems for nutrient and energy recovery when combined with wastewater treatment. This research assessed the performance of a high rate algal pond (HRAP) and photobioreactors (PBRs) in terms of wastewater treatment efficiency and the potential to recover energy through biogas and to extract pigments from the biomass. Results indicated that efficient wastewater treatment was achieved (removing up to 92% of NH4+-N and 55% of COD). The production of biogas from the biomass grown in the HRAP (207-258 mL CH4/g VS), as well as the extraction of phycocyanin (PC) and phycoerythrin (PE) from the cyanobacterial biomass grown in the PBRs (up to 14.1 mg PC/g DW and 6.36 mg PE/g DW) were successfully achieved.

Keywords: Microalgae; resources recovery; wastewater treatment

INTRODUCTION Microalgae-based wastewater treatment systems have received renewed interest due to their potential capacity to not only remove pollutants from wastewater, but also to generate bioproducts from microalgal biomass, including bioenergy, nutrients and valuable compounds (Van den Hende et al., 2016; Solé-Bundó et al., 2017). In this context, this research aimed to investigate the use of microalgae-based systems (high rate algal ponds - HRAPs and photobioreactors - PBRs) to treat urban wastewater and the biomass valorisation for recovering bioenergy (i.e. biogas) and valuable bioproducts (e.g. phycobiliproteins).

MATERIALS AND METHODS The experimental set-up treating real municipal wastewater (UPC-Barcelona) consisted of a primary settler, a HRAP (470L) and a secondary settler. The biomass grown in the HRAPs, which consisted mainly of green microalgae (e.g. *Chlorella* sp.) and diatoms, was later thickened and used to carry out a biochemical methane potential (BMP) test (Figure 1.1). Co-digestion of microalgae and primary sludge (1:1, w:w) and thermal pre-treatment (TPT), at 75°C during 10h, were also investigated.

Figure 1.1 Scheme of the microalgae-based wastewater treatment pilot plant located at UPC (Barcelona, Spain).

Part of the secondary effluent was used to feed two lab-scale PBRs (2 L), mixed with centrate from an anaerobic digester to obtain two different volume ratios of HRAP effluent:centrate: 5:1 in PBR 1 and 3:1 in PBR 2. The biomass grown in the PBRs, which consisted mainly of cyanobacteria (*Phormidium* sp. and *Nostoc* sp.), was subjected to freeze-thawing and ultrasonic cycles in sodium phosphate buffer at pH 7. The supernatant was collected and measured in a spectrophotometer (λ = 562, 615 and 652 nm) for quantifying the phycobiliproteins. Physicochemical parameters were monitored on a regular basis in the HRAP and PBRs.
**RESULTS AND DISCUSSION** The results obtained over a period of 260 days operating the HRAP and 60 days operating the PBRs showed that both systems could be effectively used for wastewater treatment as relatively low effluent concentrations are obtained (even in PBR2, which had higher influent concentrations). The average values for wastewater parameters are shown in Table 1.1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HRAP Influent (mg/L)</th>
<th>HRAP Effluent (mg/L)</th>
<th>Removal (%)</th>
<th>PBR1 Influent (mg/L)</th>
<th>PBR1 Effluent (mg/L)</th>
<th>Removal (%)</th>
<th>PBR2 Influent (mg/L)</th>
<th>PBR2 Effluent (mg/L)</th>
<th>Removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS</td>
<td>201 ± 132</td>
<td>52 ± 37</td>
<td>78 ± 19</td>
<td>167 ± 120</td>
<td>65 ± 48</td>
<td>61 ± 52</td>
<td>117 ± 100</td>
<td>71 ± 67</td>
<td>40 ± 35</td>
</tr>
<tr>
<td>VSS</td>
<td>185 ± 112</td>
<td>49 ± 32</td>
<td>77 ± 19</td>
<td>88 ± 70</td>
<td>38 ± 26</td>
<td>57 ± 53</td>
<td>71 ± 60</td>
<td>55 ± 35</td>
<td>23 ± 12</td>
</tr>
<tr>
<td>COD</td>
<td>353 ± 208</td>
<td>114 ± 65</td>
<td>62 ± 22</td>
<td>150 ± 47</td>
<td>73 ± 31</td>
<td>53 ± 25</td>
<td>230 ± 57</td>
<td>97 ± 45</td>
<td>55 ± 25</td>
</tr>
<tr>
<td>NH₄⁺-N</td>
<td>24 ± 11</td>
<td>1.5 ± 1.3</td>
<td>93 ± 6</td>
<td>28 ± 4</td>
<td>2 ± 1</td>
<td>92 ± 13</td>
<td>55 ± 8</td>
<td>8 ± 6</td>
<td>83 ± 21</td>
</tr>
<tr>
<td>TP</td>
<td>2.3 ± 1.8</td>
<td>1.7 ± 1.4</td>
<td>37 ± 52</td>
<td>3.9 ± 4.3</td>
<td>0.1 ± 0.4</td>
<td>88 ± 51</td>
<td>6.6 ± 8.5</td>
<td>0.1 ± 0.3</td>
<td>92 ± 34</td>
</tr>
</tbody>
</table>

Figure 1.2a shows the results of the BMP test, with a methane yield ranging from 207 to 258 mL CH₄/g VS and co-digestion reaching the highest yield. Figure 1.2b shows the average amount of phycocyanin (PC) and phycoerythrin (PE) extracted from the biomass grown in each PBR (no significant differences observed between both PBRs). Results were similar to the productivity of 16.9 mg PC/g DW reported by Wood et al. (2015), who also used wastewater to grow cyanobacteria.

The experiment showed that the coupling of HRAPs and PBRs can be effective for urban wastewater treatment, highlighting the potential use of wastewater as a growth medium for cyanobacteria to reduce the production cost of phycobiliproteins, while recovering energy through biogas from residual biomass. Further studies are being carried out to investigate the use of other microalgal species treating saline wastewater.

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**REFERENCES**


Recovery and Recycling of Nutrients from Wastewater with Algae


*AlgEn, algal technology centre, Ile, Brmčičeva 29, Ljubljana, Slovenia; maja@algen.eu, ana@algen.eu, borut@algen.eu, matej@algen.eu, robert@algen.eu
**University of Ljubljana, Biotechnical faculty, Agricultural department, Jamnikarjava 101, Ljubljana, Slovenia; rok.mihelic@bf.uni-lj.si, lara.resman@bf.uni-lj.si

Abstract: Algal pond systems (APS) are being tested at the demo sites in Slovenia and Spain to evaluate and optimise the resource recovery from wastewaters by algae and the subsequent valorisation of algal biomass as a secondary raw material for various products, namely material fillers, biogas substrate, agricultural biostimulants and fertilisers. When APS was used to treat the digestate from a thermophilic biogas plant, the maximum volume treated daily in 100 m² main pond was 500 L, with an average 90% COD reduction (COD in digestate was in the range 6000 – 10.000 mg/L), 91% N removal, 64% P removal and biomass production of up to 30g/m²day¹ in the summer months. For biogas production, a pre-treatment of biomass is needed to increase the biogas production, most efficient method being a thermal pre-treatment. Thermal pre-treatment proved to be most efficient also for the biostimulative effects on crops in the preliminary testing.

Keywords: Algae; demo site; wastewater

Algae are an efficient organism for the nutrient recovery from various wastewaters (WW). Their biomass can be further exploited as a secondary raw material for the production of fertilizers, animal feed, biofuels or higher-added-value products like agricultural biostimulants. Remaining water can be returned to the environment, recycled back to technological processes or used for the irrigation in agriculture.

Utilization of WW as a nutrient source for algal growth greatly reduces the expenses of biomass production. Algal pond systems (APS) use the symbiotic relationship of algae and bacteria to uptake the nutrients and organic matter from the wastewater. Instead of energy demanding aeration, APS use algal photosynthesis to provide the necessary oxygen to bacteria. Additionally, algae can produce biomass by utilizing CO₂ from the fuel/industry gases, improving the carbon footprint. To make the algal production truly economically viable, further research and development is needed for the optimization (Sutherland et al. 2015).

DEMO SITES Demo site in Ljubljana (Slovenia, Figure 1.1) is operating continuously already since 2013, demonstrating the algal-bacterial treatment of biogas digestate. It consists of two algal ponds, 100 m² main pond for the wastewater treatment and biomass production, and 10 m² inoculation pond for the continuous inoculation culture. The system is connected to SCADA and controlled online, collecting the data of relevant parameters. CO₂ is provided from a fuel gas from the nearby biogas plant through diffusor in the ponds. Harvesting is performed with the sedimentation and DAF. In 2017, the demo was complemented with a two-phase anaerobic digestor and processes adapted to a higher salinity.
A new APS is being built at the demo site in Seville (Spain), to treat the wastewater from slaughterhouse (project Water2Return). Two inoculation ponds and almost 400 m² main pond will be fed with a digestate from anaerobic digester, following the wastewater pretreatment with nitrogen extraction and Bacillus fermentation. Additionally, various APS were developed and are now being tested on a smaller scale in the Algae Park (Ljubljana, Slovenia).

To valorize the produced algae, the biomass is utilized for several products: biogas substrate (AlgaeBioGas), material fillers (Saltgae), agricultural biostimulants and fertilizers (Water2Return).

**FINDINGS** In the first years of operating the Ljubljana demo centre, APS was used to treat digestate from a thermophilic biogas plant. The maximum volume treated daily in 100 m² main pond was 500 L, with an average 90% COD reduction (COD in digestate was in the range 6000 – 10,000 mg/L), 91% N removal, 64% P removal and biomass production of up to 30 g/m²day⁻¹ in the summer. APS enabled also effective use of the excess heat and odor reduction. The algal-bacterial community changed between winter and summer. For biogas production, tests showed a pre-treatment of biomass is needed to increase the biogas production. The most efficient method was thermal pre-treatment, which increased the methane production for 62% (Lavrič et al. 2017). The biomass proved to be a good filler for materials.

To test biostimulative effects, the produced microalgal biomass was subjected to several different pre-treatments (ALG - no treatment, ALG+90 - thermal pre-treatment, ALG+EM - fermentation using commercial microorganisms, ALG+E - enzymatic pre-treatment) and the effect of cell lysis was observed microscopically. The biostimulation effect of ALG, ALG+90 and ALG+EM was tested on the garden cress Lepidium sativum (test in Petri dishes) and barley Hordeum vulgare (between paper method) germination in comparison with the deionised water (control).

The untreated microalgae biomass and extracts had negative effect on the garden cress seed germination if concentrations were ≥ 1% (volume percentage). Thermally digested microalgae biomass from the first batch (Nov. 2017) expressed distinctly pronounced root growth, 2.2-times longer roots compared to the control, while no biostimulating effect was observed with products from the second batch (April 2018). Microscopic pictures showed the most efficient cell lysis at high temperature pre-treatments.

In conclusion, APS can be used for the resource recovery from wastewater and algal biomass further as a secondary raw material for various products.

**REFERENCES**

algaebiogas.eu, Saltgae saltgae.eu, Water2Return water2return.eu


Integration of Microalgae Culturing as a Side-Stream Process into Wastewater Treatment Plants: An LCA Evaluation

L. Rigamonti*, C. Tua**, E. Ficara***

*Politecnico di Milano, Department of Civil and Environmental Engineering (DICA), Piazza Leonardo da Vinci 32, 20133, Milano, lucia.rigamonti@polimi.it
**Politecnico di Milano, DICA, Piazza Leonardo da Vinci 32, 20133, Milano, camilla.tua@polimi.it
***Politecnico di Milano, DICA, Piazza Leonardo da Vinci 32, 20133, Milano, elena.ficara@polimi.it

Abstract: The IMAP Project aims to investigate the integration of a microalgae culturing within an existing wastewater treatment plant in the surroundings of Milan. In this facility, microalgal open ponds have been designed to be fed with the supernatant from the digestate dewatering, rich in nutrients, and with the CO2 from the flue gas from the combined heat and power unit. The produced algal biomass is sent to the anaerobic digesters for an extra-production of biogas. This paper deals with the Life Cycle Assessment analysis of the system, carried out to evaluate possible environmental improvements in the wastewater treatment due to the new algal unit.

Keywords: microalgae; Life Cycle Assessment (LCA); WasteWater Treatment Plant (WWTP)

Microalgae are microscopic, photosynthetic organisms, with simple growing requirements that can be used as source of food, feed, fine chemicals/pharmaceuticals. Due to their high oil and carbohydrate content, they can also be converted into liquid fuels as well as into gaseous energy carriers. In the latter applications wastewater can be used as water and nutrient source to improve process sustainability (Collotta et al., 2018). For example, centrate from the anaerobic digestion of municipal sludge can be used as a culture medium, with a high removal nutrients rate and extra-production of biogas (Cho et al., 2013; Marazzi et al., 2019).
In the studied system, the algal cultivation area was set at 0.1 m²/P.E. (i.e. in a land restricted area) and, at the full scale, will comprise open ponds with an average biomass productivity rate of 7.8 g SS/m²/day (275 days of annual operativity for 20 years). The pond design was selected according to the criteria of environmental sustainability. Microalgae will be fed with the supernatant from the digestate dewatering, rich in nutrients, and the flue gas from the Combined Heat and Power (CHP) unit of the facility with a CO₂ content equal to 11% v/v. The produced microalgal suspension will be sent to the anaerobic digesters, where it will be partially converted into biogas with extra energy production in the CHP unit. The remaining biosolids will be subjected to a recovery treatment (Figure 1.1).

![Figure 1.1 Analysed system with the main input and output flows.](image)

The environmental performances of the new system were evaluated by using the LCA methodology. Only the processes that differ between the current wastewater treatment and the future treatment were included, i.e. microalgal ponds construction, flue gas pre-treatment before its injection into the ponds, treatment of the residual biosolids, variation of the direct air emissions from the WWTP, and variation of the electric energy consumption from the Italian grid by the WWTP. The chosen functional unit was the treatment of 1,000 m³ of wastewater entering the facility. The system was modelled mainly with primary data deriving from measurement campaigns at the algal pilot plant and at the other analysed WWTP units, assuming the year 2017 as the reference period. Thirteen impact categories on the environment and the human health, the cumulative energy demand indicator and two indicators about the consumption of water and soil were calculated.

REFERENCES


Use of Microalgae Grown on Fish Tank Residual Nutrients as Feed for Copepods to Enable Circular Bio-Economy in Aquaculture

L.A. Ahrens *, A.M. Christensen ***, C.O. Letelier-Gordo***, S. Trapp*, B. Valverde-Pérez

* Technical University of Denmark, Department of Environmental Engineering, Building 113, DK-2800 Kgs. Lyngby, Denmark (Corresponding author: bvape@env.dtu.dk)
** Technical University of Denmark, DTU Aqua, Section for Oceans and Arctic, Kemitorvet, Building 202, DK-2800 Kgs. Lyngby, Denmark.
*** Technical University of Denmark, DTU Aqua, Section for Aquaculture, The North Sea Research Centre, DK-9850 Hirtshals, Denmark.

Keywords: Green micro-algae; nutrient recovery; aquaculture

Aquaculture involves farming freshwater and saltwater fish populations under controlled conditions, mainly for producing food. While some aquaculture practices may have ecological benefits (e.g., cultivation of shellfish may act as filter improving water quality), tank effluents often have high nutrient and organic carbon content which need to be treated either before recirculation to the tanks or discharge to the environment (Bregnballe, 2015). So far, the use of biofilters for nitrification-denitrification is the most widely applied practice for water remediation. Treatment of these effluents with green microalgae enables nutrient capture and valorisation as an alternative protein source and is less resource intensive than conventional treatments (Rasouli et al., 2018). Furthermore, algae are rich in pigments that are valuable antioxidants, like carotenoids. Algae can be harvested and added as ingredient for different feeds for animals. Yet, the cost of harvesting and downstream processing is rather high and usually makes the overall process unfeasible. Thus, alternative harvesting methods are needed to ensure feasible nutrient recovery via green microalgae cultivation.

This study will focus on the development and optimization of algal cultivation, which aims to balance protein, lipid and pigment production to maximize the overall nutritional value of microalgae. The algae will be cultivated in the effluent from a 1500 ton/year production of yellowtail amberjack (Seriola lalandi), previously treated with a biofilter, drum filters and UV light. The sampling protocol consisted in 24 h pool samples, with a sampling frequency of an hour. Three different solid retention
times will be applied and nutrient removal and macromolecular algal biomass composition (including protein, carbohydrate, lipid and pigment content and quality) will be characterized. Two different algal species will be compared, namely Tetraselmis sp. and Rhodomonas salina.

Algal biomass can be employed as part of the feed formula for fish and crustaceans. However, harvesting cost (e.g., flocculation, drying, etc.) are usually the bottleneck for full scale commercialization. Hence, this study explores the use of algae cultured in residual nutrients as feed for the copepod Acartia tonsa. Contrary to algae, copepods are easier to harvest due to its larger size. Furthermore, copepods can be used as feed for fish larvae, without the need of further processing, offering a cost-efficient alternative to normal microalgal biomass utilization. Copepod macromolecular composition will be monitored as well, and benchmarked against existing literature.

This study will serve as proof of concept for a new value chain in aquaculture, which follows the model of circular bio-economy.

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HIGH VALUE CHEMICALS/MATERIALS RECOVERY
Photoelectrocatalytic Production of Hydrogen and Commodity Chemicals from Desalination Brine

L. Mu*, W.A. Tarpeh*

*Dept. of Chemical Engineering, Stanford University, Stanford CA 94305 USA  wtarpeh@stanford.edu

Abstract: Desalination is a promising approach to convert seawater and brackish water into potable fresh water; however, widespread implementation is limited by high process inputs (e.g., energy, cost) and inadequate brine management. Recovering value-added products such as energy and commodity chemicals from concentrated brine could potentially address both challenges. In the proposed research, we apply photoelectrochemical water splitting and salt splitting to generate hydrogen fuel (H₂), sodium hydroxide (NaOH), and hydrochloric acid (HCl) from desalination brine. Particularly in a world facing water scarcity, potable water is not an ideal influent for water splitting. Salt splitting is used to generate acids and bases from various salts; using sodium chloride requires controlling chloride oxidation. With this approach, we reimagine “waste” brine as a source of valuable products: fuel, acids, and bases.

Keywords: water splitting; electrochemistry; salt splitting

INTRODUCTION

Desalination plants generate brine at 55% of the volume of collected seawater (Meneses et al., 2010), meaning over 13 million m³ of brine are produced daily around the world (Lattemann and Höpner, 2008). Managing this large volume of brine contributes considerable costs, energy input, and environmental impacts relative to the entire desalination process (Elimelech and Phillip, 2011). All three barriers limit desalination and scale with its adoption (Tong and Elimelech, 2016). Recovering valuable products from brines increases the control volume for the system under consideration, effectively increasing the costs, energy inputs, and environmental impacts of business as usual to include brine management and conventional production. Achieving several goals simultaneously may increase the competitiveness of resource-efficient brine treatment, but requires multiscale evaluation of a combined process and comparison with existing practice.

Generating commodity chemicals facilitates integration with existing supply chains, consumers, and transport. In particular, hydrogen gas, sodium hydroxide, and hydrochloric acid can all be used on-site at desalination plants, which avoids transport and facilitates decentralized treatment. In this project, we focus on identifying and characterizing potential catalysts for selective oxidation of water over chloride to enable HCl production.

MATERIALS AND METHODS

Photoanodes were fabricated according to previous work (Mu et al., 2016). Sodium and chloride concentrations were measured by dual ion chromatographs (Dionex, ThermoFisher) at regular time points during operation. Electrochemical cells were fabricated using polycarbonate housing and ion exchange membranes (Fumatech). Nanopure water was fed into each electrode compartment.
Reactors were operated in batch mode with recirculation, and then continuous flow. In both cases, grab samples were taken at regular times to characterize concentration trends. Hydrogen and oxygen were measured by in-line gas chromatography.

RESULTS AND CONCLUSIONS Four anodes were evaluated for their activity toward oxygen evolution over chloride oxidation: strontium titanate (SrTiO3), iridium-coated titanium mixed metal oxide, aluminium fluoride (AlF3/Al) and indium tin oxide (ITO) glass. Based on promising selectivity, SrTiO (Mu et al., 2016) was nanopatterned and exhibited a sixfold increase when combined with Pt-CuOx (Figure 1.1). For all experiments, elemental iron was used as an electrocathode. Photoanodes were also evaluated at the device level and compared for brines of varying NaCl concentration (Figure 1.2).

Conclusions from this project will introduce photoanodes that selectively oxidize water over chloride, enabling recovery of HCl and NaOH from desalination brines. Hydrogen fuel is also generated as a by-product via cathodic hydrogen evolution. Recovering commodity chemicals and fuels from desalination brine can offset costs of operating desalination plants through on-site use and off-site revenue generation. In future work, we plan to assess life-cycle impacts of conventional and recovery-oriented desalination, including greenhouse gas emissions, energy input, and costs.

Figure 1.1 Increase in hydrogen and oxygen gas evolution observed after nanopatterning SrTiO3 catalysts.

Figure 1.2 Schematic of photoelectrochemical water-salt splitting to produce HCl, NaOH, and H2 from desalination brine.

REFERENCES
Production of N-Caproate from Food Waste Without pH Control: Consecutive Lactate Formation and Chain Elongation

C. A. Contreras-Davila*, C. J. N. Buisman**, D. P. B. T. B. Strik***

* Environmental Technology, Wageningen University & Research, carlos.contrerasdavila@wur.nl
** Environmental Technology, Wageningen University & Research, cees.buisman@wur.nl
*** Environmental Technology, Wageningen University & Research, david.strik@wur.nl

Abstract: Biological chain elongation allows the recovery of carbon and value from waste streams by the production of medium-chain fatty acids (MCFA). Nevertheless, this technology usually relies on the addition of external electron donors to drive the process. Here, we steer food waste fermentation to lactate formation which is further used as electron donor for MCFA production, mainly n-caproate. Lactate was determined to be a main electron donor for n-caproate production. n-caproate was the second main metabolite produced (3.4 g/L) and n-caproate carbon specificities increased from 9 to 22% during the experiments.

Keywords: Chain elongation; lactate; medium-chain fatty acids

BACKGROUND Sustainable and cost effective biochemicals and biofuels production is important to reduce anthropogenic climate change as well as to develop a bio-based economy (Cherubini, 2010). A bio-based economy is centred in wisely designed biorefinery processes for high-yield conversion of renewable materials into chemicals, materials and fuels. Within this agenda, chain elongation is a recently developed biotechnology that makes use of open microbiomes to convert organic wastes into medium-chain fatty acids (MCFA), such as n-caproate (Steinbusch et al., 2011). MCFA can be used as building blocks for a wide range of industrial products such as antimicrobials, lubricants, bio-plastics or biofuels. Several chain elongation processes have been developed based on ethanol as electron donor despite ethanol addition negatively impacts the environmental footprint of the chain elongation technology (Chen et al., 2017). Thus, the use of sustainably-produced electron donors is relevant to improve the sustainability performance of the process. The objective of this study was to test the possibility of producing n-caproate from food waste through chain elongation of in-situ produced electron donors with reduced pH control.

Here, we steered food waste acidification towards lactate formation and subsequent n-caproate production in 0.3-L repeated-batch reactors without pH control. Food waste was added every 7-8 days. Inoculum was taken from previous food waste fermentations. All experiments were carried out at 35°C. Liquid samples were taken regularly to measure pH; C1-C8 fatty acids and alcohols by GC; and lactic acid by HPLC.
RESULTS During cycle 1 of the fed-batch fermentation, lactate was produced within 1 day (3.7±.01 g/L) causing the pH to drop to ~4.3. Subsequently, lactate was converted into acetate and n-butyrate with a corresponding increase in pH to 5.0. This same behaviour in the lactate concentrations and pH profiles was observed after each addition of food waste (Figure 1a). In cycles 2 and 3 however, n-butyrate, n-valerate and n-caproate were the main fatty acids formed during lactate consumption, all being products of the chain elongation pathway. Thus, clear, reproducible acidification and chain elongation phases could be distinguished. n-caproate concentrations were 0.6±0.01 g/L in cycle 1, 1.9±0.15 in cycle 2 and 3.4±0.20 g/L in cycle 3, being the second main metabolite produced after n-butyrate.

In single-batch fermentation (control experiment), the main products were acetate and butyrate, and n-caproate concentrations were <1 g/L after 40 days of fermentation (Figure 1b). Thus, the predominance of products of the chain elongation pathway is not a result of slow release of hydrolysis products but is promoted by the addition of substrate. Conversion efficiency and carbon specificity showed and increasing trend for n-caproate with values between 8-18% and 9-22%, respectively (data not shown).

Conversion efficiencies and carbon specificities towards n-caproate were further increased in a 1-L CSTR reactor (data not shown). 16S rDNA analyses are being done to evaluate microbial community dynamics.

By steering acidification towards lactate, we obtained an in-situ produced electron donor for chain elongation. The production/consumption of this electron donor maintains pH at suitable levels for acidification and chain elongation to happen.

REFERENCES

A potential P Fertilizer – Biochar Produced by EBPR Sludge

T. T. Qian*, Y. Zhou**

* Advanced Environmental Biotechnology Centre, Nanyang Environment and Water Research Institute, Nanyang Technological University, 1 Cleantech Loop, Singapore 637141, Singapore, ttqian@ntu.edu.sg
** School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798, Singapore, ZhouYan@ntu.edu.sg

Abstract: To evaluate the potential of EBPR sludge biochar (ES biochar) to be a phosphorus (P) fertilizer, the release behavior and bioavailability of the P in two ES biochars (i.e., E400/E700 produced at 400/700 °C) were investigated. The results show that ES biochar contained a considerable portion of fast-release P, and the readily soluble P of the ES biochar included ortho-P, pyro-P, and poly-P. E700 could facilitate the absorption of P by Pseudomonas putida (P. putida), which could be due to that low concentration of ortho-P in the medium could stimulate the absorption of P by P. putida. As some free radicals and hazardous organic matters could be released from E400 when P. putida was cultivated with E400, E400 inhibited the formation of poly-P in P. putida. The results of this study indicate that E700 could be a superior P fertilizer than E400.

Keywords: Phosphorus recovery; EBPR sludge; Biochar

As EBPR sludge (ES) contains a high amount of P (5–8% (Tchobanoglous et al., 2003)), pyrolysis of ES and then applying the solid products, i.e. biochar, to the soil, could be a sustainable way for P recovery. To evaluate the potential of ES biochar to be a P fertilizer, the release behavior and bioavailability of the P in the EBPR sludge biochar (ES biochar) were investigated.

The release kinetics of the P from ES biochar in a mineral media (with the absence of P, denoted as MM) is shown in Fig. 1.1a. It is found that the release of P almost reached the equilibrium at 48 h, which indicates that ES biochar contained a considerable portion of fast-release P. The 31P NMR spectra of NaHCO3-P of different biochar (Fig. 1.1b and 1.1c) show that the readily soluble P of the ES biochar included ortho-P, pyro-P, and poly-P.

Compared with E400-B (MM with the presence of E400), E700-B (MM with the presence of E700) could facilitate the absorption of P (Fig. 1.2a) by Pseudomonas putida (P. putida, a critical phosphate-solubilizing microorganism in soil). The less P absorption by P. putida in E400-B than that in E700-B could mainly be caused by the higher proportion of ortho-P in E400-B than that in E700-B (Fig. 1.2a and 1.2b). This
result implies that the low concentration of ortho-P could stimulate the absorption of P by *P. putida*.

Polyphosphates are important polymers involved in physiological processes in many living microorganisms (Kornberg, 1995). From the staining results, it is found that the formation of poly-P by *P. putida* was inhibited when *P. putida* was cultivated in E400-B. However, when *P. putida* was cultivated with E400-S (the solution was withdrawn after E400 was mixed with MM for 48 h), the inhibition effect did not occur. According to these results, it is assumed that two reasons could lead to the inhibitory effect of E400 on poly-P formation in *P. putida*. Firstly, the release of free radicals from E400 when *P. putida* was cultivated with E400. Secondly, the release of some hazardous organic matters (e.g. PAHs) which was enhanced by some enzyme produced by *P. putida*.

![Figure 1.1](image1.jpg) Release kinetics of P from different biochar in the mineral medium with the absence of P (denoted as MM) (a), liquid-state 31P NMR spectrum of readily soluble P in E400 (b) and E700 (c) (DOP, dissolved orthophosphates; DTP, dissolved total phosphates)

![Figure 1.2](image2.jpg) The amount of different P species with the presence of biochar (P source) and *P. putida* and the polyphosphates staining results of the sample withdrawn at the second day of the cultivation (a) and the concentration of different P species without the presence of biochar but with the presence of soluble P released from biochar and *P. putida* and the polyphosphates staining results of the sample withdrawn at the second day of cultivation. (D-Con-P, dissolved concentrated phosphates; Micro-P, the P absorbed and adsorbed by *P. putida*. E400-B/E700-B, MM with the presence of biochar E400/E700. E400-S/E700-S was the solution withdrawn after E400/E700 was mixed with MM for 48 h.)

REFERENCES


Advanced composting and bio-drying as an opportunity to recover material and energetic resources from sludges


* nogore.guerra@uvic.cat
** sergio.ponsa@uvic.cat

Abstract:
The need to change the current paradigm from linear economy to circular economy makes the recovery of resources from waste effluents one of the current and future technological priorities. In this context, sewage sludge represents a great challenge and at the same time a great opportunity for the recovery of resources, both material, and energy. Within the framework of the H2020 SMART Plant project, BETA Tech. Centre is developing two technologies to maximise resource recovery from different types of sludge. Firstly, phosphorus-rich biofertilisers are being produced through advanced dynamic composting processes treating sludge from EBPR and SCENA processes. Secondly, cellulose-rich sludge is being treated through biodrying processes to produce biomass fuel with a calorific value similar to that of pine chips.

Keywords: biofertilisers, biomass fuel, resource recovery

The continuously increasing population is bounded inevitably to an increasing waste production. For instance, it is estimated that in 2020, 13 million tons of dried WWTP sludge will be produced in Europe, while it can be considered a renewable source of materials and energy. Some technologies such as anaerobic digestion, composting or thermal energy recovery (TER) are widely used for sludge treatment. However, these technologies still have some limitations: high investment costs, operational challenges (e.g. biogas cleaning, excess of moisture for TER, etc.), low value of the products (compost and digestate), etc.

Consequently, in the framework of SMART-Plant project, two technologies are being developed to recover both, materials and energy from sludge. Firstly, through an advanced dynamic composting of P-rich sludge from a SCENA system, biofertilisers rich in phosphorus are produced. Secondly, through a biodrying system treating cellulose sludge, biomass fuel with a calorific potential equivalent to pine chips is produced. Specific advanced control systems were developed for the mentioned processes which allow the reduction of their operational costs and GHG emissions. The pilot plants built for this purpose were operated for 8 months in a real environment (WWTP of Manresa). Briefly, the pilots consisted of two reactors with an operating volume of 100 L. A diffusion net in the bottom was used to distribute supplied air while leachate was also collected. Monitored parameters were: temperature, moisture, airflow, and O₂ and CO₂ contents in exhaust gases. Labview
2017 software was used to monitor and control the systems. Customised dynamic control systems were developed for both processes. Initial mixtures of sludge and bulking material were optimised with final ratios of 1:3 (bulking agent: sludge) for both processes.

Figures 1 and 2 show the performance profiles of the systems. As can be observed, both profiles are different since main objectives are also different. Therefore, composting process is aiming to reach the highest stability of the compost while reducing the operational costs; and biodrying is intending to remove as much moisture as possible in the shortest time and consequently reducing the organic carbon that is being biologically oxidised to maximise the lower heating value (LHV) of the biomass fuel obtained and reducing the operational costs. In particular, in the composting process, the optimal oxygen uptake rate (OUR) is used as the main control parameter to provide the required aeration to the process (Puyuelo et al., 2010), and to reduce the aeration costs. In the biodrying process, airflow is controlled by a decision-based algorithm based on temperature range of the process, to maximise the evaporation and water extracting capacity of the air. An effective drying was achieved in 12 d, whereas, the process can be shortened up to 9 d to avoid an excessive organic carbon mineralisation and maximise the calorific value of the biomass fuel obtained.

![Figure 1](image1.png) **Figure 1** Temperature, airflow, and OUR profiles during P rich sludge composting trial.

![Figure 2](image2.png) **Figure 2** Temperature, airflow and MC profiles during cellulosic sludge biodrying trial.

Tables 1 and 2 show the main analytical parameters of the final products obtained, according to their final use. After the curing stage that lasted 60 d, the compost produced was very stable, reaching the required stability values (< 1 g O₂ h⁻¹ kg VS⁻¹). P content in the final composted product can be considered in the high range of values compared to a conventional compost with a P content between 1.1 and 1.9% (d.b.) (Jakubus, 2016). In the biodrying process, a final moisture content (MC) of 24.7% was achieved, fairly below the required MC to guarantee an effective combustion process in a conventional biomass boiler (Navaee-Ardeh et al., 2010). LHV of final product was higher than the values found in the literature for similar processes ranging between 4.8 and 10.2 MJ kg⁻¹ (Winkler et al., 2013; Hao et al., 2018). GHG emissions were also monitored in both processes. Emission factors of N₂O, CH₄ and tVOC were considerably lower than the values found in literature, while NH₃ emissions in composting were found to be within the range of the values for conventional sludge composting at industrial scale (Gonzalez et al., 2019).
Accordingly, LCA’s of both processes have been made showing good results from sustainability and circularity point of view.

### Table 1 Final P rich product parameters of the composting trial.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>P-rich compost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>45.6 ± 0.1</td>
</tr>
<tr>
<td>Organic matter</td>
<td>68.8 ± 0.2</td>
</tr>
<tr>
<td>TKN (%)</td>
<td>3.9 ± 0.1</td>
</tr>
<tr>
<td>Phosphorous (%)</td>
<td>2.42 ± 0.05</td>
</tr>
<tr>
<td>Potassium (%)</td>
<td>0.65 ± 0.01</td>
</tr>
<tr>
<td>C/N</td>
<td>9.5</td>
</tr>
<tr>
<td>pH</td>
<td>6.26 ± 0.03</td>
</tr>
<tr>
<td>Conductivity (mS cm⁻¹)</td>
<td>2.78 ± 0.07</td>
</tr>
<tr>
<td>DRI 24h (g O₂ kg VS⁻¹ h⁻¹)</td>
<td>0.74 ± 0.02</td>
</tr>
<tr>
<td>AT₄ (g O₂ kg VS⁻¹)</td>
<td>60 ± 2</td>
</tr>
</tbody>
</table>

### Table 2 Final biomass fuel product parameters of the biodrying trial.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Biomass fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry mater (%)</td>
<td>76.3 ± 0.1</td>
</tr>
<tr>
<td>Organic matter (%)</td>
<td>88.7 ± 0.4</td>
</tr>
<tr>
<td>HHV (MJ kg TS⁻¹)</td>
<td>17.14 ± 0.05</td>
</tr>
<tr>
<td>LHV (MJ kg⁻¹)</td>
<td>11.66 ± 0.05</td>
</tr>
</tbody>
</table>

### REFERENCES


POSTER SESSION
Nitrogen recovery from blackwater using bioelectrochemical systems


* LEITAT Technological Center, c/ de la Innovació 2, Terrassa (Barcelona, Spain)
, eborras@leitat.org, dmolognoni@leitat.org, pbosch@leitat.org, mpbernicola@leitat.org, jgarcia@leitat.org, ssanchis@leitat.org

Abstract:
In the present work, the latest achievements of Run4Life project are presented, aiming at the bioelectrochemical recovery of ammonium ($\text{NH}_4^+$) from blackwater (BW) for the production of fertilizers. The anodic biofilm of adopted bioelectrochemical systems (BES) was first acclimated to high $\text{NH}_4^+$ concentration, as a requirement for the effective treatment of BW in the anode chamber. Afterwards, the design and construction of adopted BES system is described. Preliminary results in terms of BW treatment, $\text{NH}_4^+$ recovery and energy consumption are finally exposed.

Keywords: air-diffusion cathode; cation exchange membranes; ammonium acclimation;

Introduction
Bioelectrochemical systems (BES) were previously reported as a promising technology for ammonium ($\text{NH}_4^+$) recovery from blackwater (BW) (Ledezma et al., 2015). The exoelectrogenic oxidation of the organic matter contained in BW and the resultant polarization of BES electrodes becomes the driving force for $\text{NH}_4^+$ migration from the anolyte to the catholyte through a cation exchange membrane (CEM). Application of external voltage to BES system can help increasing the process kinetics and $\text{NH}_4^+$ migration flux. A downstream separation system is then required to recover $\text{NH}_4^+$ in form of fertilizer. In this study, has been adopted a stripping system based on air bubbling over an air-diffusion cathode. The basification of the catholyte, due to oxygen reduction, causes $\text{NH}_4^+$ to convert to $\text{NH}_3$ and its stripping and recovery outside BES reactor.

Material and Methods
The experimental set-up adopted for $\text{NH}_4^+$ acclimation tests consists of 2 air-cathode microbial fuel cells (MFCs), previously inoculated with an electroactive biofilm from a laboratory-operating MFC. The two MFCs were fed with an acetate-based synthetic medium mimicking the composition of a source-separated BW. MFC1 was operated in steady-state mode at a concentration of 0.5 g-N/L. MFC2 was fed at subsequent increases of $\text{NH}_4^+$ concentration, looking for its inhibition threshold over anodic biofilm. The two MFCs were operated in chronoamperometric mode and monitored through electrochemical techniques (polarization curves and cyclic...
voltammetries). Also, physical-chemical parameters of influent and effluent wastewater were analysed according to Standard Methods: [NH₄⁺], Total Nitrogen (TN), pH, conductivity and chemical oxygen demand (COD).

For the nitrogen recovery trials a tailor-made BES reactor equipped with an air-diffusion cathode was designed and constructed (see Figure 1). In detail, the system was composed by a bicameral reactor with a cation exchange membrane (CEM) between anodic and cathodic chambers, allowing the migration of cations (as NH₄⁺) from anolyte to catholyte. There, assisted by the air bubbling system and due to the basification of the catholyte, the NH₄⁺ turned to NH₃ and migrates to the acid traps. The system was operated in batch cycles of 5 days, with synthetic medium (the same one adopted for N acclimation tests) doped with 1 g/L of N-NH₄⁺ as anolyte, and a 10.7g/L NaCl solution as catholyte. Two acid traps were installed downstream the BES reactor, each one containing a solution of 0.1 M H₂SO₄. The BES reactor was electrically operated in a 2-electrodes configuration, applying a voltage of 200 mV between anode and cathode. Process performances were assessed by means of physical-chemical parameters determination such as ammonium removal, nitrogen recovery and organic matter removal (expressed as COD) and electrochemical calculations (as anodic Coulombic efficiency).

Results & conclusions
MFC1 was successfully acclimated at a constant concentration of 0.5 g N-NH₄⁺/L (estimated nitrogen content in the Run4Life end-user BW), reaching stable performances over a period of more than 6 months: average current density of 0.7 A m⁻², 83% COD removal and 12% Coulombic efficiency. MFC2 was employed to determine the inhibitory [N-NH₄⁺] threshold. Severe affectation in biofilm performance occurred when reaching 9 g N-NH₄⁺/L, but a decrease in biofilm performance could be observed already at 3.5 g N-NH₄⁺/L. The COD and Coulombic efficiency remained constant during all the concentration gradient, around 80% and 16% respectively.

Regarding nitrogen recovery trials, 79±3% of the ammonium was removed from the anolyte during the batch treatment cycle. A 61±13% of removed N-NH₄⁺ was finally recovered in the acid traps. Moreover the COD removal rate was around 0.827±0.07 Kg/m³·d with an anodic coulombic efficiency of 10.9±1.7%.

Performed experiments demonstrate that nitrogen recovery from BW is possible using bioelectrochemical systems. Economic sustainability of proposed process is yet to be verified. For this reason, following experiments will focus on process optimization, acting on parameters like air flow-rate, catholyte composition, voltage application, etc.

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References
Can we benefit from hydroxylamine and hydrazine generating in Anammox reactors?: The possible use in nanobiotechnology applications

B. Alpaslan Kocamemi*, E. Erdim**

*Marmara University, Faculty of Engineering, Environmental Engineering, Istanbul, Turkey. bilge.alpaslan@marmara.edu.tr
** Marmara University, Faculty of Engineering, Environmental Engineering, Istanbul, Turkey. esra.erdim@marmara.edu.tr

Abstract: Hydrazine and hydroxylamine which are the key intermediates of Anammox process are powerful reducing agents widely used in various industries. This study aims to evaluate the utilization of hydrazine and/or hydroxylamine in the synthesis of nano scale zero valent iron nanoparticles (nZVI) which can be utilized in Anammox reactors to enhance growth, degradation, EPS secretion and granulation. For this purpose, first the levels of hydrazine and hydroxylamine in various lab-scale and pilot scale Anammox reactors fed with either mainstream or centrate were scanned. Later, the synthesis of nZVI particles with the effluents containing the highest hydrazine and hydroxylamine levels were studied. nZVI particles ranging between 44.2-119.5 nm were obtained. The optimization studies for the nZVI synthesis were still in progress. The use of synthesized nZVI particles for Anammox reactors and monitoring their effect on Anammox process will be the final step of the study.

Keywords: Anammox; hydrazine, hydroxylamine, nanobiotechnology

Over the last decade, Anaerobic Ammonium Oxidation (Anammox) process received great attention as an economically attractive and environmentally friendly nitrogen removal process in comparison to conventional nitrogen removal technologies, nitrification-denitrification. The real scale Anammox applications for the treatment of centrate generating from anaerobic digesters are increasing in number all over the world [Lackner et al., 2014]. The mainstream Anammox applications are under deep investigation via pilot studies [Li et al., 2018]. Besides being cost-effective, energy efficient and environmentally-friendly process, Anammox is a unique process synthesizing hydrazine (N₂H₄) as an intermediate product (Figure 1). Hydroxylamine is another intermediate of Anammox process. Van De Graaf et al. (1997) proposed a three-step model with hydroxylamine and hydrazine as intermediates: (i) reduction of nitrite to hydroxylamine by enzyme HAO, (ii) the subsequent condensation of hydroxylamine and ammonium to make hydrazine, and (iii) oxidation of hydrazine to yield end product N₂ by enzyme HZO. Later in 2006, Strous et al. proposed an alternative three-step model: (i) reduction of nitrite to NO by enzyme NirS, (ii) the subsequent condensation of NO and ammonium to make hydrazine, (iii) oxidation of hydrazine to yield end product N₂ by enzyme HZO.

Both hydroxylamine and hydrazine are known as a kind of reducing agents, which are widely used in industry and pharmacy. The high chemical reactivity of hydrazine imparts wide spectrum use in industrial applications, e.g., in rocket fuels, in power...
plants, in the production of antioxidants, photographic developers, insecticides and blowing agents for plastics. Moreover, it is used for metal recovery by chemical reduction as useful insoluble elemental metal instead of metal hydroxide sludge (Chen and Lim, 2006). There are also a few studies (Wu et al., 2010, Yang et al., 2004) in literature evaluating the use of hydrazine for the synthesis of magnetic nanoparticles, which have widespread applications in biotechnology, biomedical, material science, engineering, and environmental areas. Moreover, it is used for metal recovery by chemical reduction as useful insoluble elemental metal instead of metal hydroxide sludge (Chen and Lim, 2006). There are also a few studies (Wu et al., 2010, Yang et al., 2004) in literature evaluating the use of hydrazine for the synthesis of magnetic nanoparticles, which have widespread applications in biotechnology, biomedical, material science, engineering, and environmental areas.

The aim of this study is to first scan the hydroxylamine and hydrazine levels in various lab-scale and pilot scale Anammox reactors (Figure 2) that were either newly started-up or operating for a long period of time. Based on the scanning results, the effluents were classified as the ones containing the highest hydrazine concentration, highest hydroxylamine concentration and both hydrazine and hydroxylamine concentrations. The hydrazine concentrations varied between 2- 104 ppb while hydroxylamine ranged between 7-572 ppb. The nZVI synthesis trials with the highest hydrazine and/or hydroxylamine containing effluents were performed (Figure 3). The quality of the synthesized nZVI particles were evaluated through measurement of intensity-weighted size distribution of nano particles (Figure 4). The size of synthesized nZVI particles ranged between 44.2-119.5 nm. The optimization of nZVI synthesis is still on-going. After optimization, the synthesized nZVI particles will also be monitored through XRD and TEM analyses. Simultaneously, the studies aiming to increase hydrazine concentration in the Anammox effluents by inhibiting HZO enzyme are continuing. In view of the past study findings (Erdim et al, 2019), it is planning to utilize the nZVI particles synthesized with hydrazine recovered from Anammmox reactors for these reactors to enhance Anammox process.

REFERENCES


Figure 1. Anammox pathways proposed by (a) van de Graaf (1997), (b) Strous et al. 2006 (Wang et al., 2006)

Figure 2. Lab-scale and pilot scale Anammox reactors fed with either centrate or mainstream

Figure 3. Zero valent iron nano particles synthesis set-up
<table>
<thead>
<tr>
<th>Size (nm)</th>
<th>Size-graph</th>
</tr>
</thead>
<tbody>
<tr>
<td>119.5</td>
<td><img src="image1.png" alt="Graph" /></td>
</tr>
<tr>
<td>59.3</td>
<td><img src="image2.png" alt="Graph" /></td>
</tr>
<tr>
<td>44.2</td>
<td><img src="image3.png" alt="Graph" /></td>
</tr>
<tr>
<td>91.8</td>
<td><img src="image4.png" alt="Graph" /></td>
</tr>
</tbody>
</table>

Figure 4. Intensity-weighted size distribution of the nanoparticles using Malvern ZS90, UK
Wastewater Reuse for Agricultural Purposes: A Case Study
A. Moretti, E. Aneggi, D. Goi
Dipartimento Politecnico, Università degli Studi di Udine, 33100 Udine, Italy
alessandromrtt@gmail.com, eleonora.aneggi@uniud.it, daniele.goi@uniud.it

Abstract: One fundamental requirement in the third millennium will be the global development without altering environmental resources. Wastewater reclamation and reuse is a main topic inside every consideration. The research presented here, is a preliminary feasibility study of the reuse of wastewater for fertigation purposes. This case study focused on the analysis of depuration plant situated in Grado, an inshore town located in the southern part of Friuli Venezia-Giulia; through the GPS-X 7.0 software, an implementation of the treatment plant was made. The fundamental nutrients contained in the wastewater, basics for the vegetation growth, are nitrogen, phosphorus and potassium. These ones, if dissolved in water, can be directly pumped onto the crops, establish a fertigation practice. The final goal was to introduce the fertigation inside the ordinary process, making it the standard practice for herbaceous feeding.

Keywords: Wastewater reclamation; wastewater reuse; fertirrigation

Wastewater reclamation and reuse is a solution needed for the largest number of possible purposes. The lack of resources often penalized the agriculture practice, which can only be obtained with a higher process cost. It is possible to find the missing amount of water provision or nourishment through the wastewater reuse. In addition, a special attention should be devoted to the nutrients that have to be exploited in favour of a sustainable production.

Inside this study of Grado treatment plant we tried to understand if this reuse can be profitable and up to what level it can be. First of all, analysis focused on the maximum daily flow rate and the concentration value of the most characteristic parameters entering the plant, such as nitrogen and phosphorus concentration. Data analysis importance resides in the definition of an aggression, more or less marked, inside the treatment plant against all the interesting parameters. In particular, the reduction of basics nourishments, such as nitrogen and phosphorus, was the starting point to understand the real behaviour of the entire process. All these preliminary analyzes were then used to model the system on the GPS-X software. For the hypothesis of this study, the only useful part inside the model was the biological one, built through the anaerobic, anoxic and aerobic units followed by the secondary clarifier. These were made for the calculation of the nutrients removal rate. After this model projection, the study went on with the definition of the main characteristics concerning fertigation and the types of irrigation used for a selected herbaceous crop. The choice fell specifically on the Bermuda grass, a plant often considered as a pest that proved to be congenial for this application and suitable for various climatic conditions, indeed, it has a marked resistance against atmospheric agents, can live long periods without watering and its favorite food is composed only by the
nitrogenous part. Being that the phosphorus part inside the wastewater is always a small rate compared with the nitrogen one, Bermuda grass represented the perfect crop to which we can apply the practice of fertigation in working conditions. Figures 1 and 2 respectively show the flow and total soluble nitrogen data obtained, for 6 days of simulation, using the model described.

To satisfy the weekly water requirement of one hectare of cultivation a total water consumption of ca. 78 m$^3$ is needed, an amount that can be effectively obtained from the treatment plant without altering the functionality of the system itself. Considering the quantities of nitrogen required by the Bermuda grass in its life cycle, it has been estimated that fertigation with the quantities indicated above is a useful practice but not sufficient to cover the overall requirement. In fact, from the data obtained from the modelling in GPS-X it is obtained that the maximum concentration of dissolved nitrogen (in the denitrification unit) is about 15 mgN / l and can cover just over 15% of the total required. However, the simulation shows that it is possible to completely cover the irrigation needs of the cultivation and that through a partial fertigation the need for fertilizers can be reduced, reducing the overall costs. The study therefore shows that the nutrients present in the wastewater, which would otherwise be irretrievably lost, can be effectively used. The reuse of wastewater for irrigation of crops always involves a reduced use of groundwater source saving a precious resource and introducing a circular and sustainable cycle.

This type of grass was cultivated for a final distribution as a rolled lawn, an application of these rolls for green roofs was considered.

REFERENCES


Evaluating the Potential Production of Bio-Based Products from Waste Streams

Merve Atasoy*, Zeynep Cetecioglu**

*mervea@kth.se; **zeynepcg@kth.se

Abstract: In this paper, we discuss the potential of bio-based products from waste streams to shift petroleum-based production to bio-based paradigm. The theoretical potential production of biogas, volatile fatty acids, biodiesel and bioplastics were compared as an end-products from dairy and brewery industry wastewaters, food waste and sewage sludge by using both literature/statistical data and market information. The result of the calculations that was done in this study has shown that biodiesel and biogas from these waste sources can supply about twice the current global energy demand while the global plastic demand could be met 30 times with bioplastics. Fermentation of waste streams can provide 80 times the market demand of volatile fatty acids (VFA).

Keywords: Bio-based products; waste streams; resource recovery

INTRODUCTION

According to the United Nations World Population Prospects (2017), the global population was about 7.4 billion in 2015. Moreover, consumption of the global biomass, fossil fuels, and minerals increased from 48 to 69 billion metric tons between 1995 and 2008 (Pothen 2017). According to an estimation, the global energy demand will rise to 17 million tons in 2035. In 2015, 83% of the global energy requirement was met by petroleum sources which will be depleted in 2050 (Saxena et al., 2009). These dramatically increasing demands for material and energy sources will not be met by current sources soon (Alrefai et al., 2017). In other perspectives, the petrol-based production methods are restricted to prevent global warming and adverse environmental effects regarding United Nation Goals and Paris Agreement (2015). In view of these, the bio-based product market demand rose to 12.3% in 2015 and will be risen to 22% by 2020, with an annual growth rate of approximately 20% according to forecasters. In this paper we focused on the theoretical potential production of bio-based products from various waste streams. Specifically, we investigate the center of attention bio-based products in recent years to provide insight for further studies. Thus, biogas, volatile fatty acids (VFAs), biodiesel and polyhydroxyalkanoate (PHA) were compared as end-products from various waste streams including dairy and brewery industry wastewater, food waste and sewage sludge due to both significant volume of waste/wastewater and their valuable characterization.
Which waste streams are suitable?
The wastewater treatment plants have evolved from just ensuring discharge limits to resource recovery from the waste stream. Thus, the significance of waste streams has started to be emphasized. We reviewed the most promising waste streams regarding their production amount and composition which were dairy and brewery industry wastewaters, food waste and sewage sludge. The generation of wastewater from each source was calculated using both literature/statistical data and market information. All calculations in terms of flow rate of wastewater, amount of bio-based products and their economic value were calculated by using physio-chemical properties of waste streams, such as total and soluble chemical oxygen demands (tCOD and sCOD), total and volatile solids (TSS and VSS) as well as conversion rates which were described at the Box 1.

RESULTS AND DISCUSSION
According to result of the calculations for potential bio-based products (Fig. 1.1) from each waste-streams, approximately 87% of global energy demand can be supplied by biodiesel (500 EJ) produced from waste streams (dairy and brewery wastewaters, food waste and sewage sludge). At the same time, 50% of this demand would be met by biogas production from waste streams. In 2016, the plastic production was 335 and 60 million tons in the World and Europe, respectively. According to European Bioplastic Report, 2.05 and 0.37 million tons of bioplastics were produced at the World and Europe, respectively in 2016. It means, merely 0.6% of global plastic demand was supplied by bioplastics. However, according to our results, if waste streams would be used for bioplastic production, 30 times the global plastic demand can be supplied by bioplastics. Moreover, bioplastic production from waste streams in Europe could supply 3 times the global plastic demand. Likewise, biogas, biodiesel and bioplastic production from waste streams, total VFAs demand could be supply from waste streams. Based on the market reports, global market demand of total VFAs is around 30 Mt annually, which includes 18 Mt acetic, 400 kt propionic and 105 kt butyric acids. Approximately just 2% of this production is supplied by bio-based methods. However, there is a potential to ensure around 80 times the global VFAs market demand by using bio-based VFA production from waste streams. Contrary to production amount results, economic cost comparisons are quite various since their market value has a wide range. According to Figure 1, the most valuable product is butyric acid with 43,000 B€/year from all waste streams, since its market price relatively high than others. Also, PHA has almost the same economic value as butyric acid. 42,300 B€/year would be gain if all waste streams are used for PHA production. Though biogas and biodiesel have the highest potential production amount, they have the lowest economic value because there are several options in the market for energy production.

CONCLUSIONS
As a conclusion, more sustainable production methods from waste is possible. According to calculations, there is a great potential of bio-based products in terms of linking the production amounts with economic profits on both global and European scales. In the case of waste streams are used as a source for production:
• 87% of global energy demand would be supplied by biodiesel,
• Around 30% of global plastic demand would be supplied by bioplastics,
• Global VFA market demand would be ensured around 80 times by bio-based VFA production,
• Globally, 43,000 B€/year from butyric acid, and 42,300 B€/year from PHA could be gain.

REFERENCES


Avoiding Eutrophication In Small Water Bodies: An Hydrogenotrophic Approach

R. Barbosa*, T. Sleutels, W. Verstraete, N. Boon**

*Wetsus, European Centre of Excellence for Sustainable Water Technology, Post Office Box 1113, 8900 CC Leeuwarden, Netherlands, Raquel.Barbosa@Wetsus.nl
**Center for Microbial Ecology and Technology (CMET), Ghent University, Coupure Links 653, B-9000, Gent, Belgium, Nico.Boon@UGent.be

Abstract
Even low concentrations of phosphorus contribute to the process of eutrophication, resulting in the demand for effective and economic methods of phosphorus removal. Moreover, with current phosphorus reserves in decline, strategies that allow both the removal and recovery of phosphorus are needed. The aim of this study is to evaluate the capacity for phosphorus removal by a hydrogenotrophic biofilm reactor system. The reactor is operated as a trickling filter where water is recirculated over the biofilm. Phosphorus removal values are shown to in the order of 98% with residual below 20 µg/L. These results indicate the potential of hydrogen oxidizing biofilms for the maintenance of ecological quality.

Keywords: Knallgas bacteria; Phosphorus removal; Hydrogenotrophic

Eutrophication of natural water bodies has become a global threat and is predicted to intensify in the coming decades (1). Phosphorus has long been pointed as a key player in eutrophication of freshwater lakes, reservoirs, streams and headwaters of estuarine systems with excess inputs often associated to industrial discharges, sewage and runoff from agriculture, construction sites, and urban areas (2,3). According to Dodds et al. (1997) maintenance of stream water total phosphorus concentration below 30 μg L⁻¹ is necessary to keep a low algae growth. Nutrient mitigation and phosphorus inactivation has been achieved in lakes, lagoons, ponds and reservoirs by adding iron, alum or other commercial compounds such as Phoslock to sequester phosphorus in sediments (4). However, such strategies do not account for removal down very low levels nor to the retrieval of phosphorus. With an ever growing population and the declining of phosphate rock reserves, essential for fertilizer production, recovery strategies which fit within the circular economy concept are essential. Compared to chemical approaches, microbiological removal offers the possibility of recovering the phosphorus as a product fit, for instance, to be used as a fertilizer while still being effective and economical. Biological trickling filters are an interesting option due to their lower energy consumption, minimization of reactor clogging, reduction of post-treatment costs and relatively shorter treatment time (5). Furthermore, if hydrogen is used as a sole electron donor, no secondary contaminants persist in the treated water and sludge production can be minimized (6). The current work presents a phosphorus recovery process based on hydrogen. The reactor is operated as a trickling filter where water is recirculated over the biofilm. This study
demonstrates the potential of an hydrogen oxidizing biofilm reactor to remove phosphorus with a reactor residence time of 2 hours (Figure 1). The simplicity of the process may encourage its implementation to levels excluding the level of algal growth and thus constitute a strategy to treat lakes, ponds or recreational waters, especially where addition of chemicals and process monitoring and control should be minimized.

Figure 1. Residual phosphorus (soluble) concentration during the batch experiments.

REFERENCES

Pilot-scale Treatment of Combined Sewage Overflows (CSOs) and Its Further Possible Agricultural Reuse

A. Botturi*, S. Daneshgar*, A.L. Eusebi*, F. Fatone*

*Department of Biotechnology, Università degli Studi di Verona, 37134, Verona, Italy

Abstract: A pilot-scale treatment system was implemented for treating CSO discharges to Lake Garda, Italy. The treatment system consisted of different steps including rotating dynamic filtration, granular activated carbon adsorption and UV disinfection. Different scenarios with various combination of treatment steps have been investigated using various dilution factors for simulating overflow conditions. The results showed effective removal of TSS, COD and E. coli as well as some heavy metals including Cu, Zn, Al and Fe. However, the system was not effective for nitrogen and phosphorus removal. The final treated water has decent characteristics according to the EU regulation limits for water quality to be used for agricultural purposes and showed great potential for further reuse in some food and non-food crops irrigation as well as industrial, energy and seeded crops. Nonetheless, further nutrient removal might be needed when further restrictions are applied.

Keywords: CSO, agricultural reuse, wastewater treatment

In Europe nearly 70% of sewage systems are in the form of combined sewage systems in which a mix of municipal/industrial wastewater and storm water are carried out to the WWTP in the same pipeline (EPA, 2004). Although CSOs are considered in the normal operation of the sewage system with the aim of flood prevention, they could potentially transport different contaminants and pollutants into receiving water bodies. Consequently, this could cause several negative impacts on the receiving water bodies such as endangering the life of aquatic organisms or delimiting the recreational use of water bodies (Morgan et al., 2018). Different treatment technologies can be used for CSOs from constructed wetlands and chemical coagulations to adsorption techniques and disinfections or a combination of these technologies. Depending on the treatment technology, TSS, COD, heavy metals, micropolllutants and pathogenic bacteria could be removed effectively (Vymazal, 2013; Marsalek, 2005; El, Samrani et al., 2008; Tao et al., 2012; Tondera et al., 2015).

A pilot-scale treatment line has been implemented with 14 m$^3$/h flow rate to treat the CSO consisting the storm water and municipal wastewater collecting from the municipalities around Lake Garda, Italy. The plant consists of three main treatment steps including rotating dynamic filtration, adsorption with granular activated carbon and UV disinfection. Different scenarios have been considered depending of the different combination of treatment steps and changing the dilution factor (1:3, 1:5, 1:10) of wastewater being treated in order to simulate various overflow conditions (Table 1.1).

The results of simulated scenarios showed that using a complete set of treatment steps (scenario 3) will lead to TSS and COD removal of more than 80% and 70%
respectively (Figure 1.1). Heavy metals removal was also considerable and 57%, 70%, 74% and 46% removal were obtained for Cu, Zn, Al and Fe respectively (Figure 1.2). E. coli was completely removed out of the system by UV disinfection (~99-100%). However, this treatment was not very effective for nutrients removal (nitrogen and phosphorus) and up to maximum 30% of removal was observed, which is not sufficient and needs further nutrient specific treatment.

### Table 1.1 Technologies used in each scenario of CSO treatment for each dilution factor (1:3, 1:5, 1:10).

<table>
<thead>
<tr>
<th>Scenario N.</th>
<th>RDF</th>
<th>Sand Filter</th>
<th>GAC</th>
<th>UV</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2*</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>3*</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td>3</td>
<td>+</td>
<td>+</td>
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<td>+</td>
</tr>
<tr>
<td>4</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

Although the treated CSO could be discharged into the Lake Garda having significantly less concentrations of TSS, COD, E. coli and heavy metals, it also meets the European Commission regulation limits for some water reuse applications in terms of E. coli and TSS concentrations (JRC 2017). The EC regulation categorizes different water quality classes (from A to D, A having the highest quality) with different associated agricultural reuse. In all cases of this study TSS of <35 mg/L were obtained which fulfils the requirements for B, C and D classes. However, in terms of E. coli, the treated water in case of having 1:3 dilution factor is categorized in class D, while the higher dilution factors could be classified as class C. Water in class C could be reused for processed food crops, non-food crops including crops to feed milk or meat producing animals using drip irrigation method only. On the other hand, class D water could be further utilized for industrial, energy and seeded crops with irrigation methods. However, the low nutrients removal achieved could be a concern for further application of treated CSO and further specific nutrient removal might be needed depending on the case study.
REFERENCES


Enhancement of Sludge Solubilisation by Carbon Nanotube-coated Vessel Applied Microwave Irradiation


*Institute for Environment and Energy, Pusan National University, Busan 46241, Korea, email: kangkh21@pusan.ac.kr (K.H. Kang), big815@pusan.ac.kr (I. Byun)
**Department of Environmental Engineering, Pusan National University, Busan 46241, Korea, email: hyeon@pusan.ac.kr (J. Kim), fl2574@pusan.ac.kr (H. Jeon)

Abstract: Microwaves (MW) have great potential for sludge solubilisation, and carbon materials can act as good microwave absorbers and heat transfer media because of their high dielectric loss tangent and thermal conductivity. In this study, carbon nanotubes (CNTs)-coated MW vessels were developed by preparing a silane-CNT mixture and spray coating. In addition, sludge solubilisation by microwave irradiation was performed to evaluate the effects of the CNTs-coating at different initial total suspended solid concentrations, microwave powers, and target temperatures in uncoated and CNT-coated MW vessels. The sludge solubilisation efficiency was highest at 5% TSS, 600 W, and 100 °C in both vessels. On the other hand, the COD solubilisation and SCOD increment per MW energy were 5.08% and 4.67 mg/L/KJ higher in CNT-coated vessel, respectively. This suggests that the application of CNTs are a good way to increase the energy efficiency in microwave-based pretreatment methods.

Keywords: Carbon nanotube-coated vessel; sludge solubilisation; microwave energy efficiency

Microwaves (MW) are an increasingly utilized technology for the solubilisation of wastewater sludge with rapid heating, environmental friendliness, and low cost. The application of MW technologies depends on the microwave energy absorptivity of the reaction mixture. The heating ability of the materials by microwave is defined by their dielectric loss factor tangent (tan δ). Carbon materials, such as carbon nanotubes (CNTs), graphite, and activated carbon, have a high loss tangent compared to water, which can be transformed easily to heat by microwave energy (Menendez et al., 2010). The π-electrons in carbon materials are free to move in a delimited region of the materials and induce an electromagnetic field by absorbing microwaves.

In this study, the effects of a CNT-coated microwave vessel on the hydrolysis of wastewater sludge were evaluated at different initial total suspended solid (TSS) concentrations (3-11%), powers (400-800 W), and target temperature (60-100°C). The CNT-coating was achieved by preparing a CNT-silane mixture and spraying it onto a quartz microwave vessel. The sludge solubilisation by microwave irradiation was quantified by evaluating the decrease in volatile suspended solids (VSS) content and the increase in soluble chemical oxygen demand (SCOD).

Figure 1.1 shows the VSS and SCOD profiles of sludge hydrolysis. In this study, the most effective sludge solubilisation conditions were an initial TSS concentration of 5%, output power of 600 W and target temperature of 100°C. In microwave-based pretreatment of sludge solubilisation, the non-thermal effects of MW was higher at low TSS concentrations because floc agglomeration at high TSS concentrations inhibits MW transfer into the cell (Byun et al., 2014). Sludge solubilisation was more
effective at low MW power because the cells in the sludge are disrupted and exposed to the target temperature for longer irradiation times (Park et al., 2010).

![Figure 1.1 VSS reduction (vertical bar) and SCOD increment (scatter and line) in uncoated (black) and CNT-coated (gray) microwave sampling vessels according to the target temperature at a 5% TSS concentration and 600 W.](image)

Sludge solubilisation and VSS reduction were higher in the CNT-coated vessels than in the uncoated vessels. This can be explained in two ways: acceleration of the thermal effect by MW and the high conductivity of CNTs; and the decomposition of organic matter by radicals generated at hot spots on the CNT surface. Hot spots can be generated under MW irradiation of the surface of a carbon material, such as CNTs and activated carbon (Menendez et al., 2010). In this study, the COD solubilisation and SCOD increment per MW energy were 5.08% and 4.67 mg/L/KJ higher in the CNT-coated vessels than in the uncoated at 5% TSS concentration, 600 W microwave power, and target temperature 100°C (Table 1.1).

Table 1.1 Comparison of COD solubilisation and SCOD increment per energy between uncoated and CNT-coated vessels at a 5% TSS concentration, 600 W, and 100°C

<table>
<thead>
<tr>
<th>MW irradiation condition</th>
<th>COD solubilisation (%)</th>
<th>SCOD increment/KJ (mg SCOD/L/KJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSS 5%, 600 W of output power and 373 K</td>
<td>Uncoated vessel</td>
<td>CNT-coated vessel</td>
</tr>
<tr>
<td>COD solubilisation (%)</td>
<td>61.96±0.01</td>
<td>67.04±0.01</td>
</tr>
<tr>
<td>SCOD increment/KJ (mg SCOD/L/KJ)</td>
<td>56.87±0.74</td>
<td>61.54±0.72</td>
</tr>
</tbody>
</table>

To increase the MW efficiency for the sludge solubilisation, MW irradiation vessels were coated with CNTs. CNTs enhance the thermal effects of MW because of their high thermal conductivity. In addition, they have potential to degrade organic matter by radical generation at hot spots. The results showed that MW irradiation by applying CNTs-coated vessels is a good way to increase the biomass pretreatment and MW energy efficiency.

REFERENCES


Enhancement of the Direct Lipid Extraction Yield from Wet Algae by Optimization of the Microwave Irradiation Conditions


*School of Civil and Environmental Engineering, Pusan National University, Busan, 46241, Korea. fl2574@pusan.ac.kr, hyeon@pusan.ac.kr
**Institute for Environment and Energy, Pusan National University, Busan, 46241, Korea. kangkh21@pusan.ac.kr, big815@pusan.ac.kr

Abstract: Lipid extraction using microwaves is an energy-efficient process that eliminates the drying process, which consumes considerable amounts of energy. This study examined the conditions for the direct extraction of lipids from wet microalgae using microwaves. The irradiation conditions, such as the water content (73, 79, 83, 90, and 96%), MW power (400 to 1600 W), and target temperature (85, 90, and 95°C), were evaluated from the lipid extraction yield per total input energy. The maximum lipid yield per total input energy obtained from this study was 267.47; the conditions were a water content, microwave power, and target temperature of 79%, 800W, and 90°C, respectively. Optimization of the microwave irradiation conditions can improve the lipid extraction efficiency.

Keywords: Wet microalgae; Direct lipid extraction; Microwave

Recently, studies using microalgae as biomass have been carried out because of their high lipid content and rapid growth. Because the microalgae culture liquid contains 99% water, a dehydration and drying process is required to recover the cultured microalgae. Conventional methods, such as thermal drying, has the problem of high heat-loss and energy consumption. Microwaves generate heat inside the material itself through dipole rotation and ionic strength. This results in rapid heating, which assists with lipid extraction by increasing the pressure and destroying the cell wall from wet algae (Wahidin et al., 2014). In this study, the optimal conditions of lipid extraction from wet algae, such as the water content, MW power, and target temperature, using microwaves were evaluated according to the lipid extraction amount per total input energy.

A microalgae sample of *nannochloropsis oceanica* (Chloland Co., Korea) was used as received. The microwave conditions examined were the exposure time, temperature, and MW power. The soxhlet method using hexane solvent was used to derive the theoretical maximum amount of lipid extraction from microalgae. The samples were irradiated for the ramp time by microwaves to evaluate the lipid extraction yield per total input energy according to the water content, microwave power, and target temperature (Table 1.1). And the lipid extraction yield per total input energy were calculated using the following equations:

\[
\text{Lipid extraction yield} = \frac{\text{Extraction lipid (g)}}{\text{Theoretical maximum amount of lipid (g)}} \times 100 \\
\text{Lipid extraction yield per total input energy} = \frac{\text{Lipid yield} \times 100}{\text{Total input energy (MJ)}}
\]

Where, P, power of the microwave system, W; t, ramp time, sec
Table 1.1 Experimental conditions to optimize direct lipid extraction

<table>
<thead>
<tr>
<th>Trial</th>
<th>Water content (%)</th>
<th>MW power (W)</th>
<th>Target Temperature (°C)</th>
<th>Exposure time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96, 90, 86, 79 and 73</td>
<td>400</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Average 79</td>
<td>400, 600, 800, 1000, 1200, 1400 and 1600</td>
<td>90</td>
<td>Ramp time*</td>
</tr>
<tr>
<td>3</td>
<td>Average 79</td>
<td>800</td>
<td>85, 90 and 95</td>
<td></td>
</tr>
</tbody>
</table>

* Time to reach the target temperature

Figure 1.1 show the lipid extraction yield per total input energy according to the MW power. The results according to the different water contents were 12.89, 31.21, 48.22, 224.94, and 207.57 at a 96, 90, 86, 79, and 73% water content, respectively. When the MW power was 400, 600, 800, 1000, 1200, 1400 and 1600 W, the results were 204.76, 230.54, 267.47, 264.71, 257.15, 124.17 and 88.57, respectively. The results according to the target temperature were 225.59, 246.16, and 193.56 at 85, 90 and 95°C, respectively. Therefore, the optimal conditions in this study were a water content, MW power, and target temperature of 79%, 800W, and 90°C, respectively (Table 1.2, 2-2). Table 2 lists the lipid extraction yield per total input energy from this study and other studies. Ali et al. (2015) used microwaves at a water content of 77%, MW powers of 635W and 1021 W, reaction time of 300 sec, and temperatures of 53 and 90°C. Because microwaves use electrical energy, it is necessary to increase the energy efficiency. Optimization of the irradiation conditions for microwaves could achieve high energy efficiency. In this study, the optimized irradiation conditions were derived according to the water content, microwave power, and target temperature, and effective results were obtained.

Table 1.2 Comparison of the lipid extraction yield per total input energy

<table>
<thead>
<tr>
<th>Trial</th>
<th>Water content (%)</th>
<th>MW power (W)</th>
<th>Temperature (°C)</th>
<th>Reaction time (sec)</th>
<th>Lipid Extraction yield (%)</th>
<th>Total input energy (MJ)</th>
<th>Lipid extraction yield per total input energy</th>
<th>Reference</th>
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<td>22.18</td>
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The highest lipid extraction yield per total input energy was 267.47 at a water content, MW power, and target temperature of 79%, 800W, and 90°C, respectively. Optimization of the irradiation conditions could achieve high energy efficiency. Under these optimized conditions, direct lipid extraction from wet microalgae could be achieved using microwaves, which helps improve the energy efficiency of the lipid extraction process using microwaves.

REFERENCES


Enhancement of the Microwave Energy Efficiency by the Adaption of a Reflective-Wave Circulating Unit


*School of Civil and Environmental Engineering, Pusan National University, Busan, 46241, Korea, hyeon@pusan.ac.kr
**School of Civil and Environmental Engineering, Pusan National University, Busan, 46241, Korea, fl2574@pusan.ac.kr

Abstract: Although microwave-heating systems have several advantages, microwaves use electric energy. Therefore, it is important to enhance the energy efficiency of a microwave system to reduce the electric energy consumption. In this study, a new microwave system that circulates the reflective-wave was developed. To evaluate the energy efficiency, the energy balance was analyzed by heating distilled water at 400, 600, and 800 W power. As a result, the maximum energy efficiency of the reflective-wave circulating microwave system was 45.6±1.2% at 800 W. On the other hand, the maximum energy efficiency of the conventional microwave system was 30.4±0.1% at 400 W. These results show that the microwave energy efficiency was enhanced by approximately 15% on average by circulating the reflective-wave.

Keywords: Energy efficiency; reflective-wave circulating; energy balance analysis

Although microwave systems have several advantages in material heating, it is necessary to improve the efficiency of the microwave system, which uses electrical energy. In this study, a new microwave system that circulates the reflective-wave was developed. The energy balance and energy efficiency of the new reflective-wave circulating microwave system (RWCM) was compared with that of a conventional microwave system (CM) by heating 1 L of distilled water at 400, 600 and 800 W microwave power for 2 min.

Figure 1.1 represents a schematic diagram of the energy balance for a general microwave system. The total input electric energy (Q1) in the microwave system was calculated by recording the value of the current meter. To carefully consider the net input electric energy (Q3), the standby electric energy (Q2) used in the driving system should be excluded from the total input electric energy (Q3=Q1-Q2) (Wang et al., 2015). The net input electrical energy is converted to microwave energy, but minus the magnetron loss energy (Q4). The magnetron output energy (Q5) is obtained from the microwave power under the experimental conditions. The microwave energy irradiated into the cavity is absorbed by the sample (Q6) or by the vessel (Q7). A part of the input microwave energy (Q3) is converted to a heat of vaporization (Q8). On the other hand, the microwave energy (Q9) of a reflective-wave is obtained by calculating the total energy balance (Q0=Q1−Q2−Q4−Q6−...).
The energy conversion efficiency can be divided into two steps: the energy efficiency ($\eta_1$) of conversion from electric energy to microwave energy ($\eta_1=Q_5/Q_3$) and the energy efficiency ($\eta_2$) of conversion from microwave energy to effective heat energy ($\eta_2=Q_6+Q_7+Q_8/Q_5$). The total energy efficiency ($\eta$) can be calculated by multiplying these two energy efficiencies.

Figure 1.2 represents the energy efficiency ($\eta_1$, $\eta_2$ and $\eta$) of CM and RWCM. In figure 1.2 (a), $\eta_1$ of CM did not change significantly. On the other hand, $\eta_1$ of RWCM increased with increasing microwave power. In figure 1.2 (b), $\eta_2$ of CM changed slightly, similar to $\eta_1$ of CM. In contrast, $\eta_2$ of RWCM decreased with increasing microwave power. This result was in contrast to the $\eta_1$ of RWCM. Wang et al. (2015) reported that the energy efficiency ($\eta_2$) increased gradually from 59.7 to 62.7% with increasing heating time from 1.5 to 4 min. Figure 1.2 (c) shows the total energy efficiency of CM and RWCM. The maximum $\eta$ of the RWCM was 45.6±1.2% at 800 W, whereas $\eta$ of the CM was 28.5±1.3% at 800 W. At 400 W, however, the maximum $\eta$ of the CM was 30.4±0.1% at 400 W, whereas $\eta$ of the RWCM was 43.6±2.4%. These results show that the total energy efficiency was enhanced by approximately 15% on average by circulating the reflective-wave. The input microwave energy is the sum of the absorbed, transmitted, and reflected energy (Folgueras et al. 2007). Therefore, the energy efficiency was enhanced because the reflective-wave was circulated and absorbed into the sample.

In this study, the new microwave system that circulates the reflective-wave was developed. The energy efficiency of the new system was approximately 15% on average higher than the conventional microwave system. The microwave was not lost and absorbed into the sample by circulating the reflective-wave. In conclusion, this system uses less electric energy than the conventional microwave system. The energy efficiency can be enhanced significantly by circulating the reflective-wave.

REFERENCES


Anaerobic Digestion of Leather Pickling Wastewater and Leachate Mixture: Effect of Salinity on Reactor Performance

M. Carvalheira*, B. Oliveira*, A. M. Sampaio*, J. Cassidy*, C.S.S. Oliveira* and M.A.M. Reis*

* UCIBIO, REQUIMTE, Departamento de Química, Faculdade de Ciências e Tecnologias, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal
mic16141@fct.unl.pt; bma.oliveira@fct.unl.pt; am.sampaio@campus.fct.unl.pt; joanascassidy@gmail.com; css.oliveira@fct.unl.pt; amr@fct.unl.pt

respectively. Overall, the obtained results have demonstrated the feasibility of using anaerobic digestion for the treatment of high salinity wastewater.

Keywords: salinity; anaerobic digestion; adaptation strategy

During the pickling process of leather, salt (NaCl) is added to the fresh skins for preservation purposes, resulting in a wastewater with organic matter and high salinity. The discharge of this saline wastewater without treatment can affect the environment causing contamination of soil, surface and groundwater. Typically, these high saline wastewaters are treated with physico-chemical processes, which present high costs (Lefebvre and Moletta, 2006). Thus, more cost effective treatment processes are being pursued, such as anaerobic digestion (AD), in which besides wastewater treatment, biogas is obtained. Since the biological processes can be inhibited by the salt, these wastewaters need to be diluted, decreasing the organic matter content and, consequently, the biogas production and AD performance. Thus, mixing these saline wastewaters with other types of wastewater, that contain high organic content, can be a solution to overcome this limitation and to achieve good AD performance. Leachates, that are produced in the same industries, containing high content of organic matter, which can be removed through biological processes (Renou et al. 2008), can be an option to mix with leather pickling wastewater, increasing the organic matter content without increasing the salinity. In the scope of the EU project, SaltGae this study aims at optimising the treatment of a mixture of leather pickling wastewater and leachate using AD process was the main objective.

The leather pickling wastewater and leachate were both collected in KOTO, Slovenia. The upflow anaerobic sludge bed (UASB) reactor was inoculated with anaerobic granular sludge and operated for 77 days, at 30°C, with a hydraulic
retention time (HRT) of 3 days. The pH was controlled at 7.07 ± 0.09 by automatic addition of KOH. Three different sodium concentrations (5, 10 and 15 g Na⁺/L operated during 18, 39 and 20 days, respectively), corresponding to an organic loading rates (OLR) between 2.4 ± 0.9 and 3.7 ± 0.2 gCODsoluble/(L.d), were tested. The adaptation to different salinities was performed through a sequential increase of the of sodium concentration in the feedstock.

The gradual adaptation of microbial culture to different salinities proved to be successful, since a high conversion of organic acids (OA), between 76.5% and 92.1%, and biogas production, between 1.6 and 3.0 LBiogas/d, were obtained (Figure 1.1). However, at 15 g Na⁺/L, a decrease in the biogas production (Figure 1.1) and a granules fragmentation were observed. With the increase of sodium concentration from 5 to 10 g Na⁺/L and similar OLR, the OA conversion increased from 79.4% to 96.2% and the biogas production increased from 1.6 LBiogas/d to 3.0 LBiogas/d. However, with the increase of sodium concentration to 15 g Na⁺/L, the OA conversion efficiency and biogas production decreased to 92.1% and 1.6 LBiogas/d, respectively. This result showed that the microbial community was probably affect by sodium concentrations higher than 15 g Na⁺/L. The average methane content was 57% and the methane yield varied between 0.17 and 0.24 LCH₄/gCODconsumed. Moreover, the maximum methane production and productivity were 1.7 LCH₄/d and 0.21 LCH₄/(gCOD.d), respectively. Overall, the obtained results have demonstrated the feasibility of using anaerobic granules for the co-treatment of leather pickling wastewater and leachate.

![Figure 1.1 Biogas composition, CH₄ productivity and COD removal at increasing salinities.](image)

ACKNOWLEDGMENTS The authors are thankful for the financial support from the European project Saltgae (689785 SALTGAE H2020-WATER-2015) and Fundação para a Ciência e a Tecnologia – FCT through the grants SFRH/BPD/103501/2014 and SFRH/BPD/88817/2012. This work was supported by the Applied Molecular Biosciences Unit- UCIBIO which is financed by national funds from FCT/MCTES (UID/Multi/04378/2019).

REFERENCES


Selecting a Photo-Enhanced Biological Phosphorous Removal System Starting from Conventional Wastewater Treatment Plant Sludge

V.C.F. Carvalho*, E.B. Freitas, J.C. Fradinho**, A. Oehmen, M.A.M. Reis
UCIBIO-REQUIMTE, Department of Chemistry Faculty of Sciences and Technology, Universidade NOVA de Lisboa, 2829-516 Caparica, Portugal *virginiacfcarvalho@gmail.com
** j.fradinho@campus.fct.unl.pt

Abstract: The phototrophic-enhanced biological phosphorus removal system (photo-EBPR) was recently proposed as a more environmentally friendly alternative to conventional phosphorus removal with potential advantages towards phosphorus recovery. The present work evaluated the possibility of selecting a photo-EBPR system starting from conventional activated sludge. A sequencing batch reactor inoculated with sludge from a wastewater treatment plant (WWTP) was fed with a mixture of acetate and propionate (75%:25%) and subjected to dark/light cycles to select a photo-EBPR system containing poly-phosphate accumulating organisms (PAOs) and photosynthetic organisms, the oxygen providers for the system. The results showed that it is possible to obtain a photo-EBPR system starting from a WWTP sludge, although the process is slower compared with the selection process using as inoculum a sludge already enriched in PAOs, which indicate that a photo-EBPR system can be obtained independently of the seed sludge used.

Keywords: Phosphorus removal with limited aeration; algae as O₂ suppliers; phototrophic biological phosphorus removal

P is an element with vast applications in agriculture and industry but can negatively impact the environment when released. Reserves of P are limited, reason why it is indispensable to treat P rich wastewater streams, preferably through processes that allow P recovery and reutilization, to promote the circular economy. One of the options for treatment of P-rich wastewater streams is the enhanced biological phosphorus removal (EBPR) system, however, it requires intensive aeration and thus increased operational costs (Rosso et al., 2008).

With the goal of reducing the aeration dependence of EBPR processes, a new phototrophic-enhanced biological phosphorus removal (photo-EBPR) process was recently proposed, consisting of a consortium of polyphosphate (poly-P) accumulating organisms (PAOs) and photosynthetic microorganisms (algae, cyanobacteria) operated under 8 hours dark/light cycles (3 h dark, 4 h light and 1 h idle period, including 0.5 h of settling) , with a light intensity of 328 W/m² provided by an internal halogen lamp. During the dark anaerobic period, glycogen is hydrolysed and poly-P is degraded (P release), producing the necessary energy for volatile fatty acids consumption and its accumulation as polyhydroxyalkanoates (PHA). During the light phase, photosynthetic microorganisms produce the necessary oxygen and, consequently, PHA is consumed, providing energy and carbon for the regeneration of poly-P and glycogen pools (Carvalho et al., 2017). Photosynthetic microorganisms can also have an important role in P removal and in improving the harvested biomass properties when used as fertilizer. Indeed, algae rich fertilizers are slow ammonia
releasers which lessens NH₃ volatilization in comparison to manures (Mulbry et al., 2005). COD in the feed was adjusted during the experiments, from 60 to 160mg/L, and the P concentration in the feed was 60 mg/L. Air was supplied in the last 2 h of the light phase to prevent O₂ limitations.

Results show that in the first cycle with 60 mg/L of COD, the culture could not carry out EBPR despite VFAs being totally consumed during the dark phase (Figure 1.1-A). This suggests that the sludge from the WWTP was not enriched in PAOs and not capable of immediately performing P release/uptake cycles. However, since VFAs were completely consumed in the dark period, COD in the feed was increased and P uptake in the light phase without aeration increased up to 13 ± 1 mg-P/L (Figure 1.1-B), a feature that may have resulted from the O₂ availability from algae or direct P uptake by algae. Also, the higher carbon availability in the dark phase enabled more PHA accumulation and when more PHA is available, more P can be taken up by PAOs. The present study indicates that conventional activated sludge can be enriched in PAOs and photosynthetic organisms capable of performing photosynthetic EBPR. Although the culture selection process was slower in comparison with cultures already enriched in PAOs (Table 1.1), activated sludge is widely available and a photo-EBPR system can be readily implemented without the need of a seed sludge previously enriched in PAOs. The implementation of photo-EBPR systems will allow energy savings by eliminating the intensive aeration that increases operation costs in conventional EBPR. It can be applied to WWTP, or waste stabilization ponds, using the final P rich sludge as fertilizer.

Table 1.1 - Comparison of the results obtained in the present work with the results obtained in Carvalho et al. (2018). Fish probes: PAOmix (PAO651, PAO462, PAO846) for Candidatus Accumulibacter phosphatis and CPB_654 for Candidatus Competibacter phosphatis.

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<td>P release (mg-P/L)</td>
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Figure 1.1 - Profile of P and carbon transformation during SBR operation: A – CODfeed= 60 mg/L; B – CODfeed= 100 mg/L and B – CODfeed= 160 mg/L

REFERENCES
Impact of elevated CO₂ partial pressure on the thermodynamics and kinetics of syntrophic propionate oxidation

P.S. Ceron-Chafla*, R.E.F Lindeboom*, K. Rabaey** and J.B van Lier*
* Sanitary Engineering section, Department of Water Management, Delft University of Technology, Stevinweg 1, 2628 CN, Delft, The Netherlands (p.s.ceronchafla@tudelft.nl; r.e.f.lindeboom@tudelft.nl; j.b.vanlier@tudelft.nl)
** Center for Microbial Ecology and Technology (CMET), Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

Abstract: In this study, the effect of elevated partial pressure of CO₂ (pCO₂) on microbial conversions of interest (syntrophic propionate oxidation) was studied. Batch experiments at pCO₂=0.3 (control), 5 and 8 bar showed a reduction in the maximum substrate utilization rate (rₚₐₓₚₐₜ) of 93% for propionate oxidation and 80% for acetoclastic methanogenesis compared to the control. Calculation of the actual free energy change (ΔGᵢ) showed a decrease in the overall feasibility of syntrophic propionate oxidation (-85.8 kJ to -73.1 kJ mol donor⁻¹) due to the effect of pCO₂ on the biochemical reactions. The ΔGᵢ of propionate oxidation and acetoclastic methanogenesis became less negative whereas the ΔGᵢ of hydrogenotrophic methanogenesis became more negative. Calculations of the thermodynamic driving force (f) showed lower values for all the reactions, being propionate oxidation the most severely affected. The presented analysis suggests a possible steering effect of CO₂ in biochemical reactions, due to kinetic and thermodynamic effects.

Keywords: Pressure Fermentation; propionate; carbon dioxide

Introduction
Microbial conversion of intermediates of the anaerobic digestion process such as propionate, occur close to thermodynamic equilibrium and become feasible due to the syntrophic interaction between bacteria and methanogens (Stams and Plugge, 2009). Based on the premise that any change in the available energy has an impact on the metabolic activity (Jin and Kirk, 2016; Kleerebezem and Stams, 2000), suitable environmental conditions play a significant role to maintain the viability of this type of microbial interaction. CO₂ presents a complex behaviour in biological systems: electron acceptor, intermediate/end-product of reactions and, due to its role in the carbonate equilibrium, it may impact the local pH (Lindeboom et al. 2016). At elevated concentrations it has shown inactivation effects on microorganisms and enzymes (Manzocco et al., 2017). However, the effect of moderate concentrations on microbial interactions and metabolic pathways still remains fairly unexplored. The objective of the present study was to investigate the effects of elevated pCO₂ in syntrophic propionate oxidation, using a non-defined methanogenic community, from a kinetic and thermodynamic perspective.

Materials and Methods
Propionate conversion under elevated pCO₂ was performed in batch experiments using a setup consisting of stainless steel pressure-resistant reactors (200 mL, liquid: gas ratio 120:80) and Duran glass bottles (250 mL, liquid: gas ratio 150:100). Temperature and agitation speed (35°C and 115 rpm) were controlled using an incubator shaker (Innova® 44, Eppendorf, USA). Bottles were filled with liquid medium containing macronutrients, micronutrients bicarbonate (100 mM) as buffer and, propionate (10 mM) as substrate. Mesophilic sludge collected from an AnMBR treating food industry wastewater was used to inoculate the
reactors. The experiments at atmospheric conditions were flushed with a gas mixture (N₂:CO₂ 70:30%), whereas the reactors at elevated pressure were subjected to consecutive pressurizations with pure CO₂ (>99%) to guarantee headspace composition. Experiments lasted for 14-20 days. Gas and liquid samples were analysed using gas chromatography (Agilent Technologies 7890A, USA). sCOD, TSS, VSS and pH were measured at the end of the experiment according to standard methods.

Experimental data was fitted to the modified Gompertz equation to estimate the process parameters. The actual free energy change (ΔGᵢ¹) for the biochemical reactions was calculated over time using the measured concentrations of propionate, acetate, CO₂ and CH₄ and the equilibrium pH. The thermodynamic driving force (f) was estimated as the difference between the available energy (-ΔGᵢ¹) and the energy conserved by the microorganisms as ATP (ΔGₖ) (Jin, 2007).

**Results and Conclusions**

Increasing the initial pCO₂ from 0.3 to 5 bar affected the propionate conversion rate of the inoculum. The calculated rₘₐₓ showed a reduction of 93% due to the increased pCO₂. Also, the conversion of the produced acetate to CH₄ seemed to undergo limitations during these experiments. While performing an independent experiment using acetate as the sole substrate, when increasing the initial pCO₂ to 8 bar, the rₘₐₓ decreased by 80%, which establishes a rate unpairing effect of CO₂ in the syntrophic interaction.

The overall syntrophic propionate conversion became less feasible at 5 bar, due to the ΔGᵢ¹ of both the propionate oxidation and acetoclastic methanogenesis becoming less negative (Figure 1). According to Schink (1997), syntrophic propionate oxidation leaves a free energy change of around -22 to -23 kJ mol⁻¹ for each reaction, however, under the test conditions, this energy change became less negative. Figure 2 shows the evolution of the thermodynamic driving force (f) along the experiments and, although elevated CO₂ impacted all the reactions, propionate oxidation was most strongly affected due to the low initial ΔGᵢ¹. The experimental results clearly indicate that elevated pCO₂ affects the delicate equilibrium in electron fluxes between the syntrophic partners, due to reduction in available energy and unpaired reaction rates. Our current work opens perspectives for further research on the effects of prolonged exposure to elevated CO₂ in anaerobic communities of interest.

![Figure 1](image1.png)

**Figure 1**: a) Gibbs energy change over time for the reactions. Initial pCO₂= 5 bar, T=35°C, pH=7.7 and pH₂=1x10⁻⁵ bar. ■ Acetoclastic methanogenesis, ▲ Hydrogenotrophic methanogenesis, ♦ Propionate oxidation, ⃰ Syntrophic propionate oxidation (3), ● Syntrophic propionate oxidation (2). b) Hydrogenotrophic ● Propionate oxidation

![Figure 2](image2.png)
REFERENCES
Phosphorus Recovery from Excess Sludge through Alkaline Fermentation: Studies for Pilot-scale Design

S. Cosgun*, B. Kunt**, N. Semerci***

* Institute of Pure and Applied Sciences, Environmental Engineering Department, Marmara University, Kuyubaşı, Istanbul, Turkey, sevilcosgun@hotmail.com.tr
** Institute of Pure and Applied Sciences, Environmental Engineering Department, Marmara University, Kuyubaşı, Istanbul, Turkey, kuntbusra@gmail.com
*** Faculty of Engineering, Environmental Engineering Department Marmara University, Kuyubaşı, Istanbul, Turkey, neslihan.semerici@marmara.edu.tr

Abstract: This study focused on the preliminary studies conducted to design a 1m³/hr pilot plant to produce struvite from excess sludge and dewatering supernatant. Alkaline fermentation will be applied to release phosphorus from waste activated sludge. In this scope, sludge fermentation experiments were run with different pH conditions (8, 9 & 10) and temperatures (30°C & room temperature). Stronger alkaline conditions showed higher nutrient release, sludge solubilization, and VFA production. The mesophilic condition also enhanced the VFA production, and nutrient release. However, orthophosphate loses were observed after three days of fermentation. Therefore, three days operation time and 30°C were decided for pilot-scale operation.

Keywords: Alkaline fermentation; phosphorus recovery; struvite; pilot-scale.

METHODOLOGY Sludge and dewatering reject waters were obtained from Ataköy Enhanced Biological Wastewater Treatment Plant, Istanbul, Turkey. To achieve sludge solubilization, therefore phosphorus release, low mesophilic (ambient temperature) and mesophilic (30°C) alkaline fermentation studies were run at pH 8, 9 and 10. Phosphorus fractionation was studied according to Pardo et al. 2004 and Xu et al., 2015. TP, PO₄³⁻ NH₄, COD, and MLVSS were determined on Standard Methods (APHA, 20th edition). Volatile fatty acids (VFA) were measured by Shimadzu GC-2014. Statistical analyses were applied with the Mann Whitney U test. For struvite precipitation, dewatering reject waters were mixed with supernatants of fermented
sludges and this liquor was processed in a lab-scale struvite precipitation system. pH of the liquor was adjusted as 8.5 and precipitates were collected to be analyzed with X-ray Diffraction (XRD).

RESULTS Long-term fermentation studies were performed to determine the optimum conditions for phosphorus release. As shown in Figure 1.1, mesophilic fermentation at pH:10 showed the highest phosphorus release; however, decreases in orthophosphate concentration were appeared as fermentation continues, possibly due to phosphorus precipitation. Beside orthophosphate, organic phosphorus releases were also observed in mesophilic fermentation as a result of cell lysis. Higher pH and temperature also provided the NH₄-N and COD releases and VFA production.

![Figure 1.1 VFA productions and PO₄-p releases during fermentation.](image)

Phosphorus fraction studies were run to determine optimum pH for phosphorus recovery and behaviour of phosphorus during fermentation. As shown, non-apatite inorganic phosphorus and organic phosphorus were released into the solution during fermentation. Besides, an increase in apatite phosphorus was observed as expected, especially after three days and, these results indicate that again the short-term fermentation is suitable for the efficient phosphorus release. According to results of lab-scale studies, a fermentation tank with a working capacity as 1m³/h and an upflow crystallization reactor with a gradually increasing diameter were designed.

![Figure 1.2 Phosphorus fractions at different pH levels and during pH:9 fermentation at 30°C.](image)

REFERENCES


Y.W. Cui*, C.L. Jing
National Engineering Laboratory for Advanced Municipal Wastewater Treatment and Reuse Technology, Beijing University of Technology, Beijing 100124, China, cyw@bjut.edu.cn

Abstract: In order to achieve the major goal of minimizing carbon emission and energy consumption for a sustainable wastewater treatment, a novel two-stage SBR process was developed to migrate external carbon from aerobic phase into anoxic phase via aerobic PHA storage. Recovery of PHA by the activated sludge and in situ utilization of PHA for denitrification was demonstrated in the system treating real sewage. PHA storing organisms affiliated in phylum of Firmicutes, Bacteroidetes and Proteobacteria were enriched by controlling the ratio of feast (aerobic) and famine period (anoxic) at 0.026-0.111. In aerobic phase, the mixed culture accumulated PHA with the capacity of 6.36 C mmolL\(^{-1}\) and the yield coefficient of 0.52. In anoxic phase, the storage PHA was consumed by denitrifying nitrite with 2.12 mole ratio of carbon to nitrogen. According to model calculation, CO2 emission was reduced by 25% in comparison with conventional A2O process.

Keywords: Polyhydroxyalkanoates; Carbon storage; Endogenesis denitrification

The organic fraction in wastewater is oxidized into carbon dioxide (CO2) in aerobic tanks with a relatively high energy consumption in the conventional practice of wastewater treatment, such as A/O and A/A/O processes. Organic carbon is necessary to achieve qualified discharging effluent of nitrogen. According to kinetics of denitrification, 2.87 mg COD is required to denitrify per mg NO\(_3^-\) into nitrogen gas. Because the organic fraction is removed in the aerobic tank, extra carbon has to be input into anoxic tank to achieve the nitrogen removal. As a result, the organic matter is not utilized for the combined denitrification units, but is oxidized into CO2 in the aerobic tank, increasing the treatment cost and energy consumption. Therefore, a more sustainable way to resolve this problem relied on mitigating the organic matter from aerobic tank into anoxic tank instead of oxidization into CO2.

In this study, a novel two-stage SBR process was proposed as one sustainable solution. The first SBR (O/A SBR) was operated by aerobic and anoxic mode. In the aerobic tank, the organic matter in the sewage was stored as PHA in the sludge. Then the stored PHA in sludge was in situ utilized to denitrify nitrate in the anoxic phase. The nitrite came from the second SBR (N SBR), which nitrify the effluent of first SBR discharging at the end of aerobic phase. The nitrification and carbon mitigation were separated in two systems, showing the efficiency performance of denitrification driven by endogenous PHA (Fig.1). Continuous 100-day operation demonstrated the performance of organic conversion into PHA and the PHA utilization for denitrification was significantly related to the organic loading rates (OLR) and ratios...
of feast and famine period (F/F). Elevated OLR increased the storage of PHA with 15.32±0.39% cell content.

The comparison of the inoculated sludge and the enriched sludge showed the difference in appearance characteristics and bacterial community composition. The functional group was established as PHA producers affiliated into the phylum of *Firmicutes*, *Bacteroidetes* and *Proteobacteria*, responsible for the carbon storage in aerobic phase and the endogenesis denitrification in anoxic phase. Model calculation established that PHA productivity was 0.52±0.04 on average and specific denitrification rate was 2.76±0.42. The carbon flow analysis showed that external carbon source was converted into PHA, CO$_2$ produced by cell respiration and biomass proliferation. Compared with sludge from A2O, the fraction flowing into CO$_2$ decrease by 25% and sludge production was reduced by 15% in this process. The process showed the advantages of the CO$_2$ emission and surplus biomass, realizing carbon *is situ* recovery in sewage and decreasing the sludge disposal cost in a sustainable way.

**REFERENCES**

Pilot-Scale Study of Phosphate Precipitation Process from Synthetic Aerobic Sludge

S. Daneshgar*, A. Buttafava**, A. Callegari*, A.G. Capodaglio*

*Department of Civil Engineering and Architecture, University of Pavia, 27100, Pavia, Italy.
Saba.daneshgar@unipv.it, arianna.callegari@unipv.it, andrea.capodaglio@unipv.it
**UNECO srl, 27100, Pavia, Italy, armando.buttafava@unipv.it

Abstract: Phosphate recovery through precipitation process is an excellent method for phosphorus recovery. However, this process is not widely at full scale due to its economic limitation. This study covers a pilot-scale experimentation of phosphate recovery from synthetic aerobic sludge in the form of a valuable precipitate containing calcium phosphate as the main component. The effects of pH and retention time of the reactor have been studied. NaOH and Ca(OH)₂ have been used as to pH adjustment reagents without further chemical addition to the system. The results show that using Ca(OH)₂ as an economic pH adjustment reagent with 60 minutes retention time and at pH=9.0, it is possible to obtain a precipitate rich in amorphous calcium phosphate that has great potential of being used in fertilizer industry. This process will could be a phosphorus recovery solution as an alternative to the more expensive struvite precipitation for wastewater treatment plants that suffer from the lack of anaerobic digested sludge.

Keywords: Phosphate Recovery; Calcium Phosphate; Aerobic Sludge.

The environmental concern of the high phosphorus (P) concentration in water bodies has raised the attention towards its removal technologies [1,2]. This is particularly a more critical issue in “sensitive areas” where more stringent regulations are present for nutrients removal [3]. In addition, the increasing trend of P consumption for food production because of population growth and its limited and finite resources around the world, have increased the need for developing new technologies for its recovery [4]. The most common approach for P recovery that has been studied during past years is chemical precipitation mainly in the form of struvite or amorphous calcium phosphate [5,6].

Phosphate precipitation has been mainly studied for anaerobic digested sludge due to its high phosphorus content and because of that this process has not been widely investigated for the aerobic sludge. However, for wastewater treatment facilities that suffer from the lack of anaerobic digestion, it would be still possible to implement the phosphate precipitation process taking the sludge from the anaerobic stage of biological treatment line. It is reported that phosphorus concentration for the aerobic sludge after being under anaerobic condition could reach up to 40 mg/L [7] which is more than sufficient for effective precipitation process. In this study, phosphate recovery in the form of an ACP-rich product has been achieved for a synthetic aerobic sludge in a pilot reactor.
A pilot reactor has been constructed and the pH of the system was controlled inside the reaction zone using a PID-time proportional control system. The experimentation phase was set up with 30, 60, and 120 minutes retention times at pH=8.5 and 9.0. NaOH and Ca(OH)$_2$ were used for pH adjustment. In the first part Mg and NH$_4$ were added to promote struvite precipitation and then some experiments were carried out without chemical addition.

![Figure 1.1](image)

Figure 1.1 Left: phosphorus concentration in time for reactions without chemical addition, right: precipitates composition based on TGA results.

The results show that phosphorus removal is not dependent on the retention time of the system and it rapidly decrease initially and then reaches to a stable value from where it does not improve anymore (Figure 1.1, left). It was observed that 60 minutes of retention time is enough for the completion of the reaction. In the experiments with chemical addition, high P removal was achieved (88%) but the final precipitate was a mix of struvite and ACP with ACP being the main component. About 87% P removal was achieved using Ca(OH)$_2$ at pH=9.0 without chemical addition. The results of thermal gravimetric analysis demonstrate that nearly 20% of the final precipitate was related to the H$_2$O and less than 5% associated with carbonate precipitation (Figure 1.1, right). This suggests that the major part of the final precipitate is amorphous calcium phosphate. Comparing to previous experiments less pH reagents was used to control the pH (Table 1.1) that makes the process also less expensive to operate.

<table>
<thead>
<tr>
<th>Chemical Addition</th>
<th>pH reagent</th>
<th>pH</th>
<th>pH reagent (g/m3)</th>
<th>P recovery %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>NaOH</td>
<td>8.5</td>
<td>90</td>
<td>61.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.0</td>
<td>150</td>
<td>90.37</td>
</tr>
<tr>
<td>No</td>
<td>NaOH</td>
<td>9.0</td>
<td>91</td>
<td>82.65</td>
</tr>
<tr>
<td></td>
<td>Ca(OH)$_2$</td>
<td>8.5</td>
<td>73</td>
<td>75.29</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.0</td>
<td>125</td>
<td>87.24</td>
</tr>
</tbody>
</table>

It can be concluded that using Ca(OH)$_2$ as the pH adjustment reagent without chemical addition to the system, leads to achieve high P removal while maintain a product, which contains mainly ACP and has very little impurities in terms of carbonates. This product does not have some qualities of pure struvite such as high plant availability and both nitrogen and phosphorus content. However, it is less expensive to produce and because of its high phosphorus content could be used in fertilizer industry either directly or indirectly as a raw material for fertilizer production.
REFERENCES


Phosphorus Recovery on Apatite Filters: Developing a Mechanistic Model

L. Delgado*, S. Troesch**, D. Blanc***, M. Gautier***, P. Molle*

* IRSTEA, REVERSAAL Research Unit, 5 rue de la Doua, 69100 Villeurbanne, France ; laura.delgado-gonzalez@irstea.fr; pascal.molle@irstea.fr
** Eco Bird, 3 route du Dôme, 69 630 Chaponost, France ;
*** Univ Lyon, INSA Lyon, Laboratoire DEEP, 69621 Villeurbanne France

Abstract: Phosphorus recovery from wastewater by using natural and granulated apatite (Phosclean®) filters is studied. A mechanistic model describing P retention by means of adsorption and precipitation phenomena is being developed with the HP1® software. This tool is able to account for hydraulics into the porous media, as well as, chemical speciation by using its PHREEQC® package. Phosphorus retention capacity and kinetics of both materials seem to be significantly different mainly because the apatite’s surface in the Phosclean® product is not readily accessible to act as seed for Ca-P precipitation. This may lead to two different retention mechanisms and therefore, to two different models.

Keywords: Phosphorus retention; modelling; apatite filters.

As worldwide phosphorus (P) resources are in depletion (Reijinder, 2014), P recovery from wastewater has become a major issue to overcome P scarceness. P removal from wastewater using natural apatite filters has shown great retention capacity (Molle et al., 2011). Several full-scale filters have been implemented using a granulated apatite filter (Phosclean®) as a tertiary treatment in wastewater treatment plants (WWTP) for small and medium size communities. P retention is accomplished by adsorption and precipitation phenomena leading to the formation of hydroxyapatite (HAP) onto the materials surface. This P recovery solution provides a major advantage regarding other technologies since the composition of the filtration bed and the precipitates have the same nature. Therefore, the media may be reused again as a filtration material or even for fertilizer’s production once the filter is not reactive anymore, or once the filter gets to the end of its lifespan because of chemical clogging. Nevertheless, Phosclean® appears to behave differently than natural apatite (Delgado et al., 2018). Consequently, new column lab experiments have been implemented with Phosclean® and natural apatite to point out mechanisms and limitations for each material (Delgado et al, 2019). These experiments are used to develop a mechanistic model with the aim to define in which conditions HAP precipitation can be ensured and improved.

The HP1 software (HYDRUS coupled with the PHREEQC package) is used here to develop a geochemical model in porous media capable of describing P retention onto these materials. This study aims to achieve a better understanding of P retention mechanisms and kinetic rates providing a model that will allow to precisely design the filters. The model is developed under hydraulic saturation conditions and it is based on saturation indexes and dynamics of amorphous calcium phosphate (ACP) and/or...
octocalcium phosphate (OCP) as precursors for HAP precipitates. It also accounts for \( \text{CO}_3^{2-} \) ions competition that may take place under calcocarbonic conditions. Thermodynamic supersaturation may also be included, as well as, relevant ion substitutions into the HAP crystal lattice.

Experiments in laboratory pilots have been conducted over two years to deepen on the retention mechanisms and kinetics for both natural apatite and the Phosclean® materials, under controlled conditions. The study includes anions and cations monitoring at the inlet, outlet and along the pilot column at different retention times, in order to build a proper speciation model. Acid neutralisation capacity (ANC - NF EN 14429) tests are also carried out to better describe the material composition. To ratify the hypothesis, SEM images and SEMx analyses have been also conducted to determine the reaction mechanisms taking place and the calcium phosphate (Ca-P) precipitate formed, in each case.

First results have shown a significant difference in between both materials in terms of P retention performance and kinetics. SEM images evidence a lack of accessibility for Ca-P complexes to attain the coated apatite inside the Phosclean® pellet, which would explain such different retention capacities. Solution supersaturation seems to be the key factor to trigger Ca-P precipitation onto the granulated apatite surface. On the contrary, supersaturation does not seem to be necessary for natural apatite to allowed Ca-P precipitation. Therefore, a model with and without seed crystal presence may account for these differences. The presentation will detail the mechanistic model for both apatite materials and it will explain in which conditions P retention may be limited or not.

**REFERENCES**


Phosphorous retention in granulated apatite: assessing the maximum saturation level, kinetics and reaction mechanisms. WETPOL2019 Conference, Aarhus, Denmark.


Design and Optimisation of Integrative Process Systems for Resource Recovery from Wastewater

A. Durkin, M. Millan-Agorio, M. Guo
Department of Chemical Engineering, Imperial College London, London, SW7 2AZ, UK, alexander.durkin14@imperial.ac.uk, miao.guo@imperial.ac.uk

Abstract: A major bottleneck in designing sustainable resource recovery facilities lies in selecting process configurations to satisfy multiple conflicting decision criteria. A surrogate-based superstructure optimisation framework is presented to simultaneously optimise flowsheet configuration and the design of the comprising process units. A commercial process simulator is coupled with Matlab to facilitate input-output Sobol’ sampling. Support vector machines are integrated in the sampling to implement feasibility constraints and maximise sampling efficiency. Artificial neural networks are then fitted to the input-output samples to increase tractability of the optimisation problem. Optimal solutions are identified by mathematical optimisation of the resulting multi-objective problem. This study uses process systems engineering insights to provide a modelling framework for designing optimal flowsheets for recovering resources from wastewater.

Keywords: Superstructure optimisation; surrogate modelling; flowsheet design

This knowledge gap can be addressed with superstructure optimisation methodology which considers a network composed of all potential process technologies and the interconnections between them (Henao & Maravelias, 2011; Yeomans & Grossmann, 1999). The superstructure flowsheet can then be optimised whilst simultaneously accounting for conflicting objectives and various feasibility and design constraints. The individual process units can be designed using commercial simulators, however, the complexity of the underlying models, particularly in the case of wastewater treatment, increases computational cost and poses challenges regarding initialisation of decision variables and boundaries.

Surrogate models of process units can be derived to reduce computational complexity and enable more tractable optimisation problems. By treating the process units as “black-box” models, surrogate functions can be fit to sampled input-output data from commercial simulators. This is particularly useful when including
biochemical technologies in the superstructure, where these processes usually exhibit high dimensionality and model complexity.

Figure 1.1 Surrogate-based superstructure optimisation framework. The steps shown in layered boxes are performed for each process unit considered in the superstructure. Each surrogate model is then used in the superstructure optimisation step which outputs updated variable bounds and sampling regions for the relevant unit processes.

A case study on resource recovery from industrial mycoprotein fermentation wastewater is presented in this study to demonstrate the framework’s functionality. Overall, we demonstrate that process systems engineering insights can be effectively implemented to the topic of resource recovery. A computational framework is presented for modelling optimal flowsheets for recovering resources from wastewater. Such a framework ultimately assesses process viability within an integrated flowsheet, under multiple design criteria, therefore assisting in resource recovery technology deployment.

REFERENCES


Phosphate Recovery from Wastewater Using Porous Calcium Silicate Hydrate Derived from Carbide Slag

Dexin Fang*, Zhuoyao Fang**, Fangying Ji*

* Key Laboratory of Three Gorges Reservoir Region’s Eco-Environment, Ministry of Education, Chongqing University, Chongqing 400045, China, fdx@cqu.edu.cn
** State Key Laboratory of Pollution Control and Resources Reuse, School of the Environment, Xianlin Campus, Nanjing University, Nanjing 210023, China, 2252248874@qq.com
† Corresponding author, email: jfy@cqu.edu.cn

Abstract: This study investigated the phosphate recovery performance of a porous calcium silicate hydrate (P-CSH) derived from carbide slag. The prepared P-CSH exhibited distinct skeleton structures and abundant pores (average at 10.88 nm). The Ca:P molar ratio in the phosphate recovery product was determined to be 1.49-1.64 by ICP-OES and EDS, and the main component was Ca₃(PO₄)₂ and Ca₅(PO₄)₃OH according to XRD patterns. For mechanism study, FTIR and XPS spectra revealed that the Ca-OH group was directly associated with phosphate recovery, which will be transformed to Ca-P after reaction. The equilibrium pH was an important factor, experimental and Ksp-based theoretical calculation results revealed that the optimal pH was ~8.5 for phosphate recovery. Besides, the influence of coexisting SO₄²⁻ and HCO₃⁻ can be avoided by adjusting the equilibrium pH within 5.3-10.2. The P-CSH synthesized from carbide slag has shown great potential for phosphate recovery.

Keywords: porous calcium silicate hydrate; phosphate recovery; equilibrium pH

Phosphorus is an essential nutrient for biological growth, but excessive phosphorus discharged into freshwater and coastal marine can lead to the deterioration of water quality. Globally, oxygen-depleted surface water ‘dead zones’ caused by nutrient-driven algal blooms is still expanding (Smith et al., 2013; Elser and Bennett, 2011). On the other hand, phosphorus is also a non-renewable resource without known replacement. Therefore, it is urgent to recover phosphorus from wastewater for preventing it from entering water bodies. In the last three decades, the calcium-rich industrial by-product or waste slag has been considered as economical and effective materials for phosphate recovery (Yamada et al., 1986; Pratt et al., 2007). As by-products of steelmaking industry, the highly alkaline steel slags have been widely demonstrated as efficient substrates for phosphate recovery in many international studies. The high alkalinity and high calcium content make it favourable for phosphate binding because the slag can release sufficient calcium ions (Ca²⁺) and hydroxide ions (OH⁻) into bulk solution, facilitating the formation of calcium-phosphate precipitates under supersaturated conditions (Johansson Westholm, 2006).

As a by-product from hydrolysis of calcium carbide (CaC₂) for the production of acetylene, carbide slag is mainly composed of calcium hydroxide (Ca(OH)₂), exhibiting strong alkalinity. At present, such kind of slag is mainly applied to flue gas treatment or used as chemical additive (Li et al., 2015; Hanjitsuwan et al., 2018).
However, when these applications cannot completely consume the huge amount of carbide slag, the excessive part is usually disposed by landfill, which buries a huge ecological risk and does not comply with the 3R (reduce, reuse and recycle) principle. Considering that the carbide slag is rich in calcium and features high alkalinity, it might be a potential material, just like steel slag, for phosphate recovery via calcium-phosphate precipitation.

Inspired by previous studies, a porous calcium silicate hydrate (P-CSH) has been developed with hydrothermal method using carbide slag as raw material, aiming at recovering phosphate from wastewater. The P-CSH was developed from industrial by-products, making the chemical recovery of phosphate become more cost-effective. Besides, the P-CSH has a low toxic effect and its product can be used as a phosphorus resource for industrial utilization. The Ca:P molar ratio in the phosphate recovery product was determined to be 1.49-1.64 by ICP-OES and EDS, and the product was mainly composed of Ca$_3$(PO$_4$)$_2$ and Ca$_5$(PO$_4$)$_3$OH according to XRD patterns. The interaction mechanism between P-CSH and phosphate was analyzed by means of morphology and spectroscopy characterization. It was found that the Ca-OH group of P-CSH was directly involved in phosphate recovery, during which the Ca-OH will be transformed to Ca-P group after reaction. The influence of contact time and dosage were examined separately to determine optimal conditions. The effect of equilibrium pH and coexisting ions were evaluated by experimental and theoretical methods. The potential removal capacity and reusability of P-CSH were evaluated by nine cyclic batch experiments and were regenerated by calcination.

![Diagram](image.png)

**Figure 1.1** Experimental and theoretical evaluation of the effect of equilibrium pH (6.5–10.5) on phosphate removal capacity and efficiency of P-CSH. (a) is the experimental phosphate removal capacity affected by equilibrium pH, (b) is the theoretical calculation of the equilibrium phosphate concentration based on the $K_{sp}$ of Ca-P precipitate with the initial Ca:P molar ratio of 1:1-3:1, and (c) indicates the dominant Ca-P product type at different Ca:P ratio and equilibrium pH conditions.
REFERENCES


Phosphorus Removal by a Sequence Batch Moving Bed Biofilm Process

A.B. Fanta*, S. Sægrov**, S.W. Østerhus***

*Department of Civil and Environmental Engineering, Norwegian University of Science and Technology, S.P. Andersens Veg 5, N-7491, Trondheim 
*abaynesh.b.fanta@ntnu.no **sveinung.sagrov@ntnu.no ***stein.w.osterhus@ntnu.no

Abstract: This research investigated Bio-P removal from actual municipal wastewater at cold (10 °C) and warm (20 °C) temperatures using a sequence batch moving bed Bio-P reactor (SB-MBBR). Compared to the cold reactor, the warm reactor contained relatively higher Poly-P content in the biomass. The unstable Bio-P performance in the cold reactor could be due to thick biomass growth and that the biomass may contain glycogen-accumulating organisms (GAOs). Overall, the warm reactor performed very well; whereas, the cold reactor showed significant removal of SCOD although it showed unstable Bio-P performance. The diluted wastewater and influent concentration variations challenges the Bio-P process in addition to the low temperature operation. The results are supported by microbial community assessment.

Keywords: Moving Bed Biofilm; phosphorus; temperature

Enhanced bio-P removal followed by P recovery is an alternative approach to address this and the fact that P is a limited resource. Temperature influence the Bio-P process (Brdjanovic et al., 1998). In cold climate such as Norway, the low temperature may reduce the microbial activity, the anaerobic substrate uptake rates and cell growth (Zhou et al., 2018). Unlike the activated sludge process, a moving bed biofilm (MBBR) process can retain more biomass without sludge recirculation (Ødegaard et al., 1994), and thereby possibly reduce problems due to low temperature and concentration variations. This study aims to investigate the potential of MBBR Bio-P processes under challenging operational conditions.

METHODOLOGY Two sequence batch moving bed biofilm reactors, SB-MBBR (working volume of 13 L) were operated at 10 and 20 °C temperatures for 211 days. The reactors operated in anaerobic-aerobic cyclic process with three cycles per day (i.e. 3 h and 15 min anaerobic and 4 h and 45 min aerobic phases). The composition of the wastewater and the overall treatment results are presented in Table 1.1. Biofilm carriers were sampled for total biomass determination as TS (g TS/m²) and microbial community analysis. The biomass Poly-P content and observed growth were evaluated. Kinetic study was conducted to see the phosphate release, SCOD consumption and P uptake rates.

RESULT AND DISCUSSION The total attached biomass was 12.2 and 16.1 g TS/m² for warm and cold operated reactors respectively. The Poly-P content of the
biomass was 0.06 and 0.04 mg total P/mg TSS for warm and cold reactor respectively. This shows that the warm reactor contained higher amount of phosphate accumulating organisms relative to the cold reactor. The primary PO₄-P released to COD consumed ratio was 0.3 and 0.1 mg PO₄-P/mg COD for the warm and cold reactors respectively. Both reactors showed a rapid COD uptake rate in the first 0.5 h. However, the cold reactor showed a very slow P release and P uptake rates and low P release to COD consumed ratio (Figure 1.1). This may be due to: i) a very thick biofilm growth, which may hinder the substrate diffusion; ii) the growth of GAOs; and iii) the effect of lower temperature on anaerobic substrate uptake rate (Brdjanovic et al., 1998; Geiger and Rauch, 2017). It is commonly believed that PAOs prefer cold temperature compared to GAOs (Lopez-Vazquez et al., 2009). However, the results in this study indicates that the unstable Bio-P performance at low temperature may be due to growth of GAO like organisms. Overall, the warm reactor performed very well; whereas, the cold reactor showed significant removal of SCOD although it showed unstable Bio-P performance. The diluted wastewater and influent concentration variations challenges the Bio-P process in addition to the low temperature operation. The results are supported by microbial community assessment.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>SB-MBBR1 (warm reactor, 20°C)</th>
<th>SB-MBBR2 (cold reactor, 10°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Effluent</td>
</tr>
<tr>
<td>PO₄-P (mg/L)</td>
<td>4.7±1.7</td>
<td>1.5±2.0</td>
</tr>
<tr>
<td>NH₄-N (mg/L)</td>
<td>35.2±13.5</td>
<td>3.0±8.0</td>
</tr>
<tr>
<td>SCOD (mg/L)</td>
<td>182.9±90.0</td>
<td>32.4±11.1</td>
</tr>
</tbody>
</table>

Figure 1.1 Kinetic study information on warm and cold reactors performances.

REFERENCES


Role of Fermentative Hydrogen as Electron Donor in Bio-Electrochemical Systems for Nutrient Recovery


* Wetsus, European Centre of Excellence for Sustainable Water Technology, Oostergoweg 9, 8911MA Leeuwarden, The Netherlands
** Sub-Department of Environmental Technology, Wageningen University, Bornse Weilanden 9, P.O. Box 17 , 6700 AA Wageningen, The Netherlands
* Corresponding author: annemiek.terheijne@wur.nl

Abstract: This work investigated the competition of an electroactive bacteria (EAB) syntrophic biofilm with methanogens for hydrogen (H2) gas from different sources in microbial electrolysis cells (MECs). Ethanol (EtOH) was used as model compound to create H2 from fermentation. 70% of 1 mM EtOH was converted into electricity (e-) and total converted charge was 20% higher than for the same amount of acetate, meaning that H2 from EtOH fermentation was used by EAB rather than by methanogens. Cumulatively adding 1 mM EtOH without medium exchange resulted in stable conversion of H2 to e- rather than methane (CH4) over the course of 2 weeks (77% to 67% e-). With H2 gas, 68% H2 was converted into e- rather than CH4 (16%) with no carbon source added, but only 53% e- with 69% CH4 when 50 mM bicarbonate was provided. This shows that electrogens can outcompete methanogens for H2 as additional electron donor in MECs for nutrient recovery.

Keywords: substrate competition; bio-electrochemical systems; hydrogen oxidation

Bio-electrochemical systems (BES) have been investigated as energy efficient technologies for nitrogen recovery (Kuntke et al. 2018). The main limitation found for nitrogen recovery was the amount of available electron donor to produce sufficient electrical current to remove the respective nutrient from wastewater. Hydrogen gas (H2) could be an electron donor in BES, which could be fed directly as gas or come from fermentation of complex organic compounds. Ethanol (EtOH) is a suitable model compound to investigate fermentative H2 since 1 mol EtOH can be fermented directly into 1 mol acetate (Ac) and 2 mol H2. However, methanogenic H2-oxidation is one of the main competing electron sinks for electro-active bacteria (EAB) for electricity generation from H2 and lowers the Coulombic efficiency of BES (as indicated by thermodynamic calculations). In this study, we investigated under which operational conditions EAB could outcompete methanogens for H2 utilization from both EtOH fermentation and gaseous H2.

We used H-type electrochemical cells with synthetic medium, 50 mM phosphate buffer at pH 7.8, a bipolar membrane and a graphite felt as anode. The medium was replaced and the anode carefully rinsed with MilliQ water every time the generated current had passed its maximum during start-up phase. All of this reduced pH limitations for EAB and removed planktonic microorganisms, giving a competitive advantage to biofilm forming microorganisms on the anode. Electron balances were established once stable conversion rates to electricity were achieved.
When 1 mM EtOH was added, 70 ± 0.3% of electrons were converted into electricity within 5 hours (Figure 1.1). This is higher than the 60% reported by Parameswaran et al. 2009 under similar conditions. Since our conversion yielded little more than the theoretical maximum conversion for Ac originating from EtOH fermentation (66.6%), subsequent studies were performed. With 1 mM of pure Ac a higher conversion efficiency (87 ± 5%) was found after 3 h. This was around 20% less total charge converted from Ac than from EtOH, while methanogenesis stayed below 1%. This confirms that H₂ from fermentative sources such as EtOH can be converted to electricity by EAB similar to gaseous H₂ (as shown by Rodenas et al. 2017), but also from fermentative sources such as EtOH. It furthermore shows that the competition between EAB and methanogens for substrate can be shifted favourably towards EAB through an operational strategy. The thereby grown biofilm also outcompeted methanogens over 14 days for EtOH without medium replacement with daily addition of 1 mM EtOH. Substrate conversion to electricity stayed above 66% with 2 - 4% methanogenesis. Yet, when open circuit conditions were applied after 14 days, methanogenesis more than doubled to 9 % within 3 days. This was proof that methanogens were active, but outcompeted by EAB for EtOH. Limiting available carbon and using 50/50% H₂/N₂ gas as headspace gave 68% conversion to electricity and 16 % methane after 7 days. In presence of 50 mM bicarbonate, 53% was converted to electricity and 69% to methane after another 7 days.

In conclusion, the electrogenic biofilm was successfully steered towards outcompeting methanogens for fermentative H₂. The biofilm also converted gaseous H₂ in presence of a carbon source to electricity at similar efficiency as methanogens to CH₄. This indicates that both H₂ sources could be used as electron donor for efficient and sustainable nutrient recovery in BES.

![Figure 1.1 Bio-electrochemical oxidation of 1 mM EtOH and subsequently 1 mM Ac at -0.3 V vs. Ag/AgCl anode potential, displayed as current density generated over time (A) and charge conversion to electricity (B). Dashed lines in (B) show the necessary charge in electricity generated to signify 100% conversion of the respective substrate. The experiment was carried out in duplicate.](image)

**REFERENCES**


Tools for the Selective Production of Purple Bacteria in Raceway Reactors as Source of Microbial Protein

A. Alloul*, D. Adamczyk, S.E. Vlaeminck**

University of Antwerp, Research Group of Sustainable Energy, Air and Water Technology, Belgium, *Abbas.Alloul@UAntwerpen.be, **Siegfried.Vlaeminck@UAntwerpen.be

Abstract: To relieve tensions in the food chain, wastewater resources can be upgraded to microbial protein, which can be used as feed ingredient. We propose the production of purple non-sulphur bacteria (PNSB) on brewery wastewater in a more cost-efficient raceway reactor, i.e. systems open to air. Batch tests were performed to explore the potential metabolic conversions by PNSB and non-PNSB occurring in a raceway. A yield of 0.44 g CODbiomass g⁻¹ CODremoved for light aerobic conditions or 2.3x lower compared to light anaerobic growth was observed. This reflects COD oxidization to CO₂ by PNSB and non-PNSB. Production of CO₂ increased and pigments content decreased at higher oxygen transfer rates (OTR), which indicates an augmented chemoheterotrophic growth. Raceway experiments showed that PNSB can be produced in a reactor open to air (0.25 g TSS L⁻¹ d⁻¹). However, 12h-light/12h-dark decreased pigment content by 1.2-1.6x and increased CO₂ formation roughly by 1.3x indicating an increased chemoheterotrophic over photoheterotrophic growth.

Keywords: single-cell protein; purple phototrophic bacteria; resource recovery

INTRODUCTION

The conventional food chain is a cascade of inefficiencies. Upgrading nutrients from wastewater to microbial biomass could improve the efficiency, with this protein-rich product used as animal feed (Verstraete et al. 2016). Brewery wastewater is a potential interesting source to upgrade resources to microbial protein due to the suitable COD concentration and the potential to prevent faecal contamination. Purple non-sulphur bacteria (PNSB) cultivated under anaerobic photoheterotrophic conditions in closed photobioreactors (PBR) provide an excellent target group for protein production on wastewater, as they can be produced highly selectively (Alloul et al. 2019). However, costs for a PBR are roughly one order of magnitude higher compared to an aerobic sludge tank. This study therefore aimed to cultivate PNSB in a raceway reactor open to air, a more cost-efficient system and unravel tools (e.g. OTR, light/dark) for the selective production of PNSB. The first objective was to map out the potential metabolic conversions of a PNSB and non-PNSB under light aerobic conditions in batch (i.e. photoheterotrophy, and aerobic and anaerobic chemoheterotrophy) and investigate the effect of OTR on the different metabolisms. Secondly, batch raceway reactor tests were performed on three synthetic brewery wastewater media as it is expected that carbon availability (complex vs. simple medium) influences the PNSB selectivity.

MATERIAL AND METHODS

Flask batch experiments were first performed to determine the PNSB growth kinetics of their photoheterotrophic, aerobic and anaerobic chemoheterotrophic metabolism, all potential conversions possible in a raceway. Four tests were executed with Rhodobacter capsulatus as inoculum under
RESULTS AND DISCUSSION Batch tests showed a 2.3x lower biomass yield for light aerobic conditions (prevail in raceway) compared to light anaerobic growth (Fig 1.1A), reflecting the oxidation of COD to CO2 by PNSB and non-PNSB (Fig 1.1B). Dark aerobic growth had a yield of 0.29 g COD biomass g⁻¹ COD removed, lower than light aerobic conditions due to absence of photoheterotrophic growth (1-to-1 substrate-to-biomass conversion). No growth was observed under dark anaerobic conditions as Rb. capsulatus is not able to convert VFA without an external electron acceptor. Experiments performed with a lower OTR (72 mg O₂ L⁻¹ d⁻¹; data not shown) under light conditions showed a higher biomass yield, because less COD could be oxidized. Therefore, the degree of oxygen entry is a potential tool to decrease chemoheterotrophic growth of non-PNSB. Overall, the results of this screening enables to assess the potential selectivity of PNSB in a raceway reactor based on the COD oxidized to CO₂ (only chemoheterotrophic growth) and pigments formed.

All raceway reactor experiments (Fig1.2) showed an increased pigment concentration (data not shown), therefore demonstrating that PNSB are able to grow in a non-axenic raceway reactor open to air. The 12h-light/12h-dark increased the amount of chemotrophic biomass formed and decreased the pigment content roughly by a factor 3. This indicates dark periods with COD availability lower the PNSB selectivity. Overall, chemotrophic biomass production was higher for the VFA medium (more CO₂ production; COD balance not shown) compared to the two types of brewery wastewater probably due to the accessibility of VFA as carbon source by competing aerobic chemoheterotrophs. Future continuous reactor experiments will focus on OTR management and feeding regime in order to improve PNSB selectivity (community will be examined).
**Figure 1.2** Impact of light regime and medium on biomass productivity (left y-axis) and COD removal rates in raceway experiments (right y-axis), using three media (a VFA mixture, and raw and fermented synthetic brewery wastewater) with continuous illumination (blue) and 12h-light/12h-dark regime (grey).

**REFERENCES**


Solar Drying as a Nature-Based Approach for Nutrients Recovery from Digested Animal Manures

L. Morey*, V. Riau*, L. Tey*, C. Biel*, À. Porta**, J. Soler***, B. Fernández*

*GIRO Program, Institute of Agrifood Research and Technology (IRTA), Torre Marimon, E08140 Caldes de Montbui, Barcelona, Spain. lluis.morey@irta.cat; victor.riau@irta.cat; laura.tey@irta.cat; carme.biel@irta.cat; belen.fernandez@irta.cat.

**Porgaporsc, Carrer Sant Miquel, 53, 25245 Vila-sana, Lleida (Spain). info@ecobiogas.es.

***EMA depuració i Enginyeria de l’Aigua, SL. Avda. Sant Jordi, 176 Bajos, 17800 Olot, Girona (Spain). adm@edepura.com.

Abstract: Solar drying, a nature-based technology, with low environmental impact and energy cost, is being used for the first time for nutrient recovery from anaerobically digested animal manures. The final product is comparable to other organic fertilizers. In this work, a mass balance of combined digestate treatments (solid-liquid separation, stripping, acidification and solar drying) is presented to evaluate the potential of this technology, identifying its bottle-necks and feasibility at full-scale as well as its environmental impact by gaseous emission monitoring.

Keywords: resource recovery, digestate, solar drying, high-quality fertilizers.

INTRODUCTION Animal-derived waste, particularly manure, is widely used as a fertilizer, but its value is commonly low or negative because of its high moisture content and low nutrient concentration (Mehta et al, 2015). The nitrogen and phosphorous content of animal manures ranges 2.7-30.7 gTN kg⁻¹ and 1.8-28.6 gTP kg⁻¹, depending mainly on the type of animal (Generalitat de Catalunya, 2000). Therefore, concentration processes are usually required, being thermal technology one alternative. Among other processes as composting, solar drying has been thoroughly applied to preserve agricultural products as well as a dewatering process of municipal sewage sludge (Pirasteh et al. 2014). The aim of this work is to assess, at full scale, the technical feasibility of an innovative approach through solar drying and stripping, applied to digested manures, to produce an organic fertilizer product. Important aspects such emissions monitoring and minimization strategies are addressed, as well as the agronomical characterization of final fertilizers.

MATERIALS AND METHODS The process diagram at full-scale is shown in Figure 1, which is run in parallel with a full-scale agroindustrial biogas plant (Lleida, Spain).

Figure 1.1 Diagram of the process, indicating gaseous emissions monitoring points.
Digestate is divided into a concentrated stream (CF after the centrifuge) that is submitted to solar drying previous acidification, while the centrate (C) is addressed to a stripping/scrubbing unit. The lonely required chemical is sulphuric acid in the acidification and the scrubbing units. All streams are analysed by their physico-chemical parameters (total solids (TS), total and inorganic carbon, total ammonia and nitrogen (TAN, TN), total phosphorous (P2O5), total potassium (K2O), heavy metals, conductivity and pH) (APHA, 2005) and their fertilizer potential (through vegetable crops growth tests) (OECD, 2006). Mass flows are monitored on-site (full scale). The nutrients recovery indexes are calculated based on mass balances including the gaseous emissions (greenhouse gases, ammonia) (EPA, 2001), which are monitored in the main process units (centrifuge, stripping, degassing, solar drying) and intermediate storage tanks.

**RESULTS** The objective of centrifuge and solar drying units is to increase the TS content (set value of 13-16% and 80-88%, respectively), while stripping is designed to improve the N-recovery (N-recovery of 9-13% of TN-Digestate). The main streams that can be submitted to solar drying and the dried products are summarised in Table 1.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Flow (t d-1)</th>
<th>TS %*</th>
<th>TN %*</th>
<th>TAN %*</th>
<th>TP %*</th>
<th>N-recovery (%TN)**</th>
<th>P-recovery (%TP)**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digestate</td>
<td>4.4</td>
<td>7.07</td>
<td>0.71</td>
<td>0.36</td>
<td>0.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>dried-Digestate</td>
<td>88.90</td>
<td>7.00</td>
<td>3.87</td>
<td>2.14</td>
<td>100</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>CF</td>
<td>21.8</td>
<td>13.49</td>
<td>1.12</td>
<td>0.40</td>
<td>0.16</td>
<td>63</td>
<td>91</td>
</tr>
<tr>
<td>dried-CF</td>
<td>3.3</td>
<td>88.90</td>
<td>7.00</td>
<td>3.87</td>
<td>1.06</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>LN</td>
<td>4.5</td>
<td>0.86</td>
<td>0.58</td>
<td>0.53</td>
<td>0.02</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>dried-CF&amp;LN</td>
<td>3.7</td>
<td>80.00</td>
<td>6.29</td>
<td>3.48</td>
<td>0.97</td>
<td>69</td>
<td>93</td>
</tr>
</tbody>
</table>

For example, in the first experimental trial, the organic fertilizer obtained directly from the digestate had 11.1% moisture, 38.7 gTAN kg⁻¹, 70 gTN kg⁻¹ and 10.6 gTP kg⁻¹, which are above the established limits from Spanish legislation on fertilizers (Decreto-ley 506/2013). Other trials were designed to improve the N&P recovery or to formulate fertilizers depending upon plant growth requirements. For example, the low N-content stream (LN; stripping outflow) is susceptible to be mixed with CF, previously to be dried. When a blend CF:LN = 1:1 was transformed, the final product had 20% moisture, 34.8 gTAN kg⁻¹, 62.9 gTN kg⁻¹ and 9.7 gTP kg⁻¹, getting a N&P recovery of 69% TN-Digestate and 93% TP-Digestate (Table 1).

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**REFERENCES**


Bioelectrochemical Technologies for Resource Recovery in Wastewater Treatment Wetland Systems


* Department of Green Chemistry and Technology, Ghent University. Coupure links 653, 9000 Gent, Belgium
b Group of environmental engineering and microbiology (GEMMA). Universitat Politècnica de Catalunya - BarcelonaTech C/Jordi Girona 1-3, Building D1-105, 08034 Barcelona, Spain
+This is the first author’s address, Marco.Hartl@ugent.be
++This is the second author’s address, Gijs.DuLaing@ugent.be

Abstract: Bioelectrochemical systems (BES) such as Microbial Fuel Cells (MFCs) or Microbial Electrolysis Cells (MECs) are part of a relatively new research field. MFCs use exoelectrogenic microorganisms as catalysts in order to produce current from the oxidation of organic compounds (Logan et al., 2006). MFCs need a redox-gradient between electrodes to produce a current, which occurs naturally in constructed wetland (CW) systems. MEC is a modified MFC, with the main difference that an external power source is supplied to control the potential between anode and cathode and thereby achieve thermodynamically otherwise unfavourable reactions (Rozendal et al., 2006). The implementation of MFC or MEC in CWs has shown promising results so far mainly for improving water recovery through enhanced nutrient removal from wastewater. The hoped-for recovery of energy in the form of electricity in CW-MFC systems is still far from being usefully efficient to date. Amongst other applications, pure MECs were investigated for hydrogen and methane production, however, whether this is applicable in CWs demands further research.

Keywords: Constructed wetland; microbial electrolysis cell; microbial fuel cell

In the case of water recovery through wastewater treatment and nutrient removal, laboratory and meso scale experiments implementing MFCs in CWs have shown that ammonium and COD removal could be improved by up to around 30% (Corbella and...
Puigagut, 2018; Hartl et al., 2019; Srivastava et al., 2015; Yadav et al., 2012). CW-BES systems showed similarly promising results for improvement of COD and ammonium removal by applying relatively low currents in the range of 10-15 mA (He et al., 2016; Wang et al., 2017).

The highest electricity production by a pure MFC and a CW-MFC system are 12 W·m⁻³ (Logan and Rabaey, 2012) and 2 W·m⁻³ (L. Xu et al., 2017), respectively. Solar panels produce for example 175 W/m² (Panasonic HIT® Photovoltaic Module, 2012). Therefore, it seems that energy recovery through electricity production by MFC or CW-MFC technology is to date far from being usefully efficient.

Due to the possibility of achieving thermodynamically otherwise unfavourable reactions through the implementation of MECs there is a variety of further possibilities to use these systems. An example would be the production of methane or hydrogen in MEC systems (Ivanov et al., 2013; Wagner et al., 2009). However, whether these processes will be efficient enough in pure MEC systems or whether it is applicable to implement MECs for such purposes in CWs demands further research. New applications of electrochemical systems in wastewater treatment wetlands are currently being investigated. Results will be presented at the conference.

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REFERENCES


Abstract: Expected legislation change should lead us to develop economically accessible, efficient and high-capacity sorbent with specifically modified surface (metal oxide nanoparticles) for tertiary treatment at the municipal wastewater treatment plants. Optimized nano-enriched sorbents are prepared from different substrates (biochar, sand, slag) to achieve the most favorable ratio price/capacity. Sorbents are developed and tested in the lab-scale and compared to products that are recently at the market. Pilot-scale verification is going to be processed to compare sorbents not only each other but also to competitive technologies, i.e. ion exchange, coagulation, sedimentation, membrane filtration, sand filtration at two smaller municipal wastewater treatment plants (1200 and 3500 PE).

Keywords: phosphorus recovery; sorption; nanoparticle modified materials

Phosphorus promotes secondary pollution of water, especially the growth of cyanobacteria that produce dangerous life-threatening toxins for lower organisms. Elevated concentrations of phosphorus are caused by his income from both point (wastewater treatment) and non-point sources. Local legislations on wastewater treatment plant quality outlet are derived from UWWT Directive (91/271/EEC) and those limits for phosphorus removal are not stringent and thus lead to the large pollution of recipients. Municipal wastewater treatment plant outlets belong between main sources of water for recipients (streams, rivers, lakes, etc.) in recent periods of drought. Treated wastewater quality should thus anticipate recipient deterioration. We cannot observe this phenomenon even although wastewater treatment plant operators fulfill their outlet limits since starting concentration for proliferation of cyanobacteria in the recipient is between 20 – 50 µg P/L. Government direction 401/2015 in the Czech Republic says that we do not need to remove phosphorus at wastewater treatment plants up to 2000 PE and TP has to be removed to 3 mg/L for WWTPs up to 10 000 PE. This situation led to the rapid deterioration of recipients and raised the need of the extensive communication between wastewater treatment engineers and limnologists leading to the more stringent legislation soon and hopefully we can expect phosphorus outlet limits under 1 mg/L even also for smaller point pollution sources. Phosphorus is recently being depleted from the environment and belongs between critical raw materials defined by European Union and should be recycled as much as possible due to the strong dependency of European Union on its import. European Union made several steps in the last decade leading to the establishment of European Phosphorus Platform followed by establishment of several national platforms (the Netherlands, England, Germany, Switzerland, Czech Republic, etc.) and some countries (Germany, Austria and Switzerland) already put into practice.
legislation on obligatory phosphorus recovery from wastewater treatment plant facilities.

Our research anticipates stricter outlet phosphorus limits and tries to develop novel sorbents from waste materials and functionalize them for better phosphorus removal efficiency and aims economy of possible phosphorus recovery. Smaller municipal wastewater treatment plants remove phosphorus recently via simultaneous precipitation by metal salts (Fe or Al), however this technology have limitation for stringent outlet phosphorus parameters. It is necessary to dose bigger stoichiometric ratio of those salts to achieve desired outlet limits around 0.5 mg/L. It also leads to the recipient salination due to high concentration of those salts. Alternative technologies will be thus critically evaluated from its efficiency and economical point of view to compare possible application of those technologies in the future.

Project has started before several months and two project lines are followed simultaneously. First project line includes critical comparative study of recently used materials for phosphorus removal in water treatment (ion exchange resins, sorbents, reactive sorbents, etc.) in the line with literature search on applicability of those materials in the full-scale. Second project line includes sorbent material development and its testing from material point of view, but also in the laboratory in the phosphorus removal efficiency and technology robustness. Those two lines will issue into the pilot-plant built-up in autumn 2019 where will be those novel sorbents evaluated at two municipal wastewater treatment plants together with other recently used technologies (coagulation, coagulation + sedimentation, coagulation + sand filtration, coagulation + membrane filtration, ion exchange).

Our poster presentation will include comparison of results achieved in the lab-scale for recently used ion exchange resins and sorbents compared with our novel sorbents by balance achievement, its maximum sorption capacity, sorption and regeneration kinetics and price evaluation. Second part of the presentation will include sorbent material development and its functionalization.

![Figure 1.1 Different functionalization of biochar sorbents](image)

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Short Branch Chain Fatty Acid Production from Methanol by an Open Culture Enrichment


* Center for Microbial Ecology and Technology (CMET), Ghent University, Coupure Links 653, 9000 Ghent, Belgium, shengle.huang@ugent.be
** Department of Biotechnology, Delft University of Technology, Van der Maasweg 9, 2629 HZ, Delft, Netherlands, r.kleerebezem@tudelft.nl
*** CAPTURE, www.capture-resources.be

Abstract: Iso-butyric acid (IBA) is a valuable platform chemical of high demand. Whilst research has focused on using genetically modified organism to produce IBA, other research has reported the production of IBA by open culture from non-sterile feedstock. A recent study showed IBA production from acidified organic waste by adding methanol, which appears in different industrial wastewater. However, little is known on the ecology of such IBA producing microbiota. In this study, we applied 16S rRNA sequencing technique to characterize the microbial community dynamics under different operation conditions, which is associated to the system performance. The result suggests that the relative abundance of two major OTUs, i.e. Clostridium spp. and Eubacterium spp., is significantly correlated with the relative productivity of IBA and Butyric acid. The knowledge on microbial population paves way for future engineering of bio-recovering IBA from organic waste streams.

Keywords: Chain Elongation; methanol; open culture

Chain Elongation (CE) is a process to recover resource from organic waste by which different electron donors are used to elongate short chain fatty acids (i.e. acetate) into longer chain fatty acids (Spirito et al. 2014). In a MeOH driven CE, adding Methanol (MeOH) to acidified organic waste can stimulated IBA production in an open culture batch system (Chen et al. 2016), which commences the opportunity to produce IBA from organic waste without sterilization. In addition, MeOH is an important organic constituent in certain industrial wastewater, e.g. paper mill Kraft
condensates (Minami et al. 1991) and coal-gasification condensate (Mohr and King 1985). However, despite IBA production was observed in open culture fermentative systems, the ecology of the SBCFA producing microbiota and the driving force for SBCFA production remains elusive. In this study, we aim to link IBA production and dynamics in microbial population under different operational conditions, to depict the potential key players and their interaction in a MeOH driven SBFCA producing system, which will benefit the forthcoming exploration on expanding the product profile of resource recovery by open culture fermentation systems.

RESULTS AND CONCLUSIONS In the total operational period of 220 days, four phases were applied to the system. Microbial community analysis based on 16S rRNA revealed the dominance of the two bacterial OTUs, Clostridium spp. and Eubacterium spp. (Together they accounted for 54% to 87% of the total reads). In Phase I, HRT was gradually decreased from 20 days to 3 days as substrate depletion was observed. The major product in this period was n-butyrice acid (BA) (maximum 160.5 mM-e.day⁻¹) and the presence of Eubacterium spp. was dominant. This particular OTU shares 99.5% similarity with E. limosum ATCC 8486 over the consensus base pairs, which is a strain that is known for utilizing one-carbon compounds for the production of short chain fatty acids (Pacaud et al. 1986, Song and Cho 2015). In Phase II, apart from raising the bicarbonate concentration in the medium from 30 mM to 90 mM to increase its availability, an ultra-filtration hollow fiber membrane module was added to the effluent line to retain biomass in the first 20 days of this phase. An escalated abundance of Clostridium spp. resulted in the increase in both BA production rate (from 104.7±27.8 to 133.6±14.0 mM-e.day⁻¹) and the IBA production rate (from 13.0±7.4 to 84.4±11.1 mM-e.day⁻¹). BES (2-bromoethanesulfonate, 25mM) was added to the medium in Phase III to inhibit the methanogenic activity. Surprisingly, IBA production immediately eliminated and the relative abundance of Clostridium spp. decreased. Subsequently, BES was removed from the medium after 7 HRTs. The IBA production rapidly recovered (77.6±11.4 mM-e.day⁻¹) along with relative abundance of Clostridium spp., while BA production slightly increased (from 165.7±34.1 to 183.6±22.6 mM-e.day⁻¹) and methane production remained lower than 0.1 mM-e.day⁻¹.

![Figure 1.1](image.png)

**Figure 1.1** Correlation of the relative abundance of the two key OTUs with the relative productivity of the two key products.

This study investigated the microbial community dynamics and the reactor performance under different conditions in a MeOH driven SBCFAs producing system. We conclude that (i) the relative productivity of IBA and BA is linked to the relative abundance of Clostridium spp. and Eubacterium spp., (ii) the addition of methanogenesis inhibitor BES can inhibit IBA production alongside with the growth of Clostridium spp.
REFERENCES
Iron-reducing Biocathode for PO₄³⁻ Remobilization from FeP Complexes Contained in Wastewater Sludge

D. Sun, X. Chen, X. Zhang, P. Liang, X. Huang*

State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, China, E-mail: sdy930928@163.com
*Corresponding author, E-mail: xhuang@tsinghua.edu.cn, Tel: +86-10-62772324, Fax: +86-10-62771472

Abstract: Phosphorus remobilizing from the wastewater sludge produced in chemical phosphorus removal process is a key challenge for nutrient resource recovery in future wastewater treatment plants (WWTPs). In this study, the proof-of-concept of an electrical potential induced iron-reducing biocathode is demonstrated, aiming to reduce Fe³⁺ and release PO₄³⁻ from the FeP complexes contained in the wastewater sludge. Compared with non-potential applied biocathode, the PO₄³⁻ release efficiency could be improved by more than 45% in the iron-reducing biocathode. The kinetic equation of Fe³⁺ reduction in iron-reducing biocathode could be expressed as: \[ \frac{dα}{dt} = k'(1 - α)^{2/3} \]

The cyclic voltammetry (CV) curves and microbial community analysis indicated that the applied potential could benefit the electron transfer during the reducing process.

Keywords: Phosphorus recovery; biocathode; sludge treatment

INTRODUCTION

In the future WWTPs which would act as energy and phosphorus factories (Nowak et al., 2011; Li, 2005), PO₄³⁻ and COD would be synchronously removed by adding Fe salt as coagulant, and thus generate concentrated sludge. Such sludge could be further digested to produce biogas, and after which PO₄³⁻ is supposed to be recovered from the digested sludge. But how to release PO₄³⁻ from the FeP complexes contained in the digested sludge is remained to be investigated (Wilfert et al., 2015). In this study, a novel iron-reducing biocathode combining biological and electrochemical processes was proposed to remobilize PO₄³⁻ from the FeP complexes contained in the sludge. Fe³⁺ could be reduced to Fe²⁺ through a microbial reaction chain in the biocathode and thus release PO₄³⁻ into the supernatant. Different electrical potentials were applied on the biocathodes to explore the performance of Fe³⁺ reducing and PO₄³⁻ releasing. The feasibility of iron-reducing biocathode was verified by the comparison with non-potential applied biocathode which utilized organic as the sole electron donor. The reaction kinetic of Fe³⁺ reduction was also analysed. CV curves and microbial community analysis were conducted to investigate the electron transfer and Fe³⁺ reduction mechanisms.

RESULTS AND DISCUSSION

Electrical potential induced biological reduction

As shown in Fig. 1A and C, Fe³⁺ reduction and PO₄³⁻ release both were affected by the applied cathode potential. Higher cathode potential resulted in faster Fe³⁺ reduction and PO₄³⁻ release. After 3 days’ operation, the maximum Fe²⁺ production (76.9 mg/L) and PO₄³⁻ dissolution (58.8 mg/L) were achieved at the cathode potential of 650 mV. It was anticipated that cathode potential could affect how much energy was available for...
electricity production (Ter Heijne et al., 2010). Thus, higher cathode potential would lead to higher current and more electrons that Fe$^{3+}$ could accept to transform into Fe$^{2+}$. The control experiment using the same type of biocathode but without external potential application was conducted, utilizing sodium acetate as the sole electron donor. The Fe$^{3+}$ reduction and PO$_4^{3-}$ release (Fig. 1B and C) both were inferior to the previously talked performances in the potential-applied group. The highest release proportion of PO$_4^{3-}$ was only 6.2 % in non-potential applied biocathode during the 3-day operation, which could barely reach 1/8 of that achieved in the iron-reducing biocathode, 51.7 % (Fig. 1C). Microbial community analysis was conducted after all the experiments finished. Compared with the control group, cathode potential stimulated the enrichment of Geobacter in the iron-reducing biocathode. Geobacter is a representative exoelectrogenic bacteria which could transfer intracellular and extracellular electrons to reduce Fe$^{3+}$. The electron transport chain composed of cytochromes c played an important role in the electron transfer process (Fig. 1E). A higher reduction peak current of biocathode was achieved in the CV curve of the potential-applied group than that achieved in the control group, indicating a higher concentration of cytochromes c contained in the biofilm.

**Reaction kinetic analysis**

Fe$^{3+}$ reduction in the biocathode is a non-autocatalytic reaction. Based on the calculation of experimental data, \( \ln(\frac{dc_{Fe}^3}{dt}) \) was linear (r > 0.99) to \( \ln c_{Fe} \) (Fig. 1D) when different particle sizes (P1-P4) of FeP complexes were tested, which suggested that the Fe$^{3+}$ reduction rate was only relevant with the total concentration of Fe$^{3+}$ in FeP complexes under constant temperature (T), particle size and biocathode potential. Therefore, the Fe$^{3+}$ reduction in the iron-reducing biocathode was hypothesized to be an n-order reaction. However, the reaction kinetic equation could have theoretical significance only when the value of n is 0, 1/2, 2/3 or 1 (Criado, 1977). To confirm the reaction order, the constant \( k' \) was calculated based on the experimental data with different values of n. Ultimately, the best linearity was obtained when n=1 (r > 0.99), and the kinetic equation of Fe$^{3+}$ reduction would be: \( da/dt = k'(1 - \alpha)^{2/3} \), where \( \alpha \) is the reacted fraction of Fe$^{3+}$ in FeP complexes, \( k' \) is the reaction rate constant (d$^{-1}$), t is the operation time (d).

**Relations to the conference**

In this work, the iron-reducing biocathode was proved to be an effective and energy-efficient way for PO$_4^{3-}$ release and recovery from the FeP complexes contained in
wastewater sludge, which would help to tackle the phosphorus recycle challenge in the future WWTPs.

REFERENCES


Li, J.Y., Effects of Fe(III) on floc characteristics of activated sludge, Journal of Chemical Technology and Biotechnology, 80 (2005) 313-319.


Enhanced Nitrogen Removal Using Corncob as Carbon Source and Biofilm Carrier: Performance and Microbial Shift

L. Huang*, J. Ye **

* Key Laboratory of Three Gorges Reservoir Region’s Eco-Environment, Ministry of Education, Chongqing University, Chongqing 400045, China, 1640998799@qq.com
** Key Laboratory of Three Gorges Reservoir Region’s Eco-Environment, Ministry of Education, Chongqing University, Chongqing 400045, China, yejy8888@163.com

Abstract: In this paper the solid biodegradable agricultural by-product corncob was used as solid carbon source and biofilm carrier to enhance nitrogen removal process from real domestic sewage. The performance of the reactor with corncob was compared with that of the control reactor (with addition of unbiodegradable fiber carrier). The results showed that corncob achieved a higher total nitrogen (TN) removal efficiency during long-term operation. The dynamic changes of biofilm microbial communities between two groups were further discussed to reveal the influence of organic matter derived from corncob on the structure and evolution of the biofilm microbial community. This work provides a new combined method of agricultural waste disposal and wastewater treatment.

Keywords: Nitrogen removal; agricultural by-product corncob; biofilm microbial community

Nowadays, many rivers, lakes and marine ecosystems have been suffered from nitrogenous pollution in worldwide due to the human activities, such as increment of chemical fertilizer use in agriculture (Vitousek et al., 2009). Considering that nitrogen (N) enrichment of water poses a huge threat to public health, aquatic ecosystems and biodiversity, it is urgent to reduce nitrogen loads discharged into aquatic systems. However, the carbon source required for biological denitrification is often insufficient in real sewage, especially in developing countries, resulting in the sewage tail water with high nitrate level (Tang et al., 2018). In order to improve the nitrogen removal efficiency, many researchers tried to add external carbon sources to enhance denitrification. Among various carbon sources, the agricultural wastes, such as corncob, cotton and rice straw, have recently received great attention, owing to the excellent denitrification capabilities and low-cost advantages (Yang et al., 2015). However, previous studies paid more attention on the denitrifying effects of these solid carbon sources, while until now less information was revealed on the structure and evolution of biofilm microbial communities under the acclimation of organic matter derived from solid carbon sources.

Based on previous studies, the agricultural by-product corncob has been used as solid carbon source and bio-carrier, aiming at enhancing nitrogen removal process from wastewater. The performance of corncob added reactor was compared to that of the control reactor (with addition of unbiodegradable fiber carrier). The effluent concentration of total nitrogen (TN) in corncob added reactor was lower than that in
control reactor, indicating a higher TN removal efficiency achieved by corncob. Correspondingly, the denitrifying bacteria had much higher abundance in corncob group than in fiber carrier group. Moreover, denitrifying bacteria were found to be positively correlated to heterotrophic bacteria in biofilms. These findings not only provide a new combined method of agricultural wastes recycling and wastewater treatment but also offer insight into the relationship between dynamic changes of biofilm microbial community and organic matter release of agricultural by-product.

Figure 1.1 Biofilm microbial community compositions of (a) bacterial phyla in R_Cor (> 0.1%), (b) bacterial phyla in R_Fib (> 0.1%) and (c) classified genera in R_Cor and R_Fib (top 50). R_Cor was the reactor filled with corncob. The other (R_Fib), fed with unbiodegradable fiber carrier, was used as a control reactor.

Figure 1.2 The relative abundance of functional genera. (a) and (b) are abundance of functional genera of biofilm samples from R_Cor and R_Fib, respectively. (c) and (d) are the correlation analyses of the nitrate-reduction bacteria (NAR) and nitrite-reduction bacteria (NIR) with heterotrophic bacteria (HET), respectively.

REFERENCES


Diffusion gradients in thin films as a potential monitoring tool to assess trace metal bioavailability in anaerobic digestion

A.Ilic*, G. Du Laing**, J.Bartacek*

*Department of Water Technology and Environmental Engineering, Technicka 5, 166 28 Prague 6, Czech Republic, ilicil@vscht.cz
**Laboratory of Analytical Chemistry and Applied Ecochemistry, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, Gent, 9000, Belgium, gijs.dulaing@ugent.be

Abstract: Supplementation of trace metals to anaerobic systems should be optimized in order to omit decrease in biogas production, due to their deficiency or low bioavailability. In our work, we assess the diffusive gradients in thin films (DGT) as a promising technique to determine biologically available TMs in a digestate. The assessment was done by checking parameters such as different deployment times of DGT cells and mixing effect. From the preliminary results, we can conclude that DGT can be applicable to anaerobic digestate for Fe determination and for Co and Ni with previously checking optimal deployment time.

Keywords: anaerobic digestate; trace metals; DGT

Recovering energy as biogas, through anaerobic digestion of organic matter is well established process in wastewater treatment. When wastewater and waste sludge are treated anaerobically, it is of great importance that biogas production is maximized by optimizing the activity of microorganism. The activity of the microorganisms can be hindered if trace metals are not present in the bioavailable form in the reactors, thus their supplementation may be needed. Moreover, if the digestate is to be applied as a fertilizer, optimization of trace metals supplementation in the digestate is relevant due to the concentration limits of metals allowed. For example, Zn and Ni are the two trace metals with proved stimulating effect on anaerobic digestion, but are also on the list of heavy metals with negative consequences on soil and the environment if present in excessive concentrations.

In order to optimize supplementation, the first step is to determine the amount of bioavailable metals in the digestates. Up to know, there is not a straightforward method that provides this information, with majority of techniques giving their own operationally defined fractions, that are complex to interpret. Our research focused on applying diffusive gradients in thin films (DGT), as a tool to determine the liable fraction of metals in the digestate (Zhang and Davison 2015). Although DGT technique is well established for an application in waters, sediments and soils, the research regarding its application to digestates is very limited (Laera et al. 2018). Additionally, we want to see at which DGT measured concentration of metals will activity of the methanogens be decreased and how the supplementation of a metal affects the change in DGT fraction.

Application of DGT to digestate was tested for different deployment times of the device, so as for mixing effects. The tested metals were Fe, Ni and Co. Our preliminary results show that DGT can be applied for Fe for any deployment time from 3h up to 6 days (not all the data shown), while for Co and Ni determination, deployment time should be shorter than 5 h (Fig.1). We will verify the results for different digestates and draw a conclusion regarding applicability of the device.

Optimal supplementation of trace metals to engineered anaerobic systems would decrease consumption of valuable resource such as trace metals, maximize microbial activity and it could be used for control of digestate application as a fertilizer.
**Figure 1.** The comparison of accumulated mass Co, Ni and Fe in metal deprived anaerobic digestate in relation to different deployment times

**REFERENCES**


Profiled Membranes: A Novel Approach to Mitigate Internal Concentration Polarization in Forward Osmosis

M. Jafari a, b *, A. D’haese b **, M. C. M. van Loosdrecht a, C. Picioreanu a

a Department of Biotechnology, Faculty of Applied Sciences, Delft University of Technology, Van der Maasweg 9, 2629 HZ, Delft, The Netherlands
b Particle and Interfacial Technology group (PaInT), Department of Applied Analytical and Physical Chemistry, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium

* This is the first author’s address: M.Jafarieshlaghi@tudelft.nl
** This is the second author’s address, Arnout.dhaese@ugent.be

Abstract: This study investigates a novel approach to reduced Internal Concentration Polarization (ICP) in Forward Osmosis (FO) process. Magnitude of ICP drastically reduces water flux in FO process. ICP magnitude can be reduced by decreasing membrane thickness. However, decreasing membrane thickness reduces membrane strength. In this study, water flux and membrane maximum deformation (which shows membrane strength) of support layer with different thickness have been compared experimentally and computationally. Finally, profiled membrane was proposed as a potential approach for trade-off between high water flux and membrane strength.

Keywords: Profiled membrane; Forward osmosis; fluid-structure interaction model

INTRODUCTION Forward Osmosis (FO) is a osmotically driven membrane process, which demonstrated high potential due to its limited energy consumption and fouling (Lee et al. 2010). Back diffusion of salt from concentrated solution (draw solution) to diluted solution (feed solution) leads to accumulation of salt in support layer. Salt accumulation in support layer is known as Internal Concentration Polarization (ICP) cause significant water flux reduction in FO process. Reduction in support layer thickness can significantly mitigate ICP and increase water flux, however, membrane strength and durability need to be considered (Wang et al. 2017). In this study, we suggested a profiled membrane (tessellated support layer) to increase water flux (by decreasing support thickness) while membrane is reinforced through tessellation. Profiled membranes are formerly used in Electrodialysis membrane to improve mixing properties (Pawlowski et al. 2016).

MATERIAL AND METHOD A novel fully coupled fluid-structure interaction model (FSI) in which fluid flow, solute transport and solid mechanics were coupled to evaluate water and salt fluxes as well as membrane structural displacement under FO process. Membrane hydraulic and mechanical properties obtained experimentally and used for further development of FSI model. In this study, membrane performance properties were evaluated based on average water and salt fluxes and maximum membrane displacement. Profiled membrane (tessellated support layer) were compared with conventional membrane using a novel FSI model.
RESULT AND DISCUSSION Figure 1.2 shows water flux distribution in membrane surface for both conventional and profiled membrane. It is shown that water mainly permeate through thin part of the membrane (Figure 1.2a-b). This confirms that support layer tessellation has minor impact on water flux for membrane with identical support layer thickness. However, Figure 1.2c-d demonstrates that membrane tessellation significantly reduces membrane displacement by increasing membrane strength. Figure 1.2e shows comparison between conventional thickness membrane (L_s=100 \mu m) with thin profiled membrane (L_s=40 \mu m). While water flux has increased from ~10 L/m^2/h for conventional membrane to 17 L/m^2/h for profiled membrane, maximum membrane displacement for both membranes are identical (~10 \mu m).

CONCLUSION Profiled membranes have high potential for production of membranes with elevated water flux while ensuring membrane mechanical strength in FO process.

REFERENCES

Enhanced Removal of Endocrine Disrupting Chemicals (EDCs) from Urban Wastewaters for Reuse Purposes


* Istanbul Technical University, Faculty of Civil Engineering, Department of Environmental Engineering, 34469, Maslak, Istanbul, Turkey. ozlem.karahan@itu.edu.tr; tolmez@itu.edu.tr; dogruelse@itu.edu.tr; koyuncu@itu.edu.tr; toroz@itu.edu.tr; tanika@itu.edu.tr; kinaci@itu.edu.tr
** ITUNOVA Technology inc. Istanbul Technical University, Ayazaga Campus, 34469, Maslak, Istanbul, Turkey. adudu.allaremek@itunovatto.com.tr; ceren.eropak@itunovatto.com.tr; suna.cinar@itunovatto.com.tr; onur.kiraz@itunovatto.com.tr; ercan.citil@itunovatto.com.tr
*** Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Water Management, 06560, Yenimahalle, Ankara, Turkey. aybala.kocorhon@tarim.orman.gov.tr; esra.siltu@tarimorman.gov.tr; sibelmine.gucver@tarimorman.gov.tr
**** Istanbul University, Faculty of Pharmacy, Department of Pharmacology, Beyazıt, Istanbul, Turkey. aokyar@istanbul.edu.tr
***** Istanbul University, Faculty of Pharmacy, Department of Pharmaceutical Toxicology, Beyazıt, Istanbul, Turkey. gulozhan@istanbul.edu.tr
****** Gazi University, Faculty of Pharmacy, Department of Pharmaceutical Toxicology, 06330 Hipodrom Etiler, Ankara, Turkey. ismetc@gazi.edu.tr
******* Middle East Technical University, Department of Environmental Engineering, 06800 Cankaya, Ankara, Turkey. uyetis@metu.edu.tr

Abstract: Reuse of treated urban wastewaters as an alternative water resource has recently become a necessity. However, micropollutants like endocrine disruptors should also be removed during treatment in addition to conventional pollutants, since they pose a great risk not only on freshwater resources, but also bear a risk in reuse applications. For the reuse of treated wastewaters for irrigation, it is important to understand the fate of these micropollutants in the conventional wastewater treatment plants (WWTPs). This study presents the occurrence and fate of endocrine disrupting chemicals (EDCs) in different urban WWTP configurations and presents the best treatment performances for the removal of EDCs from urban effluents for reuse practices. High removal efficiencies have been achieved for a number of the EDCs in different processes, while comparatively lower removal performances were observed for some of the studies EDCs.

Keywords: Endocrine disrupting chemicals; adsorption; membrane filtration

INTRODUCTION Reuse of treated urban wastewaters is considered as one of the most promising alternatives for providing alternative water resources. European Union (EU) is trying to set the regulatory limits for reuse of treated wastewaters for agricultural use so as not to jeopardize human health (EU, 2018). Urban wastewaters contain micropollutants which can be toxic and eco-toxic chemicals, heavy metals, endocrine disruptors and carcinogenic compounds in addition to conventional pollutants (Fatta-Kassinos et al., 2010). Therefore, it is important to understand the fate of these micropollutants in the conventional wastewater treatment plants (WWTPs) for considering their reuse potential after treatment. This study presents the
presence and fate of endocrine disruptors in different urban WWTP configurations and presents the best treatment performances for the removal of EDCs from urban effluents for reuse purposes.

**RESULTS AND DISCUSSION** The studied urban WWTP configurations have the following treatment schemes: i) Physical treatment units + oil & grit removal, ii) Physical treatment units + oil & grit removal - primary sedimentation - aeration - clarifier, iii) Physical treatment units + oil & grit removal - anaerobic/anoxic/aerobic tanks - clarifier, iv) Physical treatment units + oil & grit removal - primary sedimentation - anaerobic/anoxic/aerobic tanks – clarifier. Number of EDCs detected in the influent were ranged between 67 and 85 whereas in the effluent the number of EDCs were between 48 and 57 in pilot plants. Treatment efficiencies of parameters which were detected at pilot plant no.3 inlet through four measurement periods are given in Figure 1.1.

![Figure 1.1. Pilot Plant No.3 WWTP Treatment Efficiencies.](image)

Laboratory-scale treatment studies were conducted on effluents of pilot plant no.3 and 4 different treatment methods were applied such as ozonation, advanced oxidation with peroxone (O$_3$+H$_2$O$_2$), activated carbon adsorption and nanofiltration. It is observed that 4 of the 18 EDCs detected in pilot plant no.3 WWTP effluent can be treated by all processes below the limit of detection (LOD); the highest yield observed for 9 EDCs is filtration, for 1 EDC is peroxone, for 2 EDCs adsorption, ozonation, peroxone, and for 2 EDCs ozonation, peroxone and filtration processes.

High removal efficiencies have been achieved for some of the EDCs in different processes, while comparatively lower or even negative removal efficiencies were observed in some others. The concentrations of the EDCs that were not found in wastewater samples but are detected after advanced treatment applications are either slightly higher than LOD or at the same order of magnitude of LOD. Since these chemicals are not oxidation by-products, they were probably masked by the presence of other compounds and analysed as <LOD; however, they could be detected in the simplified matrix of treated wastewater above LOD levels.

**REFERENCES**


Abstract: Bio-based production of materials from waste streams is a pivotal aspect in a circular economy. This experimental study examined the impact of inoculum and pH on volatile fatty acids production from food waste. The results from batch anaerobic digestion experiments revealed that VFA production was more significantly influenced by pH than the inoculum type. The highest VFA efficiency was observed under pH 10 between 69%-84% of the soluble COD on day 10 for all inoculum types, while the highest acidification ratio ranged between 39-42% on day 15 when the pH was 5. The inoculum taken from food waste digester reached the highest acidification ratio of 84% in alkaline conditions, while the acidification efficiency under acidic conditions was almost similar for all the tested inocula.

Keywords: Food waste; volatile fatty acids; inoculum; pH

INTRODUCTION Excessive waste generation as a consequence of global population growth and economic development is a grave concern. Food waste comprises a major part of municipal solid waste. It is estimated that one third of the global generated food is disposed as waste (Braguglia, et al. 2017). Waste treatment methods such as landfilling and incineration promulgate harmful environmental effects. Anaerobic digestion (AD) is an alternative approach that is drawing attention as it opens new avenues in proper waste management as well as production of value-added materials from waste streams. Food waste is a promising feedstock for AD processes due to its biodegradability and nutrient-rich nature (Xu, et al. 2018). Volatile fatty acids (VFAs) are the intermediates of AD that can be utilized as renewable carbon sources with a broad range of applications such as bioplastics production (Atasoy, et al. 2018). Until today, various researches have optimized the operational parameters of AD aiming for VFA production. Yet, the effect of inoculum on the fermentative production of VFAs is a grey area. In this study, three different anaerobic digestion sludges were used to investigate the influence of inocula on VFA production efficiency under alkaline (pH 10) and acidic (pH 5) conditions.

MATERIAL AND METHODS Anaerobic batch reactors were set-up using 150-mL serum bottles with three different inocula from full scale anaerobic digesters. Inoculum 1 originated from the mesophilic anaerobic digester treating primary sludge (PS), waste activated sludge (WAS) and food waste (FW). Inoculum 2 was obtained from mesophilic anaerobic digester treating PS, WAS and glycerol. Inoculum 3 was taken from a food waste digester. Food waste was used as substrate. The experiments were designed with F/M 2, under two initial pH conditions; pH 5 and pH 10. The reactors were incubated at 35 °C with shaking of 125 rpm over a period of 30 days. Soluble chemical oxygen demand (sCOD), pH and total VFA content were measured. Bacterial characterization was performed by 16S rRNA next generation sequencing. The composition of the VFAs were determined using an Intuvo 9000 GC system.
RESULTS AND DISCUSSION In pH 5-experiments, acidification prolonged till day 15 until it reached its highest efficiency of $40 \pm 2\%$ for all three different inocula and exhibited a declining trend afterwards (Figure 1.1). The pH values were within the range of $5 \pm 0.4$ and increased after day 15. The highest acidification ratio (AR) under pH 10 was $84\%$ for inoculum 3, which was twice as much as the ratio using the same inoculum under pH5. AR was $73\%$ and $69\%$ for inoculum 1 and inoculum 2, respectively. pH dropped sharply in day one of alkaline experiments due to VFA accumulation A decremental trend in acidification yields was observed for alkaline experiments after day 10 as pH increased towards neutral values indicating the initiation of methanogenesis stage. Higher VFA yields under alkaline conditions, can be attributed to the dominance of the bacterial families *Lachnospiraceae*, *Clostridiaceae*, *Ruminococcaceae* and *Tissierellaceae*. Similarly, Dahiya et al. (2015) obtained higher VFA yields under alkaline conditions due to improved hydrolysis of the organic substances.

![Figure 1.1 Acidification ratio of pH 5 and pH 10 experiments](image)

Under both acidic and alkaline experiments, higher acidification ratios were achieved with the inocula which were acclimated to digestion of food waste (inoculum 1 and 3). Detailed composition of the obtained VFAs and the bacterial community alterations will be presented in the conference.

CONCLUSIONS Our results revealed that pH plays a more significant role in VFA production in comparison to inoculum in batch fermentation experiments. The presence of digested food waste in the inoculum positively influenced the VFA generation under alkaline conditions, however it did not have any substantial effect in acidic experiments. In long-term operation, the pH in the reactor is shifting towards neutral, therefore a pH-controlled system is required for continuous operations.

REFERENCES
Ion-exchange Resins for Metals Recovery (Cu and Zn) from Acidic Mine Waters

X. Vecino*, M. Reig*, J. López*, C. Valderrama*, O. Gibert*, J.L. Cortina*,,**

*Chemical Engineering Department, UPC-Barcelona TECH; Barcelona Research Center for Multiscale Science and Engineering, C/Eduard Maristany 10-14, Campus diagonal-Besòs, 08930 Barcelona, Spain, xanel.vecino@upc.edu

**Cetaqua, Carretera d’Esplugues, 75, 08940 Cornellà de Llobregat, Spain

Abstract: Environmental and economic concerns over the last decades have introduced new research opportunities for the application of several techniques in order to improve the removal of contaminants, as well as to explore methods to recover added-value elements. One example could be the recovery of metals ions from mining activity wastewaters in an approach to circular economy scheme. Therefore, in this work the separation and recovery of Zn and Cu, from acidic mine waters, as valuable metals is proposed. For that, an ion-exchange process with resins using a fixed bed configuration is used at lab-scale. A solvent impregnated (e.g. Lewatit VP OC 1026) and a chelating (e.g. Lewatit TP 207) resins were used for the recovery of Zn and Cu, respectively. Results showed that it was possible to separate and concentrate both metals (Zn around 10 times and Cu about 40 times). For that, ion-exchange resins provide a circular economy approach for metallurgical processing plants.

Keywords: ion-exchange; acidic mine waters; metal recovery.

INTRODUCTION Mining industry is the major producer of sulfuric acid-rich effluents, which often contain high concentrations of heavy metals (e.g. Cd, Cr, Hg, Ni, Pb, Cu, Zn, among others), and non-metals (e.g. As, Se) (). The most widespread method used to mitigate acidic effluents is an active treatment involving a chemical-neutralizing agent to increase the pH of water, causing the precipitation as hydroxides and carbonates of many of the metals present in the solution. After this, metal-rich sludge is obtained. Although chemical treatments can provide effective remediation of acidic mine drainage, they have some disadvantages, such as high operating costs and sludge disposal problems (López et al. 2019). Therefore, as prices for several valuable metals (e.g. Zn and Cu) are increasing over the last years, the main objective of this work is to separate and recover Cu and Zn-rich streams, from mining effluents, by means of ion-exchange resins using a fixed bed configuration.

MATERIALS AND METHODS Previous to the ion-exchange stage, a pre-treatment step was planned to remove solids and precipitates in order to prevent column clogging. In this pre-treatment, Fe and Al were removed with H2O2 (35%) and 2M NaOH increasing the pH up to 4.8. Resins used in this work consisted of Lewatit VP OC 1026 (solvent impregnated resin) and Lewatit TP 207 (chelating resin) for Zn and Cu recovery, respectively. Before use, Lewatit TP 207 was converted into Na+ form by washing the resin sequentially with 1 M NaOH solution and distilled water (until
pH = 7), while Lewatit VP OC 1026 was not converted since it is a polymeric matrix impregnated with a solvent extractant.

The separation of Zn and Cu was carried out in two consecutive steps. First separation stage was focused on Zn adsorption from an acidic mine water. For that, 30 g of Lewatit VP OC 1026 resin were packed in a column and feed solution was circulated through it at 2.0 mL/min and pH=2.7. Once the Zn was removed from the initial acidic mine water, the feed pH was adjusted at 3.5 before being treated by the second column set-up, using Lewatit 207 resin (4 g), and fed at 1.4 mL/min. For desorption steps, 100 g/L of H₂SO₄ solution was used at 1.0 and 0.7 mL/min for Zn and Cu recovery, respectively.

Metal concentration was determined by Inductively Coupled Plasma (ICP) atomic emission spectroscopy (OES) and mass spectrometry (MS); conductivity and pH were also measured during the process.

RESULTS AND DISCUSSION After the pre-treatment stage, the acidic mine water was composed by: 771 mg Zn/L, 272 mg Cu/L, 22 mg Al/L, 2 mg Cd/L, 195 mg Mn/L, 1976 mg Mg/L, 1115 mg Na/L and 496 mg Ca/L. In this step, 100% Fe and 90% Al removal were achieved successfully, whereas target metal loss (Zn and Cu) was below the 10% of the inlet concentration. On the other hand, it was possible to recover Zn (23.3 ± 2.2 mg Zn/g resin) and also to concentrate it around 10 times by the elution process using Lewatit VP OC 1026 resin; while the Cu recovery was around 37.8 ± 2.1 mg Cu/g resin and it was concentrated around 40 times using Lewatit 207 resin.

Overall, the application of ion-exchange process with resins shows a great potential in the separation and recovery of valuable metals from acidic mine waters (Zn and Cu) to promote the circular economy scheme in the hydrometallurgical industries.

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REFERENCES

Recent Developments in Ammonia Recovery using Electrochemical Systems


* Wetsus, European centre of excellence for sustainable water technology, P.O. Box 1113, 8900CC Leeuwarden, The Netherlands, philipp.kuntke@wetsus.nl, mariana.rodrigues@wetsus.nl, tom.sleutels@wetsus.nl, bert.hamelers@wetsus.nl, cees.buisman@wetsus.nl
** Department of Environmental Technology, Wageningen University, P.O. Box 17, 6700 AA Wageningen, The Netherlands Annemiek.terHeijne@wur.nl

Abstract: In this work we present recent developments in ammonia recovery using electrochemical systems. We operated hydrogen gas recycling electrochemical systems (HRES) designed to recover ammonia from source separated urine and evaluated their performance in terms of recovery efficiency and energy use. The HRES were optimised using the load ratio concept (applied current / ammonia loading) to reach high recoveries at low electric energy input. The systems were able to operate current densities up to 100 A m⁻², reaching ammonia removal rate of 600 g N m⁻² d⁻¹ at an electric energy input of 6.5 kWh/kgN. Furthermore, comparison of these performance indicators to reported values from bio electrochemical systems (BES) and other electrochemical systems (ES) shows that the HRES can outcompete both BES and ES.

Keywords: Ammonia recovery; electrochemical systems; wastewater; urine; energy demand; resource recovery

The nitrogen cycle is largely affected by human interference such as ammonia fertilizer production and ammonia removal processes on industrial scale. Both ammonia production and removal require large amounts of energy. Therefore, electrochemical systems (ES) for ammonia recovery have been investigated by various research group as these systems promise both energy and chemical efficient ammonia recovery. (Kuntke et al., 2018a)

In this work, we used hydrogen gas recycling electrochemical systems (HRES) to investigate the recovery of ammonia from urine. In the HRES, hydrogen gas (H₂) produced at the cathode was oxidized at the anode. The current obtained from these reactions can be used to recover ammonia from wastewater. Furthermore, these reactions allow for high current densities at low applied cell voltages, which promises high ammonia removal rates at a low energy demand. (Kuntke et al., 2017) The HRES employs ion exchange membrane to separate ammonia from the wastewater and gas permeable hydrophobic membranes to recover ammonia in an acid solution. Two types of HRES were used for these experiments; a type 1 HRES employing one cation exchange membrane for ammonia separation and an up scaled type 2 HRES employing anion and cation exchange membranes for ammonia separation. The performance of these HRES for ammonia recovery was evaluated using the load ratio concept, which matches current density to the ammonium load. (Rodriguez Arredondo et al., 2017)
The performance of the type 1 HRES was evaluated at a fixed current density of 20 A/m², while changing the Load Ratio stepwise from 1.3 to 3.5. The results (Figure 1) showed that a higher load ration results in a higher recovery and at the same time increases the energy demand. In agreement with earlier experiments, a Load Ratio of 1.3 was found to be a reasonable compromise between a high recovery and energy demand. (Rodríguez Arredondo et al., 2017)

The performance of the type 2 HRES was evaluated at a fixed load ratio of 1.3 and at current densities of 20, 50 and 100 A/m². The ammonia removal rate increased linear with the increase of current density peaking at 100 A/m², 598±24 gN/m²/d. The ammonium recovery, however, decreased from around 74±2 % at 20 A/m² to 58±2 % at 100 A/m². (Kuntke et al., 2018b) The energy demand for ammonia recovery of HRES type 2 was found to be lower than HRES type 1.

As shown in Figure 1.1, competing current driven ammonia recovery systems (i.e. BES and ES) were found to be either more energy demanding (ES) or limited to lower ammonia recoveries (BES). Additionally, ammonia recovery in BES is often limited by maximum obtainable current density and long term stability. (Kuntke et al., 2018a)

![Figure 1.1 Energy demand (a) and ammonia recovery (b) of different types of electrochemical system at various applied load ratios. In general HRES allow for a higher recovery than BES and a lower energy demand than ES. Data sources for BES and ES: (Kuntke et al., 2018a)](image)

The results obtained with the HRES show that energy efficient ammonium recovery is possible at high current densities over longer periods. Future developments of this promising technology will focus on further upscaling, demonstration and operation under realistic conditions with different types of wastewater.

REFERENCES


Anaerobic Sludge Digestion in Circular Economy: Single-Stage versus Two-Stage Temperature-Phased Systems

I. Lanko***, I. Ferrer*, P. Jenicek**

* GEMMA – Group of Environmental Engineering and Microbiology, Department of Civil and Environmental Engineering, Polytechnic University of Catalonia, BarcelonaTech, c/ Jordi Girona 1-3 (Email: ivet.ferrer@upc.edu)
** Department of Water Technology and Environmental Engineering, University of Chemistry and Technology, Technicka, 5, 166 28, Prague, Czechia (Emails: lankoi@vscht.cz,)

Abstract: Considering WWTP with implemented anaerobic digestion (AD) as an energy production plant is not something extraordinary, whilst looking at its full recovery potential as a part of circular economy is something new and of a pretty nice appearance. The extent of resource, energy and product possible recovery depends on the technologies applied at each step of wastewater treatment. When talking about wastewater sludge management, we refer to the key spot and crucial point of circular economy at WWTP. In the work, a digestate (digested and dewatered sludge) was considered as a concentrated source of valuable resources, energy and products. The digestate was obtained at different temperature conditions of AD. Temperature-phased anaerobic digestion (TPAD) – a two-stage system that combines mesophilic and thermophilic ranges – is considered as a beneficiary from both single regimes not only in process stability and AD efficiency, but also being a part of circular economy.

Keywords: Circular economy; resource recovery; temperature-phased anaerobic digestion (TPAD)

INTRODUCTION There are a lot of studies being conducted for the latest decades on TPAD efficiency over single mesophilic and thermophilic reactors (Riau, 2010; Lv, 2016). There are also some that look at WWTP as an aggregation of a huge resource variety that can be recovered and reused (Fagerstroem, 2018). To our best knowledge, the performance of two-stage system shows its superiority over mesophilic and thermophilic single systems in most of AD efficiency parameters. Thus, it was decided to check if it corresponds to resource recovery potential and collects all benefits over a single-stage system. The study answered the questions regarding TPAD digestate as a crucial point of circular economy: if the digestate can be used as a fertilizer, if energy recovery is high enough, which nutrients and products can be recovered from the reject water.

MATERIALS AND METHODS Two single-stage (mesophilic and thermophilic) reactors and one two-stage lab-scale TPAD system (Figure 1.1) were constructed to evaluate AD efficiency of in terms of organic degradation, methane production and digestate quality.
The experiment was conducted at the following working parameters (Table 1.1).

<table>
<thead>
<tr>
<th>Type of reactor</th>
<th>Abbreviation</th>
<th>Hydraulic retention time (HRT), days</th>
<th>Mixing speed, rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single, mesophilic (37°C)</td>
<td>M</td>
<td>15</td>
<td>110±1</td>
</tr>
<tr>
<td>Single, thermophilic (55°C)</td>
<td>T</td>
<td>15</td>
<td>110±1</td>
</tr>
<tr>
<td>Two-stage, thermophilic, (55°C, the first stage)</td>
<td>TPAD1</td>
<td>3.1</td>
<td>95±1</td>
</tr>
<tr>
<td>Two-stage, mesophilic (37°C, the second stage)</td>
<td>TPAD2</td>
<td>10.6</td>
<td>110±1</td>
</tr>
</tbody>
</table>

For digestate quality assessment were performed such analyses as separation via centrifugation and mechanical pressing; also microbiological tests were run to estimate the extent of pathogen deactivation.

RESULTS AND CONCLUSIONS The performance of two-stage TPAD system performs advantageous over single-stage systems (both – mesophilic and thermophilic):

A) as regard to energy recovery (specific methane production, \( \text{CH}_4/\text{gVS}*\text{d} \)), up to 32% and 41% higher than in mesophilic and thermophilic ranges, respectively;

B) from the hygienic point of view, TPAD system shows the better results over mesophilic regime and can compete with the thermophilic one: at HRT of 15 days, it does not contain any \textit{Escherichia coli}, only 25CFU/g of coliforms and 250CFU/g of \textit{Clostridium perfringens};

C) in terms of nutrient recovery, after TPAD, the reject water has on 13% higher content of total Phosphorus in both single regimes; as regard to Nitrogen, after TPAD, total Nitrogen content in the reject water is around 3% higher than in mesophilic conditions and up to 11% – than in thermophilic;

D) regarding the bioplastic production, the ratio of total FVA to daily COD dose in TPAD is almost 1/3 higher than in the thermophilic reactor (36.9% and 26.4%, respectively), the total amount of acetic and propionic acids in TPAD is higher, at least, on 22.2%.

REFERENCES


Steering Microbiomes Towards New Biochemical Production: Iso-Caproate

K.D. de Leeuw*, C.J.N. Buisman, D.P.B.T.B. Strik**
Environmental Technology, Wageningen University & Research, Bornse Weilanden 9 6708WG Wageningen
* kasper.deleeuw@wur.nl
** david.strik@wur.nl

Abstract: We have developed a microbiome capable to produce branched MCFAs, i.e. iso-caproate via chain elongation fermentation. Various experimental phases were tested to allow the development of a bioprocess in which iso-caproate was continuously produced with a selectivity of 20% based on carbon atoms at a rate of 0.86 g L^{-1} day^{-1} and a concentration of 1.4 g L^{-1}. This is the first time shown that iso-butyrate was elongated to iso-caproate using ethanol as electron donor. Within the developed microbiome straight chain elongation for the production of n-caproate was still dominant (55% selectivity).

Keywords: chain elongation; iso-caproate; open culture

INTRODUCTION Anaerobic treatment provides the means to efficiently produce renewable chemicals from organic residues. By applying various selective pressures during mixed culture fermentation processes new valuable biochemicals can be produced. Chain elongation fermentation is suitable to recycle organic waste into medium chain fatty acids (MCFAs). Previous studies on chain elongation have primarily focused on production of straight chained MCFAs (Angenent et al., 2016). The possibility to produce branched-MCFAs, however, would further expand the application spectrum of chain elongation technologies, because branched MCFAs have different physical properties compared to the straight forms. We have developed a microbiome capable to produce significant amounts of branched MCFAs, i.e. iso-caproate via chain elongation fermentation (de Leeuw et al., 2019). The necessary feed stocks for this process are iso-butyrate (Chen et al., 2017) and ethanol, which can both be produced via fermentation.

MATERIAL AND METHODS The experiment was performed in a lab-scale continuous up flow anaerobic reactor. In different phases the effect of various substrates was tested, among others n-butyrate, iso-butyrate, methanol and ethanol. The system was then characterized by analysis of the steady state mass balances for the total amount of carbon and electrons in the liquid and gas phase. During the steady state of important phases 16s RNA sequencing was performed to analyse the microbial compositions.
RESULTS AND CONCLUSIONS

Elongation of iso-butyrate with ethanol to iso-caproate

A graphical summary of the research is depicted in figure 2. In our developed system iso-caproate was continuously being produced with a selectivity of 20% based on carbon atoms at a rate of 0.86 g L\(^{-1}\) day\(^{-1}\) and a concentration of 1.4 g L\(^{-1}\). Within the developed microbiome straight chain elongation for the production of n-caproate was still dominant (55% selectivity).

![Figure 2](image)

**Figure 1.1** The figure shows an overview of the net volumetric conversion rates, averaged over the steady state periods with corresponding confidence intervals. The phases are indicated by a roman numeral and a designation at the top. Consumption of compounds is indicated as negative volumetric conversion, while formation is indicated with a positive number. Figure taken from submitted paper (de Leeuw et al., 2019).

A microbiome in constant competition

Based on the 16sRNA microbial community analysis and putative fluxes of substrates and products the selection pressure and observed microbial composition dynamics could be explained. Competing microorganisms that directly oxidize ethanol stimulate chain elongation towards straight MCFAs by supplying additional acetate. This excessive ethanol oxidation to acetate is maintained by various possible syntrophic interactions that cause the formation of side products such as methane, iso-butanol and n-hexanol.

CONCLUSIONS

Iso-caproate is a biochemical produced for the first by an anaerobic chain elongation bioprocess. Up to 20% of the feedstock was directed to this branched-MCFA. The challenge now lies within (i) optimizing the microbiome in such a way that the various possible competing processes are annihilated and; (ii) improving reactor design and operation such that higher conversion rates and titers can be achieved so that industrial application becomes viable.

REFERENCES


Characterizing the Organic Matter in LB-EPS and TB-EPS of Aerobic Granular Sludge Using Parallel Factor (PARAFAC) Analysis

D. Li*, S. Zhang*

* Key Laboratory of Water Science and Water Environment Recovery Engineering, Beijing University of Technology, lidong2016@126.com

Abstract: Recent decade, aerobic granules technology has been widely used in wastewater treatment and recovery. In this study, the LB-EPS and TB-EPS of aerobic granules from five same lab-scale aerobic granules reactors were extracted. Fluorescence excitation-emission matrix (EEM) spectroscopy coupled with parallel factor analysis (PARAFAC) were applied to characterize the dissolved organic matter (DOM) in the extracting solution of LB-EPS and TB-EPS as well as the DOM in the influent (domestic wastewater) and effluent of the lab-scale reactors. PARAFAC models were developed and the components in above samples were identified. The humification index (HIX) and the fluorescence index (FI) were calculated to measure the degree of humification and microbial contribution to the humic material. Results suggested that TB-EPS contained 4 components while a 1-component model was developed for LB-EPS. Meanwhile the LB-EPS and TB-EPS basically share the same degree of humification but there are more microbially produced DOM in LB-EPS than in TB-EPS.

Keywords: PARAFAC-EEM; aerobic granular sludge; extracellular polymeric substances

Recent years, parallel factor (PARAFAC) analysis coupled with fluorescence excitation-emission matrix (EEM) spectroscopy has been becoming a popular tool to identify and characterize components from the EEM datasets. For example, Jia et al. (2017) stratified the extracellular polymeric substances (EPS) of the anammox sludge developed PARAFAC models, by which the components in the EPS were identified. Yet the EEM-PARAFAC analysis has not been applied to characterize the stratified EPS in aerobic granules systems while the aerobic granules technology has been widely used in the world. So the aim of this study was to develop PARAFAC models to identify different components in loosely-bound EPS (LB-EPS) and tightly-bound EPS (TB-EPS), the PARAFAC models of the influent and the effluent of the aerobic granules reactors were also studied to better understand the constitution of the EPS.

The LB-EPS and TB-EPS were extracted by a heat method according to Jia et al. (2017). Fluorescence measurements were taken in a 1 cm cell using a Lengguang Technology F97 Pro spectrofluorimeter. EEMs were collected at excitation wavelengths 200-900 nm every 10 nm and emission wavelengths 200-900 nm every 1 nm with a 10 nm slit width. In this study, MATLAB software with the DOMFluor toolbox (Stedmon & Bro, 2008) was applied to develop PARAFAC model following the protocols. The number of the components in each sample was determined based on the residuals of each model. The humification index (HIX) (Gabor et al., 2015) was calculated to measure the degree of humification as HIX=(∑IEm435→480)/(∑IEm435→480)
IEm300→345) at Ex 250 nm. And the fluorescence index (FI) was calculated as FI=IEm470/IEm520 at Ex 370 nm to measure the degree of microbial contribution to the humic material.

**Figure 1.1** EEM fluorescence spectra of LB-EPS (figure 2a) and TB-EPS (figure 2b). Identified components plots of the TB-EPS (figure 2c, d, e, f).

PARAFAC modelling successfully decomposed the influent and the effluent datasets into two (INF-C1, INF-C2) and four (EFF-C1, EFF-C2, EFF-C3, EFF-C4) individual DOM components which were identified as Baker and Curry (2004) reported, respectively. INF-C1 and INF-C2 were both humic acid-like substances; EFF-C1 was substances related to hydrophobic acids; EFF-C2, EFF-C3, EFF-C4 were humic acid-like substances. Besides, the HIX value of the effluent (1.459) was greater than the effluent (0.835), which indicated that effluent had higher humification degree and the PARAFAC results were proofed. Meanwhile, four components (TB-C1, TB-C2, TB-C3, TB-C4) were decomposed from the TB-EPS datasets while only one component (LB-C1) was decomposed from the LB-EPS dataset as shown in figure 1. LB-C1 was soluble microbial by-product-like substances; TB-C1 and TB-C3 were tryptophan or protein-like substances; TB-C2 was marine humic acids substances; TB-C3 was substances related to hydrophobic acids. The results demonstrated that the fluorescent components in the LB-EPS were mainly protein-like matters. The FI value of LB-EPS was 2.558 while of TB-EPS was 1.310 which indicated that more substances in LB-EPS were derived by microorganism than in the TB-EPS. Nevertheless, the location of EFF-C1 was similar with TB-C4, which suggested that some substances of TB-EPS may come from the effluent. This will deepen our understanding of the relationship between aerobic granules and wastewater.

**REFERENCES**


Production of Se-enriched Duckweed On (Waste)Water as an Alternative Protein Source for Animal Feed or Micronutrient Fertilizer

J. Li*, L. Otero-Gonzalez**, P. N. L. Lens***, G. Du Laing****

* Laboratory of Analytical Chemistry and Applied Ecochemistry, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium, Jun.Li@UGent.be
** Laboratory of Analytical Chemistry and Applied Ecochemistry, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium, Lila.OteroGonzalez@UGent.be
*** UNESCO- IHE Institute for Water Education, 2601 DA Delft, The Netherlands, piet.lens@wur.nl
**** Laboratory of Analytical Chemistry and Applied Ecochemistry, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, 9000 Ghent, Belgium, Gijs.DuLaing@UGent.be

Abstract: Selenium (Se) is an essential micronutrient for humans and animals, but it is also frequently present in toxic concentrations in wastewater. (Waste)waters loaded with Se may be considered as potential sources of Se to be recovered and reused. In this study, we investigated the use of the aquatic plant duckweed as remediation agent to remove Se by phytoextraction, and evaluated the potential of the Se-enriched duckweed as an alternative protein source or Se fertilizer. The protein content and Se speciation analysis of the Se-enriched duckweed together with agronomic fertilization trials results demonstrated that the production of Se-enriched feed supplements or fertilizers from Se-containing (waste)waters may be feasible, which contributes to the worldwide drive for resource recovery and circular economy. However, it should still be explored how to avoid that hazardous elements that also may be contained in Se-rich wastewaters end up in the Se-enriched dietary proteins and fertilizers.

Keywords: Selenium recovery; protein source; micronutrient fertilizer

Human activities put increasing pressure on water resources, resulting in high loadings of metals and metalloids in the water bodies (Jan et al., 2015). Biobased methods have been developed to recover these elements for further reuse. Selenium is an essential trace element involved in the biosynthesis of essential proteins (Hatfield et al., 2014). However, the excessive Se found in some agricultural runoffs or industrial wastewaters may also be hazardous to organisms (Schiavon et al., 2017). The Se in wastewater may be recovered and valorized to improve the Se level in food products produced in Se sufficient areas. In this study, duckweed (Lemna minuta) was incubated in medium with 0-5 mg/L of Se (dosed as Na2SO3) to assess the ability of duckweed for Se removal from (waste)water. The Se speciation and protein content of Se-enriched duckweed was analyzed to evaluate its potential as an alternative Se-enriched feed supplement. Additionally, a biofortification experiment was performed to explore the potential use of Se-enriched duckweed as an organic crop fertilizer. Green beans were grown in soil supplemented with different doses of Se-enriched duckweed and the Se content was measured in the bean tissues.

The results showed that duckweed accumulates a high concentration of Se up to 1153 mg/kg, which accounted for a 7%-22% Se removal in the medium containing 0.5-5 mg/L Se. The maximum Se bioconcentration factor (BCF) of duckweed reached 343. The protein content in freeze-dried Se-enriched duckweed was approximately
200 mg/g. Part of the Se absorbed by duckweed was transformed to organic Se forms such as Se-cystine, Se-methylselenocysteine and Se-methionine (Fig. 1.1), which have proven to have beneficial nutritional value for humans/animals. Additionally, the soil supplementation with Se-enriched duckweed significantly improved the Se content in different tissues (roots, stems, leaves, seeds) of green beans (Fig. 1.2). For instance, duckweed application at rates equivalent to 1 and 5 mg Se/kg soil increased the Se content in the seeds up to 4 and 17 times compared to the non-supplemented control, respectively. These results suggest that duckweed with a substantial content of proteins offers the possibility of removing Se from (waste)water while producing micronutrient-enriched dietary proteins and fertilizers. However, it should still be further explored how to avoid that hazardous elements that also may be contained in Se-rich wastewaters end up in the Se-enriched dietary proteins and fertilizers. This may be obtained through e.g. selective adsorption of cationic elements prior to the use of duckweed for Se removal, or extraction (and purification) of the Se-enriched proteins from the Se-enriched duckweed prior to consumption.

![Figure 1.1](chromatogram.png)

Figure 1.1 Chromatogram of Se speciation in Se-enriched duckweed compared with that of a Se standard solution of 100 ppb each species (1) Se-cystine, (2) Se-methylselenocysteine, (3) selenite, (4) Se-methionine, (5) γ-glutamyl-methylselenocysteine, (6) selenate, and (7) γ-glutamyl-Semethionine.

![Figure 1.2](se_content.png)

Figure 1.2 Se content in different tissues of green beans grown in soil supplemented with Se-enriched duckweed

REFERENCES


Evaluation of a Nanofiltration Membrane on Metal Valorisation from Acidic Mine Waters

J. López*, M. Reig*, X. Vecino*, O. Gibert*, C. Valderrama*, J. L. Cortina*,**,

* Chemical Engineering Department and Barcelona Research Center for Multiscale Science and Engineering, UPC-Barcelona-TECH, C/ Eduard Maristany 10-14, E-08930 Barcelona, Spain
** CETaqua, Carretera d’Esplugues 75, E-08940 Cornellà de Llobregat, Spain

Abstract: The depletion of mining sites makes necessary to find another way to recover valuable metals such as Rare Earth Elements (REEs). For that, Acidic Mine Waters (AMWs) can be a resource since present relatively high concentrations of REEs, which are indispensable for the high-tech industry. On the other hand, nanofiltration (NF) membranes offer a good opportunity for acid recovery and to concentrate metals in solutions. The performance of a NF membrane (NF270) was evaluated to treat a synthetic solution simulating an AMW from the Iberian Pyrite Belt (SW Spain). Additionally, a mathematical model was developed to predict the performance of the NF270 membrane.

Keywords: Rare earth elements; nanofiltration; sulphuric acid

INTRODUCTION The European Union has identified a list of critical materials containing i) those of high importance to their economy and ii) those of high risk associated with their supply, including Rare Earth Elements (REEs) (European Commission Report, 2018). REEs can be presented in acidic mine waters (AMWs) at relatively high concentrations (two orders of magnitude higher than in natural waters) (Noack et al., 2014). Nowadays, efforts to recover valuable elements are being towards the application of membrane technologies. Nanofiltration (NF) membranes can exhibit a high permeation of mono-charged ions (e.g. H\(^+\)) and high rejection of multi-charged ions (e.g. metals) (Mullet et al., 2014). Then, it could be possible to concentrate the metals in the feed side, while a purified sulphuric acid stream could be obtained as permeate. Mathematical models such as the Solution-Electro-Diffusion (SED) can describe the transport of species across NF membranes by means of membrane permeances, but there is still a lack of models to scale up NF applications.

MATERIALS AND METHODS A NF membrane (NF270 from Dow Chemical), whose active layer is made of poly(piperazineamide), was tested in a flat-sheet cross-flow equipment (0.014 m\(^2\)). Firstly, experiments were performed over a range of pH (1.0 to 2.5) in order to reproduce different acidities typical of AMWs. These synthetic solutions simulated a typical AMW from the Iberian Pyrite Belt (SW Spain). Experimental data was adjusted to the SED model to determine membrane permeances to species (Eq. 1):

\[
\dot{j}_t = -P_t \cdot \left( \frac{d\gamma_t}{dx} + c_t \cdot \frac{d(ln \gamma_t)}{dx} + z_t \cdot c_t \cdot \frac{d\varphi}{dx} \right)
\]  

where \( \dot{j}_t \), \( P_t \), \( c_t \), \( \gamma_t \) and \( z_t \) are the flux across the membrane, the membrane permeance, the concentration, the activity coefficient and the valence charge of
component i, respectively. x and \( \phi \) are the dimensionless position and electrostatic potential in the membrane, respectively. The permeances obtained with the SED model were used to simulate the performance of a pilot plant, by predicting the concentration profiles over time and after that, the experiment was performed to validate the results from the model. Figure 1.1 shows the scheme of the whole process.

\[ R = R_0 + R_1 \cdot X^n \]

**RESULTS** Results showed that rejection of sulphate decreased from 80% at pH 2.5 to 45% rejection at pH 1.0. This decrease was driven by: a) changes in speciation with pH, which resulted in the predominance of HSO\(_4^-\) at lower pH (<1.98) and of SO\(_4^{2-}\) at higher pH (>1.98); and by b) changes in the membrane acid-base properties, as free carboxylic and amine groups of the piperazine structure were protonated at lower pH, respectively. Metal rejection values increased from values around 75% at pH 2.5 up to values higher than 99% for pH 1.0 due to a positively charged membrane. Obtained membrane permeances were dependent on the acidity, which modified the acid-base properties of the membrane, and then affected by the transport of ions across the membranes. With the obtained permeances, the treatment of the AMW was simulated mathematically and then, the experiment was carried out to validate the model. Mathematical model was able to predict properly the treatment, within the %permeate recovery range studied (till 30%), and NF270 was able to remove metals, obtaining a permeate rich in sulphuric acid (6 g/L) with low presence of metals (< 5 mg/L).

**CONCLUSIONS** NF has proven to be effective for sulphuric acid recovery, and at the same time, to concentrate metals in solution. Moreover, SED model was able to predict properly the performance of the NF270 membrane by means of membrane permeances.

**REFERENCES**


Cultivation of Anoxygenic Purple Bacteria for Polyhydroxyalkanoate Production on Industrial Wastewater

S. Sali*, U. Onwusogh **, S. Parilakathoottu**, H. R. Mackey*

* Division of Sustainable Development, College of Science and Engineering, Hamad Bin Khalifa University, Qatar Foundation, Doha, Qatar, ssali@mail.hbku.edu.qa, hmackey@hbku.edu.qa
** Qatar Shell Research and Technology Centre, Doha, Qatar, udeogu.onwusogh@shell.com, p.sunifar@shell.com

Keywords: Anoxygenic phototroph; polyhydroxyalkanoates; nutrient limitation

Water is a key enabler in the oil and gas industry and plays a vital role in refining crude petroleum and in the processing of natural gas. Most refineries, chemical plants and gas processing facilities have onsite effluent treatment plants that enable treatment, recovery and reuse of the process water within the plant. Where the Fischer Tropsch process is deployed in converting syngas (a mixture of carbon monoxide and hydrogen) into liquid hydrocarbons, water is generated as a by-product. The water is typically treated in the ETP to remove dissolved components, mainly organic acids and alcohols. These components make the water suitable as a potential feedstock for carbon-recovery based biotechnology processes. One potential use for organic-rich wastewater is for the production of polyhydroxyalkanoates (PHA), a group of biodegradable and biocompatible polymers (Castilho et al., 2009). Recent research has highlighted the potential of purple photosynthetic bacteria for high molecular weight PHA production from a wide variety of organic compounds (Higuchi-Takeuchi et al., 2016) and their distinct ability for natural selection and PHA accumulation under continuous feeding, continuous lighting mixed culture conditions (Fradinho et al., 2016).

In this study we explore the use of purple bacteria for PHA production from a fuel synthesis wastewater. Our first stage of testing included culturing under continuous white light conditions with an ATCC 2728 media where the organics were replaced with the fuel synthesis wastewater diluted to a chemical oxygen demand (COD) concentration of 330 mg/L, using various seed sources including pond water, seawater, and anaerobic sludge. Volatile fatty acids (VFAs) comprised 7.8% of the COD and alcohols comprised 18.7%. After 10 days at 37.5 °C and 100 rpm shaking
the sample seeded with a mixture of pond and seawater had developed a purple bacteria culture, while pond water alone and anaerobic sludge had developed green phototrophic cultures. At 14 days the purple culture was distributed into 40 mL tubes for further PHA accumulation tests under six different nutrient conditions, comprising of first a growth and second a nutrient limiting stage as summarized in Table 1 (each repeated in triplicate). Nile red staining was used for PHA detection by confocal microscopy at 100x magnification with PHA content expressed as the fluorescent pixel area divided by the total biomass pixel area. Biomass quantity and pigment quantification were reported by UV-vis spectroscopy at 450 nm. Pigment extraction was achieved by a mixture of acetone:methanol (7:2 v/v) at -20 ºC. COD was determined by Hach test kits, volatile fatty acids by ion chromatography, alcohols by gas chromatography and nitrogen and phosphate by a continuous flow analyser. The culturing was conducted under the same conditions of lighting and shaking as previously mentioned. ANOVA and Tukey’s post-hoc test were used to determine statistically significant (p < 0.01) differences.

<table>
<thead>
<tr>
<th>Culturing duration</th>
<th>Stage 1 - Growth</th>
<th>Stage 2 – Nutrient Limitation</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 days</td>
<td></td>
<td>- All nutrients (28.2 mg-N/L, 17.5 mg-P/L)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Nitrogen (28.2 mg-N/L)</td>
<td>- Low phosphate (28.2 mg-N/L, 0.05 mg-P/L)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Phosphate (17.5 mg-P/L)</td>
<td>- No nutrients</td>
<td>3</td>
</tr>
<tr>
<td>Nutrient Composition</td>
<td>Phosphate (17.5 mg-P/L)</td>
<td>- No nutrients</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Nitrogen (28.2 mg-N/L)</td>
<td>- No nutrients</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

PHA content of the biomass at the end of the tests showed no significant differences despite test conditions, ranging from 15.4 to 21.6% by area. The COD removal was observed to be higher under nitrogen limitation, particularly when the growth stage was also phosphate or nitrogen limited, with COD removal reaching 99.0% for conditions 5 and 6. Despite this, these same two conditions (5 and 6) had the lowest recorded PHA content. Biomass concentrations were also not significantly different between samples, although pigment production was accelerated in samples that experienced excess nitrogen followed by nitrogen starvation (condition 4 and 6). In summary, PHA production does not seem to be influenced by nutrient limitation under continuous light conditions and was moderate with fuel synthesis wastewater. However, nitrogen limitation promoted increased pigment production and COD removal in the system.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>PHA content (%/Area)</th>
<th>COD removed (%)</th>
<th>Biomass absorbance at 450 nm (Abs)</th>
<th>Pigmentation absorbance (Abs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18.7 ± 5.5</td>
<td>94.6 ± 0.6</td>
<td>1.46 ± 0.12</td>
<td>0.083 ± 0.025</td>
</tr>
<tr>
<td>2</td>
<td>16.6 ± 6.2</td>
<td>95.9 ± 0.6</td>
<td>1.20 ± 0.24</td>
<td>0.151 ± 0.012</td>
</tr>
<tr>
<td>3</td>
<td>21.6 ± 1.4</td>
<td>94.0 ± 0.2</td>
<td>1.48 ± 0.15</td>
<td>0.120 ± 0.018</td>
</tr>
<tr>
<td>4</td>
<td>18.6 ± 4.6</td>
<td>96.7 ± 0.8</td>
<td>1.26 ± 0.15</td>
<td>0.218 ± 0.020</td>
</tr>
<tr>
<td>5</td>
<td>15.3 ± 5.3</td>
<td>99.0 ± 0.1</td>
<td>1.64 ± 0.11</td>
<td>0.157 ± 0.010</td>
</tr>
<tr>
<td>6</td>
<td>16.7 ± 4.7</td>
<td>99.0 ± 0.2</td>
<td>1.24 ± 0.02</td>
<td>0.236 ± 0.036</td>
</tr>
</tbody>
</table>

REFERENCES
The Role of Valorization of Resources of MSW Materials for Circular Economy Context: Progress, Challenges, and Perspectives: Critical Review

T. Gebregiorgis *,**

* IHE Delft Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands
** Mekelle University, Department of chemistry, Mekelle, Ethiopia
*Corresponding author (teklitgeb@gmail.com), phone Number: +31685811054

Abstract: Currently, due to an increasing in urbanization and industrialization in developing countries, a large volume of municipal solid wastes is produced that because serious environmental problems, landfill and incineration was confirmed as a promising technology for effective management based on the linear principle. However such strategies leads to shortage of areas available for waste disposal and uncontrolled release of greenhouse gases which results in results serious challenges to the society in health, socio-economic and a non-sustainable waste management. Consequently, this leads to the development of a sustainable effective solid waste management through the concept of circular economy to accomplish better efficiency of resource to pass on to future generations has now attracted more attention from the policymakers and scientists. This review discusses recent research developments in the continuous MSW processing for development of waste valorization strategies for the sustainable production of chemicals, materials, and fuels through for development of green production strategies toward the circular economy transition. It also highlights the processing mechanism of the recycling of municipal solid waste and the conversion of waste to energy and high value-added products chemicals and fuels through chemical, biological and thermal. Finally, the recent development of waste valorization strategies for the sustainable production of chemicals, materials, and fuels through for development of green production strategies toward the circular economy transition and its challenges and perspectives in the future are discussed. This review suggests that chemical valorization technology forecast future for production of high value-added products chemicals and fuels from MSW.

Keywords: Conversion of MSW to energy and chemical, environmental problems, ethanol, gasification pyrolysis, waste disposal
A Temperature-assisted Cyclic Process with Tailor-Made Carbon Microtubes for the Removal of Antibiotics from Water


* Aachener Verfahrenstechnik, Chemical Process Engineering, RWTH Aachen University, Forckenbeckerstrasse 51, 52074 Aachen, Germany, Mojtaba.Mohseni@avt.rwth-aachen.de
** Research Group EnVOC, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium, Kristof.Demeestere@UGent.be
*** Research Group EcoChem, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium, Gijs.DuLaing@UGent.be
**** DWI - Leibniz Institute for Interactive Materials, Forckenbeckerstrasse 50, 52074 Aachen, Germany

Abstract: In this presentation, we introduce a new microtubular porous carbon as an efficient adsorbent for the removal of the frequently detected antibiotic sulfamethoxazole (SMX) from water. In this adsorbent, the carbon nanotube (CNT), besides providing mesopores, fundamentally acts as a binder while powdered activated carbon (PAC) embedded in the CNT network supplies micropores which are known as high-energy centers for adsorption. In this regard, carbon microtubes (CMTs) with different PAC content were fabricated, characterized and tested in adsorption processes. In addition, the versatility of the fabrication method in tailoring the porosity and designing the inner structure has been demonstrated. Moreover, the best fabricated CMT with respect to both adsorption kinetics and capacity could be regenerated through Fenton chemistry and reused up to 12 times in a so-called cyclic process. A moderate increase of temperature (T=50°C) shows to enhance the regeneration capacity of the adsorbent up to 50% compared to ambient conditions.

Keywords: Antibiotics removal; cyclic process; tailor-made carbon

The occurrence of antibiotics in water bodies is of great concerns due to their negative impact on the environment, especially developing antibiotic resistant genes and bacteria (Bouki et al., 2013). Since these kinds of pharmaceuticals are chemically designed to suppress or hinder the growth of infection made by bacterial community, one cannot consider biological treatment as an effective removal method. Thus, physiochemical treatment methods have been regaining considerable attention regarding antibiotics removal.

Among different approaches, adsorption on powdered activated carbon (PAC) is a safe option as it does not encounter any secondary pollution like oxidation by-products which forms during oxidation process. Utilizing PAC as adsorbent, however, requires an additional separation step as well as extra efforts for carbon sludge handling and disposal. This means that fresh PAC must be continuously supplied to the system which is not only unsustainable but also energy-intensive. In addition, the degradation of antibiotics through Fenton chemistry is a viable alternative due to formation of extremely strong oxidant called OH radical. Yet, the acidic pH of Fenton
(pH=3) does not allow its direct application in wastewater treatment due to high demand of chemicals. Therefore, to avoid the pH adjustment of wastewater, Fenton process can be indirectly employed in a so-called cyclic process to regenerate the spent adsorbent (Figure 1.1).

![Cyclic Process Schematic](image)

**Figure 1.1:** This is the schematic of cyclic process used in this study.

The essential prerequisite for the cyclic process is to have an adsorbent that is easily removable from water phase. In this regard, carbon nanotube (CNT) has been chosen given their intrinsic features in fabrication of freestanding geometries like buckypapers (Li et al., 2012) and microtubes (Gendel et al., 2014). Although the functionality of CNT-made microtubes has been illustrated as a gas diffusion electrode through cyclic process to remove Acid Red 14[4], CNT is considered as expensive materials especially in the field of water and wastewater treatment while it contents much less specific surface area in comparison to PAC. Moreover, Acid Red 14 is not an eligible representative for persistent antibiotics.

**REFERENCES**


New Insights in Sulfur Precipitate Formation and Sedimentation


* Environmental Technology, Wageningen University & Research, Bornse Weilanden 9, 6708 WG, Wageningen, The Netherlands.
** Wetsus, European Centre of Excellence for Sustainable Water Technology, P.O: Box 1113, 8900CC Leeuwarden, The Netherlands.
* Corresponding author: renata.vanderweijden@wur.nl

Abstract: Sulfur is an essential nutrient for agriculture. Currently, global sulfur production is completely dependent on the petroleum industry. In a fossil fuel free world, sulfur shortage will thus become inevitable. To prevent future shortcomings, sulfur needs to be recovered from other sources. One promising source of sulfur is biogas, produced by anaerobic digestion of waste water, because it contains hydrogen sulfide (H₂S). In the biodesulfurization (BD) process under halo-alkaline conditions, the H₂S from biogas is oxidized to sulfur by a mixed culture of H₂S oxidizing bacteria. However, in this process it is essential that the sulfur forms precipitates that settle well, so that they can be recovered by gravitational sedimentation. In this study, we found that sulfur solids in five full-scale BD plants displayed different properties in terms of settleability, size and shape. With this analysis, we provide new insights how particle characteristics are related to well-settling sulfur for recovery.

Keywords: Bio-oxidation; sedimentation; sulfur

INTRODUCTION Sulfur is an essential nutrient for agriculture. Most sulfur currently used in agriculture is recovered as a byproduct when oil and gas is extracted. In the transition from fossil fuel to renewable energy, sulfur will thus become a scarce resource. A new promising source for sulfur recovery is biogas produced by anaerobic digestion of waste water, because it contains hydrogen sulfide. In the biodesulfurization (BD) process under halo-alkaline conditions, the hydrogen sulfide originating from the biogas is absorbed to clean the biogas, and is subsequently oxidized to elemental sulfur by a mixed culture of sulfide oxidizing bacteria (Janssen et al., 2009). The resulting sulfur is recovered by gravitational sedimentation. For optimal recovery and liquid-solid separation, it is essential that the sulfur particles have adequate sedimentation rates. Currently, it is unknown how properties of sulfur precipitates produced in the BD process are related to their sedimentation rates.

RESULTS AND DISCUSSION In this study, we found that sulfur particles from five full-scale BD plants displayed very different properties in terms of settleability, size and shape. The Light and Scanning Electron Microscopy photographs in Figure 1.1 show both single sulfur crystals (often bipyramidal) and aggregates. In addition, an analysis of the samples’ particle size distribution and sedimentation rate and behavior was performed, and full-scale operational data were collected on-site.
Analysis showed that the volume fraction of the small (median size=2 µm), non-settling particles can account for up to 10% of the total volume of solids for some BD plants. This is undesirable, because these particles cannot be removed from by gravitational sedimentation. The preferred particles are large aggregates of smaller particles or large crystals. For the 5 BD plants, we found that sulfur precipitates differ in morphology and size distribution. We correlated these properties with the sedimentation rates. This provides a basis to produce recoverable sulfur which can be re-used as a renewable resource.

![Figure 1.1](image-url) Light microscopy (A) and Scanning Electron Microscopy (B) pictures from two (1-2) of the five full-scale BD plants. The single, bipyramidal particles in 2-A&B show poor settleability, whereas the aggregates in 1-A&B settle well.

**ACKNOWLEDGEMENTS** We would like to thank the Wetsus Sulfur theme for their scientific input, the sulfur thesis ring for the fruitful discussion and Lourens van Langeveld for laying the foundation for some of the analyses in this study. This work was financially supported by Paqell B.V.

**REFERENCES**

Metal Recovery by Ion-Exchange Resins from Municipal Incinerated Bottom Ash

M. Reig*, X. Vecino*, J. López*, O. Gibert*, C. Valderrama*, J.L. Cortina*,**

*Chemical Engineering Department, UPC-Barcelona TECH; Barcelona Research Center for Multiscale Science and Engineering, C/Eduard Maristany 10-14, Campus diagonal-Besòs, 08930 Barcelona, Spain, monica.reig@upc.edu
**Cetaqua, Carretera d’Esplugues, 75, 0.8940 Cornellà de Llobregat, Spain

Abstract: Municipal waste incineration plants produce large amounts of bottom ashes, being higher year over year. In order to follow the circular economy scheme proposed by the EU, a recovery step is required to valorise the high added-value elements present in these ashes, such as copper (Cu), zinc (Zn) or even gold (Au). For this reason, the aim of this work is to recover these metal ions by means of ion-exchange resins at different pHs. Thus, different acid and base solutions were used to lixiviate bottom ashes from a municipal waste incineration plant in Barcelona (Spain) and two different ion-exchange resins (Purolite S940 and AuRIX 100) were tested to obtain the maximum Cu, Zn and Au recovery. Results indicate that it was possible to obtain Cu and Zn extraction percentages around 99 % at pH 5, whereas Au was extracted about 62.5 % at pH 9, after 24 h.

Keywords: Cu; Zn; Au.

INTRODUCTION Municipal incinerated bottom ash is the principal residue produced during the incineration of municipal solid wastes (Lynn et al., 2017). The composition of bottom ashes shows a combination of metallic and non-metallic elements with high added value (ISWA, 2015). For this reason, bottom ash could be a secondary source of heavy (e.g. Cu and Zn) and precious (e.g. Au and Ag) metals. Thus, the aim of this work is the valorisation of these high added-value metals in order to close a circular economy scheme.

MATERIALS AND METHODS Bottom ash was pre-treated with acid (1 M HCl and 1M H₂SO₄) and basic solutions (1 M Na₂S₂O₃) in order to obtain leaching solutions. Afterwards, Fe and Al elements were removed from these leaching solutions by precipitation using 35% H₂O₂ until pH=4.8 (adding 2 M NaOH). Then, ion-exchange experiments with Purolite S940 resin for Cu and Zn recovery and AuRIX 100 for Au recovery, were carried out in batch mode using a resin:liquid ratio of 1:10 (w/v). A range of acid pH (from 1 to 5) was tested for Cu and Zn recovery from hydrochloric and sulphuric lixiviates, whereas basic pH values (9, 10 and 11) were evaluated for Au recovery from the thiosulfate lixiviate during 24 h at room temperature.

RESULTS AND DISCUSSION Purolite S940 resin showed its maximum metal extraction (Cu and Zn) at the highest pH tested (pH=5). Results demonstrated that 98.4 % and 99.1 % of Cu extraction was possible using HCl and H₂SO₄-leaching
solution, respectively, whereas the Zn recovery was 99.1 % with HCl-leaching and 99.5 % using H₂SO₄-leaching solution. On the other hand, gold extraction by AuRIX 100 resin diminished when incrementing the leaching pH, obtaining 62.5 % of Au extraction with Na₂S₂O₃-leaching solution at pH=9.

CONCLUSIONS Overall, these promising results could allow (i) bottom ash valorization as a source of metals and (ii) the use of the ion-exchange resins as a suitable technology to recover and concentrate them.

ACKNOWLEDGMENTS This research was supported by the Waste2Product project (ref. CTM2014-57302-R) and by R2MIT project (ref. CTM2017-85346-R) financed by the Spanish Ministry of Economy and Competitiveness (MINECO) and the Catalan Government (ref. 2017-SGR-312), Spain. As well, Xanel Vecino thanks MINECO for her Juan de la Cierva contract (ref. IJCI-2016-27445) and Julio López for his pre-doctoral grant (ref. BES-2015-075051).

REFERENCES

Recovery of EPS from Aerobic Granular Sludge

M. Oosterhuis*, E. vd Knaap**, E. Koornneef***

* Postbox 1132, 3800 BC Amersfoort, the Netherlands, mathijs.oosterhuis@rhdhv.com
** Postbox 1132, 3800 BC Amersfoort, the Netherlands, Eline.van.der.Knaap@rhdhv.com
*** Postbox 1132, 3800 BC Amersfoort, the Netherlands, eddie.koornneef@rhdhv.com

Abstract: A team formed by Dutch Water Authorities, STOWA, Royal HaskoningDHV (RHDHV), ChainCraft and Technical University of Delft (TUD) is working on development of an aerobic granular sludge EPS (extracellular polymeric substances) recovery process. EPS can be extracted from the excess sludge under alkaline conditions at a temperature of circa 80 °C. Laboratory and pilot experiments showed that circa 30% of the volatile solids in excess sludge can be extracted as EPS. Precipitation of the solubilised polymers at a pH of 2.2 results in a gel containing 6-9% TS. The precipitated EPS can be applied in different ways (cement curing compound, biostimulant or additive to biocomposite material).

Keywords: Aerobic granular sludge; EPS, extracellular polymeric substances, recovery

BACKGROUND The Dutch Water Authorities are aiming for sustainable resource recovery-based wastewater systems. Recovery of phosphate is already applied at different wastewater treatment plants and recovery of other resources like cellulose fibres and polyhydroxyalkanoates (PHA) is investigated and tested on pilot scale (Ruiken et al, 2013, STOWA et al, 2017). Since the development of the aerobic granular sludge (AGS) technology [de Kreuk et al, 2005] and the characterisation of EPS in granular sludge as alginate-like exopolymers [Lin et al, 2010], EPS recovery from AGS has gained interest from the Dutch Water Authorities. Despite properties similar to alginites the extracted polymers have a very different chemical characteristic and therefore the exopolymers derived from Nereda® excess sludge have been renamed into Kaumera Nereda gum. Kaumera is a brand name for a product based on EPS from Nereda excess sludge. Kaumera means Chameleon in the Maori language which makes clear that EPS from excess sludge is a product composed of different components like polysaccharides, proteins, etc. Dependent on the restrictions of the proposed market application, the physical properties of the product (colour, viscosity, etc.) can be influenced by the extraction method. The polysaccharides in EPS are non-linear and therefore more similar to Arabic gum than to alginate from seaweed. Therefore, Kaumera Nereda gum is to our opinion a more suitable name for the extracted EPS from AGS. It is important to emphasize that the composition of the extracted EPS is dependent on the extraction procedure. Kaumera can be a sustainable alternative for existing chemicals in different applications. An extra advantage is significant reduction of the wastewater sludge volume which will have a positive effect on sludge disposal costs. Based on this prospective Royal HaskoningDHV, TUD, STOWA and the Water
Authorities initiated a research program for EPS recovery from aerobic granular sludge. The research program was financed by STOWA, two Dutch Water Authorities (Waterschap Rijn en IJssel and Waterschap Vallei en Veluwe) and subsidy programs of European Union (LIFE) and the Dutch ministry of economy (DEI subsidy). Both Water Authorities have planned to demonstrate the EPS extraction from aerobic granular sludge at full scale. The final designs are finished, and the construction has started.

RESULTS Extraction of EPS was studied on lab and pilot scale from both excess and granular sludge of different AGS plants. Lab extractions showed that circa 25% of the volatile solids in thickened granular sludge (3% TS) can be extracted as EPS. EPS extractions were performed according to Felz et al, 2016. The extraction procedure was also tested on pilot scale for extraction of excess sludge from two AGS plants. Similar extraction conditions were used as on lab scale, but the separation of extracted EPS from sludge was done by a continuous sludge decanter (type GEA UCD 305-) After HCl addition till pH 2.2, the precipitated EPS was separated with a disc centrifuge (type GEA OSD 18). A few batches of excess sludge from different Nereda plants were extracted which resulted in slightly higher EPS yields compared to lab scale. A possible explanation for the slightly higher EPS yield (34% of the VS in sludge) could be a different separation efficiency of the sludge decanter at pilot scale, see figure 1.2. Due to a lower retention time in the centrifuges and lower G-force compared to lab centrifuges, more suspended solids (and thus VS) could be present in the supernatant from the decanter and finally in the precipitated EPS. Nevertheless, the characteristics of the extracted EPS at pilot scale are comparable to extracted EPS at lab scale both showing a typical gel-forming reaction with CaCl₂, see figure 1.1. Extraction of EPS leads to two side streams; a sludge pellet (after the decanter which is used to separate extracted EPS from sludge) and an acid reject water stream from the disc centrifuge. Batch digestion tests with sludge pellet and reject water for 22 days showed biogas productions of 233-293 ml/g VS-substrate.

SIGNIFICANCE Extraction of EPS from excess sludge is technical feasible and is a promising technology for recovery of organic compounds from wastewater sludge. The extracted EPS could be applied in different sectors. For instance, as biostimulator in agriculture or as a slow release fertiliser coating. The affinity of EPS to divalent cations, e.g. Ca²⁺ and Mg²⁺, makes it a potentially suitable polymer for replacement of alginate as a coating of cement-based materials (cement curing compound) or in fertiliser where it can replace lignosulfonate. Furthermore, experiments at the TUD showed that the EPS can be a valuable additive to bio composite material since it has strong affinity to cellulose fibres. Other interesting characteristics of EPS from granular sludge are affinity to clay that gives the material flame retarding property. Although all these applications need to be developed, the Dutch Water Authorities have decided to demonstrate the extraction process. Promising market applications for the extracted EPS will be investigated together with commercial partners. Application of the extracted EPS from AGS, combined with digestion of the side streams (sludge pellet and reject water) will significantly reduce the sludge volume, produced at wastewater treatment plants and therefore the sludge disposal costs.

![Figure 1.1](image_url) Ca beads are formed when extracted EPS is dripped into CaCl₂ solution.
Figure 1.2 VS balance for extraction of EPS from aerobic granular sludge at lab scale and pilot scale.

REFERENCES


The dependency of the methanogenic pathway of anaerobic granules on their characteristics

I. Owusu-Agyeman*, Ö. Eyice**, Z. Cetecioglu***, Elzbieta Plaza****

*Department of Chemical Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, isaacoa@kth.se
** School of Biological and Chemical Sciences, Queen Mary University of London, Mile End Road London E1 4NS, United Kingdom, o.eyice@qmul.ac.uk
*** Department of Chemical Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, zeynepcg@kth.se
****Department of Sustainable Development, Environmental Science and Engineering, KTH Royal Institute of Technology, SE-100 44, Stockholm, Sweden, elap@kth.se

Keywords: Anaerobic granules; methanogenesis; municipal wastewater

INTRODUCTION

Application of anaerobic granules for directly treating municipal wastewater is a robust technology which can change wastewater treatment plants (WWTPs) from energy consuming to energy producing systems. Among the anaerobic reactors for wastewater treatment, granule-based technologies such as upflow anaerobic sludge blanket (UASB) reactors, are advantageous over other reactor types due to good efficiency and robustness (Lim and Kim, 2014; Sudmalis et al., 2018). In order to maximize methane production and increase the efficiency of anaerobic reactors treating municipal wastewater, it is important to understand how microbial community of matured granules relates to the structure of the granules and influences methanogenesis. This study was carried out to investigate the relationship between the methane producing pathways and the characteristics of anaerobic granules treating municipal wastewater.

MATERIALS AND METHODS

Two pilot UASB reactors each of a working volume of 2.5 m³, treating the same municipal wastewater under identical operational conditions were run for 239 days at temperature of 20°C and 28°C. The hydraulic retention time was set at 3 h for each of the reactors.

Wastewater and mixed liquor samples were collected by grab sampling from the influent and effluent and sampling port UASB reactors for analysis twice a week. Granular sludge samples were collected from the UASB reactors on 2018-04-19 and 2018-06-11 representing operating temperatures of 20 and 28 oC, respectively, for DNA extraction, specific methanogenic activity (SMA) test and scanning electronic
microscope (SEM) analysis. Sludge samples were taken from sample ports from bottom to top at 1.1, 1.2, 1.3 and 2.1, 2.2, 2.3 of UASB1 and UASB2, respectively.

RESULTS AND DISCUSSION

The granule characterisation showed that these two reactors had different granule size distribution. This was caused by different operational conditions during earlier study periods. The granules of UASB1 were larger (3-4 mm) and had multi-layered internal microstructure whereas those of UASB2 were the smaller (1-2 mm) and had uniform internal structure with no distinct strata. The larger multi-layered granule samples were dominated by acetoclastic methanogens, *Methanosaeta* at archaeal genus pointing to the importance of acetoclastic methanogenesis as the main pathway for methane production (Figure 1.1). The granules from UASB2 were smaller (1-2 mm) without a layered internal structure and the archaeal community was predominated by hydrogenotrophic methanogens, *Candidatus Methanoregula*.

![Figure 1.1](image)

Specific methanogenic tests (SMA) also show that the acetoclastic methanogenic activities of the sludge from UASB1 were higher (250-437 mL CH4 g⁻¹VS d⁻¹) than those of UASB2 (150-260 mL CH4 g⁻¹VS d⁻¹). SMA results reinforce our finding that acetoclastic methanogenesis is pivotal in UASB1 than UASB2.

Increase in temperature from 20°C to 28°C during presented study did not significantly change the microbial community structure but resulted in an increase in biogas production for UASB1 and stable and higher biogas production rate for UASB2 (Table 1.1). The increase in biogas production was attributed to a reduction in the methane solubility in the effluent and stable activity of methanogens. However, there was no significant difference in the performance of the two reactors due to the fact that both reactors were operating below their capacity in terms of organic loading rate to volatile solids ratio.

The study reveals that characteristics of anaerobic granules can influence methane producing pathway of anaerobic processes and may consequently affect methane production. This knowledge will contribute to resource recovery from wastewater.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>COD removal (%)</th>
<th>Biogas (L CH4/d)</th>
<th>COD removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>45 ± 13</td>
<td>619 ± 100</td>
<td>41 ± 11</td>
</tr>
<tr>
<td>28</td>
<td>51 ± 8</td>
<td>826 ± 139</td>
<td>51 ± 5</td>
</tr>
</tbody>
</table>

REFERENCES


Acid-ethanolysis of Sewage Sludge: A Viable Route to Produce Fine Chemicals from an Exhausted Biomass

L. di Bitonto, C. Pastore
CNR-IRSA, Water Research Institute, via De Blasio 5, 70132, Bari, IT
Email Address: luigi.dibitonto@ba.irsa.cnr.it

Abstract: Acid-ethanolysis of urban primary, secondary and mixed sludge, sampled from different WWTPs was investigated with the aim of obtaining a concomitant conversion of lipid into Fatty Acid Ethyl Esters (FAEEs) and of carbohydrates into Ethyl-Levulinates and Furfurals. Sewage sludge were suspended in alcohol and thermally treated (400-450 K) in presence of an appropriate and optimised amounts of H₂SO₄ and AlCl₃. After few hours (4-8 h) conversion of 99% of lipids and almost 60% of carbohydrates were obtained. The mechanism of reaction is fully investigated and the dampering effect of water was also evaluated and understood. At the end, products of reaction were easily recovered into the alcoholic phase, while inert salts residue as solids together with fulvic and humic acids. Eventually, besides the valorisation of the organic fraction of sewage sludge and stabilization of the residue, a final significant containment of solids was also achieved.

Keywords: Biofuels; Ethyl-Levulinate; fatty acid ethyl esters; sewage sludge characterization; sewage sludge valorisation

INTRODUCTION In this work, the experimental evaluation of valorisation of different urban primary, secondary and mixed sludge through a process of acid-ethanolysis was reported. In detail, lipids were efficiently converted into Fatty Acid Ethyl Esters (FAEEs, namely biodiesel) (Pastore et al 2013, Olkiewicz et al 2014), while structural carbohydrates, namely hemicellulose, cellulose and complex sugars in general, were specifically converted into Ethyl-Levulinate (EL) and furfurals (Ethoxy-Methyl Furfural, EMF and Furfural, F).

Figure 1.1 Synoptic scheme of valorisation of sewage sludge through acid-ethanolysis.
RESULTS AND DISCUSSION

**Sludge Characterization** Several urban primary, secondary and mixed sewage sludge have been up-taken from different WWTPs and characterised. For the aim of this work, the most promising sludge were found to be primary sludge, since mainly composed of lipids (20-25%TS), proteins (22-25%TS), hemicellulose (5-6%TS) and cellulose (5-10%TS). Secondary sludge were found to be composed by only 4-6%TS of lipids, 8-10%TS of carbohydrates and 30-35%TS of proteins. As far as composition of mixed sludge were concerned, 15, 12 and 25% of TS were lipids, carbohydrates and proteins respectively.

**Ethanolysis of Sludge** Reaction of ethanolysis was optimized in terms of temperature, nature and amount of catalysts and reaction time. As expected, while conversion of lipids into FAEEs resulted effective also working under mild conditions, valorisation of carbohydrates resulted to be more significantly influenced by all of the tested parameters. In Table 1.1, it is reported a trend of reactivity recorded by using dry samples, temperature of 450 K, reaction time of 4 h and a combined action of sulphuric acid and Aluminium Chloride as catalysts.

<table>
<thead>
<tr>
<th>Sludge</th>
<th>Lipid Conversion</th>
<th>Carbohydrates Conversion</th>
<th>Yield of EL</th>
<th>Yield of EMF</th>
<th>Yield of F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>%wt</td>
<td>%wt</td>
<td>%m*</td>
<td>%m**</td>
<td></td>
</tr>
<tr>
<td>Primary</td>
<td>&gt;99</td>
<td>55-60</td>
<td>32</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>Secondary</td>
<td>&gt;99</td>
<td>99</td>
<td>45</td>
<td>12</td>
<td>82</td>
</tr>
<tr>
<td>Mixed</td>
<td>&gt;99</td>
<td>75</td>
<td>36</td>
<td>8</td>
<td>81</td>
</tr>
</tbody>
</table>

The eventual copresence of water definitively changed the profile of products, since besides FAEEs, ethyl-glycosides (EG) were mostly obtained from carbohydrates. In addition, even large part of initial proteins was always solubilised and converted into the respective ethyl-esters of aminoacids.

At the end, a significant reduction of the residual solids was in any case observed.

**CONCLUSIONS** Ethanolysis of urban sewage sludge was investigated and optimised in order to valorise lipids and carbohydrates into a one single pot reaction by producing value-added compounds. Production of fine chemicals and containment of final sludge to be disposed of was ever concomitantly achieved.

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**REFERENCES**


Evaluation of Biopolymers Produced by Selected Mixed Cultures from Sieving Residues as Flocculants for Urban Wastewater Treatment

J.N. Louvet*, E. Paul*, A. Morgado-Ferreira**, M. Bounouba*, E. Blanchet*, D. Cirne**, Y. Bessière*

*LISBP, Université de Toulouse, CNRS, INRA, INSA, Toulouse, France
**VEOLIA Environnement, Centre de Recherche sur l’Eau, Chemin de la Digue, BP 76, 78603 Maisons-Laffite cedex, France

Abstract: In the context of the circular economy, materials could be recovered from wastewaters (WW) to produce valuable molecules that could be ideally used in the WW treatment chain. Cellulosic material was recovered from WW using sieve and transformed, after hydrolysis, in sugars and through a further step using a selected microbial consortia, in a cellular biomass with flocculent capacity. Sedimentation tests after coagulation & flocculation were performed to evaluate the turbidity and COD removal performances of this new bioflocculant. The bioflocculant always showed better removal performances compared to the use of the coagulant (FeCl₃) alone but slightly inferior to those obtained with the combination of FeCl₃ and polyacrylamide used as a reference flocculant. Better coagulation-flocculation performances were however obtained using a biomass selected on simple sugars instead of hydrolysate.

Keywords: Flocculant biopolymer; microbial consortia; wastewater valorisation

Valorisation of materials contained in WW for the production of molecules of industrial interest is a very appealing solution to increase the sustainability of WW treatment. With the application of sieves on raw urban wastewater, valuable COD, mainly cellulosic material, can be recovered. Hydrolysis of these cellulosic fibres gives simple sugar units that could be used directly or further transformed to produce valuable molecules (Ruiken et al., 2013). In the context of the circular economy, the production of a molecule that could be used directly in the treatment chain without too much post-processing steps should be favoured.

During wastewater treatments a coagulation-flocculation process can be applied either to increase the removal efficiency of various macro and micro pollutants or to decrease cost and global environmental impacts of the treatment. It is important however to use a flocculant that have no hazardous effect. Biopolymers might represent viable alternatives to harmful synthetic flocculating agents that are currently used (Moore et al., 2014). In recent years, a great deal of effort has been devoted to improve the production and performances of polysaccharide bio-based flocculants. In our laboratory, using an open continuous bioreactor fed with a hydrolysate from sieving residues, production of a cellular biomass with anionic flocculant capacity was achieved with success. The performances of this new type of flocculant had not been yet extensively characterized what is the purpose of this work.
In a jar-test pilot, the new bioflocculant was associated to ferrous chlorine acting as coagulant and coagulation-flocculation performances of the mixture were assessed in terms of turbidity and COD removal through sedimentation tests performed on real urban wastewater from Toulouse city, France. The operating conditions of the Jar-test were quick mixing 3 min 150 r.p.m., slow mixing 20 min 50 r.p.m. and settling time 15 min. The removal yield obtained with the new bioflocculant was systematically compared with those obtained with FeCl₃ alone and with FeCl₃ plus AN934SH, an anionic polymeric derivative of polyacrylamide (PAM) (MW 14 million g/mol) obtained from SNF Floerger, Andrézieux, France and used as the reference flocculant in this study because of its wide use in urban WW treatment. Moreover, these performances were also compared with those obtained for another flocculant cellular biomass produced in a similar reactor but fed with only pure sugars (glucose and fructose). Column settling experiments were also performed to get the distribution of settling velocity of particles and hence to be able to extrapolate the results.

Our results (figure 1) showed that the new bioflocculants have always better performances of pollution removal compared to the use of FeCl₃ alone. For the bioflocculant produced in reactor fed with simple sugars, the performances of coagulation-flocculation exceeded (up to +350%) those obtained by conjugating FeCl₃ and PAM. For the bioflocculant produced on hydrolysate, the performance of coagulation-flocculation were in general between the one of the ferric chloride used alone and the one of the FeCl₃ + PAM. However, performance as high as +189% with respect to FeCl₃ + PAM can also be observed. These variations of performances are possibly due to changes in the characteristics of the biopolymers produced in the reactor because of the complexity of the supplied hydrolysate. Future work should investigate the link between microbial population dynamics in the reactor of production and changes in flocculation activity in order to propose strategies to maintain the microbial populations able to produce the more valuable polymers.

![Figure 1](image1.png) A) Light microscope image of selected bacteria with the capsule appearing as a bright halo surrounding the cells (incubation in India ink). B) An experiment performed in a Jar-test including (from the left) 3 references (control, FeCl₃, FeCl₃ + PAM) and three tests with the bioflocculant at different concentrations.

**REFERENCES**


Survivability of PHA after Mixed Culture Accumulation


* Department of Biotechnology, Delft University of Technology, Delft, the Netherlands
** Wetsus, European Centre of Excellence for Sustainable Water Technology, Oostergoweg 9, 8911 MA Leeuwarden, the Netherlands
+ ruizhe.pei@wetsus.nl ++ alan.werker@wetsus.nl

Abstract: Recently, it was demonstrated that surplus activated sludge from wastewater treatment plants has the potential to accumulate 40% (g/g VSS) polyhydroxyalkanoates (PHAs) without further optimization. After the accumulation, PHA is to be recovered from the biomass. However, prior to any downstream processing during the storage, interpreted depolymerase activity and associated polymer losses have been observed. This depolymerase activity could happen due to intracellular and extracellular enzymes, and also due to the nature and type of the PHAs and surrounding environment.

In a first benchmark study, extant extracellular polyhydroxybutyrate (PHB) degradation in surplus activated sludge was assessed at pH 5.5, 7.0 and 10.0. It was found PHAs were degraded within 2 days at pH 7.0. However, lower pH levels were found to preserve the PHA longer times.

BACKGROUND AND PROBLEM IDENTIFICATION Polyhydroxyalkanoates (PHAs) are a family of polyesters produced by a broad range of microorganisms as a means to store carbon and energy (Koller and Rodriguez-Contreras, 2015; Rodriguez-Perez et al., 2018). Municipal surplus activated sludge has been shown to be a viable and ubiquitous biomass source for producing commercial quality co-polymer blends of poly (3-hydroxybutyrate-co-3-hydroxyvalerate), or PHBV (Bengtsson et al., 2017, 2008). A full-scale municipal WWTP without benefit of a specific optimization for microbial enrichment accumulated to 40% PHBV of the VSS (Bengtsson et al., 2017).

After the accumulation, PHA-rich biomass is harvested and thickened. The thickened wet PHA-rich biomass may need to be stored prior to further downstream processing for the polymer recovery. During storage, the metabolic activity ensue in the biomass even with pre-treatment such as a pH change (Bengtsson et al., 2017). In the previous study, even though in some cases inorganic acid was added to bring the pH down to 2, significant molecular weight loss still took place. Management of the PHA-rich biomass after accumulation becomes critical to the polymer quality control. Therefore, it is of interest to gain a fundamental and practical understanding of the short-term PHA survivability in post accumulation biomass under different process and environmental conditions. Conditions should be sufficient to preserve the polymer, while minimizing added costs associated with input of downstream.

Two different types of depolymerase enzymes may degrade the polymer depending on its location (Ong et al., 2017). When the cells are intact, PHA granules in the cytoplasm are susceptible to the intracellular depolymerases. If the cells are in some way disrupted, extracellular enzymes activity can also contribute to molecular weight and polymer mass losses. It is considered that the intracellular depolymerases are not
able to act on the polymer in crystalline form while extracellular enzymes do (Ong et al., 2017). Degradation may ensue as a surface or bulk mediated process pending the state of the granules (Laycock et al., 2017).

Thus, the fate of post accumulation PHA requires insight to both types of depolymerase activities, and the nature condition of the polymer. As a starting point the survivability of the polymer in more crystalline form and as extracellular particulate matter was investigated in the matrix of the activated sludge used to accumulate the PHA. The PHA extracellular degradation kinetics and the localization of the enzyme activity were investigated as a function of pH.

MATERIALS AND METHODS Three 1.3 L jacketed batch reactors were operated isothermally at 37°C in batch mode under selected constant pH and anaerobic conditions. pH was monitored and controlled by dosing inorganic acid/base. An aliquot of nominally 200 g PHA-free surplus activated sludge, with 2.5 g commercial PHB with particle size of 272.57±12.51 μm (volume weighted) was used to evaluate the fate of exogenous crystalline PHB. In addition, about 30 g of inoculum from a full-scale anaerobic digestor was used to ensure presence of active acidogenic activity. Two grams BES were used to inhibit the potential methanogenesis activities. The total COD and soluble COD were measured by Hach Lange methods (LCK014, LCK114 and LCK514). Soluble products, including polysaccharides and proteins, and fermentation products were monitored by LC-OCD, IC and HPLC. The PHA content was analyzed by TGA and FTIR (Arcos-Hernandez et al., 2010; Chan et al., 2017).

RESULTS AND CONCLUSION It was demonstrated that when the exogenous PHB coexisted with surplus activated sludge, the PHB degradation rate was in the order of pH 7.0 > pH 10.0 > pH 5.5. From the estimated trends in time, at pH 5.5 PHB crystalline particles may survive without significant mass loss for more than 4 days. At pH 7.0, PHB mass loss proceeded relatively rapidly after an initial 1-day lag phase. At pH 10.0, the same activated sludge revealed 4 days lag phase, and then PHB loss at an intermediate rate. It was confirmed with an abiotic control that pH change did not result in measurable hydrolytic activity and abiotic degradation. The PHB was rapidly fermented by the biomass into acetate and butyrate. Only at pH 10 was the intermediate, hydroxybutyrate monomer, detected. The localization of enzyme activity was further investigated, and a kinetic model of the process was developed.

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REFERENCES


Bengtsson, S., Werker, A., Visser, C., Korving, L., 2017. PHARIO: stepping stone to a sustainable value chain for PHA bioplastic using municipal activated sludge. STOWA.


Boosting Vivianite Recovery from Digested Sludge by Increased Iron Dosing

T. Prot*,**, W. Wijdeveld*, L. Korving*, A.I. Dugulan***, K. Goubitz***, and M.C.M Van Loosdrecht**

*Wetsus, European Centre Of Excellence for Sustainable Water Technology, Oostergoweg 7, 8911 MA, Leeuwarden, The Netherlands
**Dept. Biotechnology, Delft University of Technology, Van der Maasweg 9, 2629 HZ Delft, The Netherlands
***Fundamental Aspects Mat & Energy Group, Delft University of Technology, Mekelweg 15, 2629, JB, Delft, The Netherlands

Abstract: In the CPR WWTP of Nieuwveer (The Netherlands), the quantity of Fe dosed has been doubled and the consequences on the sludge line have been studied. The main focus of this study is the evolution of the vivianite (Fe(II)3(PO4)2*8H2O) content in the sludge. Mössbauer spectroscopy analyses revealed that the percentage of phosphorus present as vivianite jumped from 20 to 50% due consequently to the Fe dosing increase. The more phosphorus as vivianite, the more can be recovered by magnetic separation. Moreover, the functioning of the WWTP was not impaired by the higher iron dosing. The phosphorus in the effluent has decreased from 1.2 to 0.4 ppm allowing discharge in a more sensitive medium.

Keywords: Vivianite, phosphorus recovery, magnetic separation

MATERIAL AND METHODS The studied WWTP is an AB plant with Solid Retention Time of 0.5 day for the A-stage, 13 days for the B-stage and 20 days for the digester. Sludge has been sampled at 4 different points (A-stage, B-stage, before digestion, after digestion) every 2 weeks for 150 days to be sure that a steady-state was reached. The liquid fraction was analysed for elemental composition with ICP-OES. The supersaturation index of vivianite requires Fe^{2+} concentration, obtained with the ferrozine method (Viollier). The solid phase was characterized with Mössbauer spectroscopy and XRD for the vivianite content. Microscopy and SEM-
EDX were used to characterize the crystals (Vivianite, FeS…) while microwave digestion was performed prior to ICP-OES for the elemental composition of the solids.

RESULTS AND CONCLUSIONS

- A new Mössbauer spectroscopy method is proposed for a better quantification of the vivianite in digested sludge

- The formation of vivianite and FeS in digested sludge is supported by thermodynamics calculation
- Several results suggest that different forms of vivianite form throughout the wastewater treatment process.
- The WWTP functioning has not been impaired by the higher Fe dosed. The P in effluent and H₂S in the biogas decreased.

The share of phosphorus as vivianite increased, making more phosphorus available for recovery via wet-magnetic separation.

REFERENCES


Nutrient Removal from Wastewater in Small-Scale PVA-Gel Based IFAS System

A. Rajpal a, *, N. Tomar a, Y. Ukai b, A.A. Kazmi a

a Research Associate, Indian Institute of Technology Roorkee (IITR) Uttarakhand (India), 247667, * Corresponding author, ankur.envt@gmail.com

a Master Student, Indian Institute of Technology Roorkee (IITR) Uttarakhand (India), 247667, nilesh.tomar.1801@gmail.com

b R & D Manager, Yuu Ukai Kuraray Co., Ltd., 892 Tsuitachi, Saijo-shi, Ehime 7938585, Japan

Yuu.Ukai@kuraray.com

a Professor, Indian Institute of Technology Roorkee (IITR) Uttarakhand (India), 247667, absarakazmi@yahoo.com

Abstract Aim of this study is to evaluate the performance of 50 m$^3$/d small-scale scale BNR plant using PVA gel as biomass carrier. The process design was based on the performance of laboratory scale oxic with PVA gel beads- anoxic and oxic configuration with 10% filling fraction of PVA gel media in first oxic reactor. The 50 m$^3$/d small-scale STP was designed at 6-h HRT Himalayan region at the bank of River Ganges. Average MLSS ~286 to 592 mg/L, ~3194 to 6421 mg/L and 4352 to 6809 mg/L in PVA gel reactor, anoxic reactor and in aerobic reactor respectively. Average removal of COD, BOD and TSS were observed >80%, >88% and >90% respectively. Total-N decreased remarkably, with mean removal efficiency of >80% after achieving steady state. Hence, present study investigated that IFAS system configuration is effective to achieve desired discharge objectives.

INTRODUCTION The conventional activated sludge (CAS) process is widely used but there are problems for the CAS process is that because the total number of microorganisms in per unit volume is low with a positive correlation between decreasing efficiency with decreasing temperatures in these systems (Ducey et al., 2010; Champagne et al., 2017; Chen et al., 2018). In contrast, researcher increased the interest in high nutrient removal efficient and cost-efficient like Moving Bed Biofilm Reactor (MBBR) and Integrated Fixed Film Activated Sludge (IFAS) processes.
Biomass carrier process has some advantages such as high biomass concentration, good performance of solid–liquid separation and high treatment efficiency, the technology has become a research hotspot. IFAS is a relatively novel treatment train that has at laboratory scale shown adequate water treatment, with high nitrogen removal and low sludge production rate and is a promising avenue for resource pressed developing countries (Hallvard Ødegaard 2015). Recently, several researchers have explored adding polyvinyl alcohol (PVA) gel beads to moving-bed biofilm reactors as a biomass carrier (Kuraray 2004; Hoa et al. 2006; Gani et al., 2014). A large number of microorganisms easily get attached to both the surface and inside the pores of the carrier media such as Poly vinyl alcohol (PVA) gel beads, which promotes biomass and effectively treats domestic sewage as demonstrated by the good performance in recent studies. IFAS allows two distinct biological populations to act synergistically, with the mixed liquor suspended solids (MLSS) degrading most of the BOD and the biofilm creating a strongly nitrifying population for oxidation of the nitrogenous load (NH$_4^+$) (Wang et al. 2016). Main objective of this paper is to evaluate the performance of PVA gel based small-scale advanced IFAS system treating sewage from small locality in Himalayan region at the bank of River Ganges.

MATERIALS AND METHODS

**Description of PVA Gel** PVA Gel beads, a trademark biomass carrier from Kuraray Co., Tokyo, Japan, are used as the biomass retention matrix. Beads are hydrophilic in nature and have a solid content of about 10% and specific gravity of 1.025 and available specific surface is very high (~2500 m$^2$/m$^3$) for higher growth of bacteria. They consist of 3-4 mm spherical bead with a network of 10–20-micron pores crossing through the bead, which allows cultivation of bacteria in a sheltered mode and thus reduces sloughing of biomass (Kuraray 2005; Hoa et al. 2006; Gani et al. 2014; Singh et al. 2016). Due to its better fluidity, minimum energy is consumed in mixing.

**Description and Configuration of 50 m$^3$/d PVA Gel Based Small Scale Plant** Based on the design and operational criteria by the lab-scale study, a 50 m$^3$/day small-scale sewage treatment plant integrated with three reactors, which are 1) Oxic reactor with PVA gel media, 2) anoxic reactor, 3) aerobic reactor followed by settling tank (Figure. 2.1) was installed in small locality at Kirtinagar. PVA Gel tank was operating at 10% packing ratio. The schematic flowsheet and typical photograph of the plant are shown in Figures 2.2a and 2.2 b respectively. The average daily flow to the reactor was 120 L/d with an HRT of 6 hours, 80% (96 L/d) directly feed to PVA gel tank while 20% (24 L/d) diverted to the anoxic tank for better denitrification (Swinarski et al. 2008). Temperature, DO and MLSS variation in the reactor are
shown in Table 3.1. The ambient temperature reduced to 30-10°C from May, 2018 to January, 2019. Almost after two month of start-up phase system achieved steady state. During monitoring average pH of the influent was 7.3 and for effluent was found to be 7.5. DO was fluctuated ~ 3.3 to 7.5mg/L in PVA gel reactor, ~0.1 to 0.3 mg/L in anoxic reactor and ~ 2.6 to 5.4 mg/L in aerobic reactor and during study period plant was operating under average MLSS concentration~286 to 592 mg/L, ~3194 to 6421 mg/L and 4352 to 6809 mg/L in PVA gel tank, anoxic tank and in aerobic tank respectively. During treatment process 30 ppm and 1 ppm of Alum and hypochlorite dosing was provided for ensuring phosphate and pathogen removal from the final outlet. All wastewater physic-chemical analysis was performed in accordance to standard methods (APHA, 2005).

![Figure 1.1 PVA Gel based IFAS system STP a) Schematic diagramand b) Pictorial view of capacity 50 CMD at Kirtinagar](image)

**RESULTS AND CONCLUSIONS**

**Performance Evaluation of 50 m³/d PVA Gel based small Scale Plant at Kirtinagar**

COD, BOD, TSS, Ammonia-N, Nitrate-N and Total-N removal efficiency

As shown in Figure 3.1, Average removal of BOD and TSS were observed >88% and >90% respectively. Similarly, total-N and PO₄-P decreased remarkably, with mean removal efficiency of >80% and 95%. However, average values of BOD in the influent were ~131 mg/L mg/L from and May to October but these values increases to ~401 mg/L and ~890 mg/L in November due to festival. In addition, due to starting of winter season, ambient temperature started decrease significantly from November and reduced to ~10°C in December. Subsequently, decrease in removal efficiency was observed but after a short period of 2 weeks STP recovered it selves and after wards BOD, Total-N and PO₄-P in the effluent were less than 10mg/L, 10 mg/L and 1 mg/L respectively.
Overall, performance of 50 m$^3$/d IFAS plant clearly indicated the possibilities of designing with confidence for the removal of carbon, nitrogen and phosphate in even in the colder regions.

REFERENCES

APHA, AWWA & WPCF (2005), Standard Methods for the Examination of Water and Wastewater. 20th edn. American Public Health Association, Washington, DC.


Kuraray Co. Ltd (2005), PVA GEL (presentation leaflet).


Biotechnological Approach for the Valorization of Synthetic Lignin Wastewater in a Bioelectrochemical System by *Pseudomonas putida* KT2440


* Institute of Applied Microbiology, Aachen Biology and Biotechnology, RWTH Aachen University, Aachen, Germany  
** Center for Microbial Ecology and Technology (CMET) – FBE – Ghent University, Gent, Belgium  
*** Leibniz Institute for Natural Product Research and Infection Biology – Hans Knöll Institute - (HKI), Jena, Germany

+ Email: juan.ramirez@rwth-aachen.de

Keywords: Lignin valorization, electro-fermentation, polyhydroxyalkanoate (PHA)

Abstract: We present a new biotechnological approach based on the ability of *Pseudomonas putida* KT2440 for enhancing catabolism of aromatic mixtures when discharging excess of electrons into an anode in a bioelectrochemical system under micro-aerobic conditions. The results obtained showed a slight improvement of aromatic degradation and posterior PHA accumulation for the conditions where bacterial electroactive interaction was detected, specifically when the external mediator Phenazine 1-carboxylic acid (PCA) was present. This work contributed to set a precedent for future studies on promoting anodic interaction for the production of desired products under micro-aerobic conditions using renewable substrates like lignin-derived aromatic compounds contained in complex wastewaters.

Lignocellulosic biomass is considered as the most abundant and available raw material on earth. However, significant quantities of complex wastewater streams are generated during lignin processing, which most of the times are difficult to treat (i.e. pulp-and-paper mill wastewater). In many cases, valorization of lignin waste streams represents one of the foremost challenges for the environmental sustainability and economics of new biorefinery strategies (Van den Bosch et al., 2015). The main reason relies on the inherent heterogeneity of lignin, which generates a complex mixture of aromatic compounds after different pre-treatments.

Recently, microbial strains have been tested for lignin valorization due to their ability on their metabolic pathways to “funnel” a mixture of aromatic streams into desired products (Linger et al., 2014). Some of these strains like the soil bacteria *Pseudomonas putida* KT2440 highlight because of its potential to overcome the challenges associated with lignin heterogeneity and their ability to produce valuable compounds from lignin derived aromatics. Furthermore, it has been proved that species like *Pseudomonas putida* KT2440 can interact with electrodes when an electron mediator is present, which led the bacterial metabolism to dispose excess of electrons into an anode overcoming redox imbalances and improving the bioprocess performance (Schmitz et al., 2015). We present a new concept which merge the ability of *Pseudomonas putida* KT2440 for valorizing aromatics derived from lignin...
waste streams into valuable products like polyhydroxyalkanoates (PHAs) and its potential to be used in bioelectrochemical systems (BES) to discharge excess of electrons into an anode when an external mediator (electron shuttle like Phenazine-1-carboxylic acid, PCA) is present (Figure 1.1). By doing this, the strain could improve its aromatic degradation ability overcoming the complexity and/or toxicity of the aromatic mixture.

The synthetic aromatic wastewater consisted on a lignin-model mixture (30mM) of p-coumarate, ferulate and benzoate. The strain was grown under micro-aerobic conditions in a 500ml bioelectrochemical reactor (30 °C, 200rpm, Air flow: 30ml/min, pH: 7.0, 40ugPCA/ml, 0.2V vs. RE-Ag/AgCl) to promote electron delivery to an anode (carbon material). Corresponding controls under limited oxygen conditions (conventional bioprocess without electrodes and abiotic BES) were run to compare the behaviour of conventional cell cultures with the ones using an anode as electron sink. The results obtained showed a slight positive effect on aromatic degradation rates and posterior PHA accumulation when the strain discharged electrons to an anode using PCA. This proof of principle set a base for future studies on enhancing degradation of complex wastewater containing aromatic mixtures when Pseudomonas putida KT2440 is cultured under micro-aerobic conditions.

Figure 1.1. Scheme of the biotechnological approach for aromatic wastewater valorization. Excess of electrons produced during the bacterial metabolism can be delivered to an anode through PCA (electron shuttle) to improve aromatic degradation and conversion into valuable products like polyhydroxyalkanoates (PHAs).


Selecting a PHA Accumulating Mixed Microbial Culture Using Fermented Wastewater from a Sweets Manufacturing Industry

C. Rangel*, N.D. Lourenço*, G. Carvalho***, M.A.M. Reis*

* UCIBIO, REQUIMTE, Departamento de Química, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, *c.rangel@fct.unl.pt
** Present address: Advanced Water Management Centre (AWMC), The University of Queensland, St Lucia, Queensland, 4072, Australia, g.carvalho@awmc.uq.edu.au

Abstract: Sweets manufacturing industry produces a sugar- and protein-rich effluent with high potential for resource recovery through PHA production. In this study, a PHA-accumulating culture was successfully selected using fermented sweets manufacturing effluent, which contained 50% of ethanol and 35% of lactate. Despite the fact that this is not a typical fermentate composition used in PHA production, the selection of a PHA producing culture was rapidly achieved.

Keywords: Bioplastics; polyhydroxyalkanoates; fermentation products; circular economy

The H2020 AFTERLIFE project (Advanced filtration technologies for the recovery and later conversion of relevant fractions from wastewater) proposes a flexible, cost- and resource-efficient process framed in the zero-waste and circular economy approach for the recovery and valorisation of the relevant fractions from wastewater. The first step of such process consists of a cascade of membrane filtration units for total solids separation from wastewater of three types of food industry (cheese manufacturing, fruit processing and sweets manufacturing). Then, the concentrates recovered in each unit are treated to obtain high-pure extracts and metabolites or, alternatively, to be converted into value-added products, such as volatile fatty acids (VFAs) and polyhydroxyalkanoates (PHAs).

Currently one of the greatest concerns worldwide focuses on the development of new sustainable materials that can be used to replace petroleum-based products. PHAs are biologically synthesized polyesters, completely biodegradable, and considered the most promising substitute of oil-based synthetic polymer (Chanprateep et al., 2010). Normally, PHA production from wastes using mixed microbial cultures (MMCs) is performed using a three-stage process including acidogenic fermentation of the organics in the feed, selection of a bacterial consortium enriched with PHA-storing organisms, and PHA accumulation in a fed-batch process, as displayed in Figure 1.1 (Dionisi et al., 2005; Albuquerque et al., 2007).

The goal of our work was to select a bacterial consortium enriched with PHA-accumulating organisms, using as substrate a stream resulting from the fermentation of sweets manufacturing wastewater by Innoven, a partner of the AFTERLIFE project. This stream had a total concentration of fermentation products of 1840.5 Cmmol.L⁻¹, comprising mainly ethanol and lactate (50% and 35% of the total, respectively), which is not a typical profile for the selection of a PHA accumulating culture, since VFAs, such as acetate, propionate, butyrate and valerate are preferable substrates for PHA production.
Culture selection was performed in a sequencing batch reactor (SBR) inoculated with aerobic activated sludge from a local wastewater treatment plant and operated in cycles of Feast and Famine. In this process, the bacterial consortium was subjected to alternating periods of presence (Feast) and absence (Famine) of substrate, an operation mode that is known to induce carbon storage and impose a selective pressure for PHA-accumulating bacteria. The 2 L SBR was operated in cycles of 12 hours, with a hydraulic retention time (HRT) of 1 day, a sludge retention time (SRT) of 4 days and an organic loading rate (OLR) of approximately 75 Cmmol.L⁻¹d⁻¹. Phosphate and ammonium were supplemented to the reactor, according to the ratio C:N:P of 100:7:1. The system was operated with control of pH between 6.50 and 7.90. After six SBR cycles, the depletion of lactate, acetate and iso-valerate was attained 1 hour after the beginning of the cycle. After this, cells continued to consume the remaining ethanol until its exhaustion. A biomass with a PHA content of 11.7 wt.% (0.34 g/L) was registered at the 6th day of operation with a yield of 0.44 g PHA/g S, where S corresponds to the total fermentation products concentration in the feed. The produced PHA was a homopolymer of hydroxybutyrate, namely poly(3-hydroxybutyrate). These results showed that the selection of a PHA-accumulating mixed microbial culture was possible using a VFA stream produced from fermented sweets manufacturing wastewater, in spite of its unusual VFA composition. These results are very promising in regard to the valorisation of an industrial wastewater through the production of value-added biopolymers. The reactor is currently being operated towards optimizing the productivity of the process and assessing its resilience to ethanol accumulation.

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REFERENCES
Integrating Advanced Oxidation Processes with Biofiltration for Direct and Indirect Potable Reuse in Apulia, Italy


* Department of Engineering for Innovation, University of Salento, Via per Arnesano 73100, Lecce, Italy
**AquaSoil S.r.l., via del Calvario 35, 72015 Fasano, Brindisi, Italy
*** Regional Environmental Protection Agency – Arpa Puglia, C.so Trieste 27, 70126 Bari, Italy
**** Mérieux NutriSciences Research, via Fratta 25, 31023, Resana, Treviso, Italy
***** Department of Biological and Environmental Sciences and Technologies (DiSTeBA), University of Salento, Via Prov.le Lecce-Monteroni, 73100 Lecce, Italy
******Department of Chemical and Biochemical Engineering, University of Western Ontario, London, Ontario Canada, N6A 5B9

Abstract: A comprehensive pilot study was carried out in Fasano (Brindisi, Apulia, Italy) to experimentally assess the potential of a newly developed treatment train integrating two-stage AOPs and biofiltration to reach potable reuse water quality standards from municipal wastewater. The process consisted of a two-stage AOPs with (carbon or limestone) biofiltration, the first AOP (O₃/H₂O₂) serving as pre-treatment to biofiltration and the second AOP (UV₂₅₄/H₂O₂) serving as post-biofiltration finishing step for virus inactivation and oxidation of micropollutants recalcitrant to upstream processes. The pre-treatment stage employed the O₃/H₂O₂ advanced oxidation process (10 mg/L O₃ and 10 mg/L H₂O₂ dosages, before demand), and was followed by three parallel treatment lines: (a) a membrane-based train, with ultrafiltration followed by reverse osmosis; (b) a granular-limestone-based biofiltration train; (c) a granular-carbon-based biofiltration train. Downstream the biofiltration unit, a second AOP by UV₂₅₄/H₂O₂ was operated in order to ensure advanced disinfection (15 logs MS2 credits) and mild advanced oxidation (300 mJ/cm² and 5 mg/L H₂O₂ dosage, before demand). An intensive sampling campaign was put in place combining targeted, non-targeted screening, and suspect target screening measurements. Furthermore, ecotoxicological tests with different bioassays (Daphnia Magna, Microtox, SOS Chromotest and Comet tests) and endpoints (i.e., acute toxicity, mutagenicity and genotoxicity) were carried out to further investigate the whole-effluent response to the co-existence of micropollutants and as a function of various treatment processes. Targeted measurements indicated full compliance with the Italian drinking water standards except for nitrite and chloride. Suspect target screening detected the presence, at concentration lower than 1 microgram per liter, of 13 organic micropollutants from a list of 216 candidates. Furthermore, it was possible to estimate the treatment efficacy (as total sum of micropollutants) of the individual unit process assessed in the pilot study. It was found that the total micropollutant abatement efficiency was: RO (99%) > O₃/H₂O₂ (85%) = Carbon biofiltration (85%) > Limestone biofiltration (61%) > UV₂₅₄/H₂O₂ (40%) > UF (0%). The newly developed scheme integrating two AOPs and carbon biofiltration (O₃/H₂O₂ + BAC + UV₂₅₄/H₂O₂) was able to provide, overall, a 99% abatement thus matching the removal performance (99%) of the membrane-based treatment train (UF+RO). While some of the untreated or partially treated samples showed positive response to ecotoxicological tests, no positive response was recorded for any of the effluent samples from the tested trains, even when pre-concentration factors up to 100 times were adopted.

Keywords: Potable Reuse, Process Integration, Biofiltration, Advanced Oxidation

INTRODUCTION Factors like urbanization, population growth and climate change are imposing increased stresses on freshwater resources, both locally and globally. As
a result, water scarcity is no longer the only driver for wastewater reuse, and holistic water management strategies based on fit-for-purpose applications are very much needed to help meet future water demand while protecting human health from chemical and microbiological risks. Worldwide, example of implementation potable reuse treatment trains are growing, although in a more limited fashion due to lack of social acceptance (Garcia-Cuevva, 2016; Trussell, 2014). Such trains are designed according to multi-barrier treatment concepts where unit processes are typically connected in series, and often incorporate concepts of redundancy, resiliency and robustness (Khan, 2013) at the expense of high capital cost. However, as recently reported in the literature (Santoro, 2013), alternative approaches based on the use of multifunctional reactors are possible, especially when a multitude of known and unknown organic and inorganic compounds pollutants are present. In this paper, different treatment trains aimed at achieving “fit-for-purpose” wastewater reuse applications, including direct potable reuse, were pilot-tested for the first time in Apulia (Italy), in a collaborative effort with Apulia region aimed at developing innovative zero-liquid-discharge trains for non-coastal wastewater treatment plants.

MATERIALS AND METHODS The pilot plant consisted of a 3 m$^3$/h pre-treatment stage with O$_3$/H$_2$O$_2$ advanced oxidation process by 10 mg/L O$_3$ and 10 mg/L H$_2$O$_2$ (i.e., the peroxone process), carried out in a multifunctional reactor able to simultaneously provide enhanced gas-liquid mixing, solids separation, and contact time (i.e., the MITO$_3$X technology). Equal aliquots (1 m$^3$/h each) of O$_3$/H$_2$O$_2$ pre-treated wastewater were sent to three parallel treatment lines: (a) ultrafiltration, followed by reverse osmosis; (b) biofiltration on granular limestone; (c) biofiltration on granular activated carbon. Finally, a second AOP by UV$_{254}$/H$_2$O$_2$ (300 mJ/cm$^2$, with 5 mg/L H$_2$O$_2$) was operated to both disinfect and oxidize residual contaminants. Figure 1.1 shows the different treatment lines, as well as the sampling ID associated with each of the sampling points.

An intensive sampling program was carried out using targeted measurements, non-targeted screening and suspect target screening. Moreover, ecotoxicological tests with different assays (Daphnia Magna, Microtox, SOS Chromotest and Comet tests) and endpoints (i.e., acute toxicity, mutagenicity and genotoxicity) were carried out to further investigate the whole-effluent response to the combination of micropollutants and treatment processes. Such holistic monitoring strategy allowed for a global evaluation of the whole-effluent water quality status attainable by the integrated pilot plant (Chibwe et al., 2017; Liernert et al., 2007). The data collected during the study can be summarized as follows:

- Targeted measurements of 72 water quality parameters, regulated by the Italian Decree n. 31/2001, and augmented with additional micropollutants of emerging concerns such as nitrosodimetylamine (NDMA), perfluoro-octanoid acid (PFOA) and perfluorooalkylic substances (Vecitis et al., 2009), di-oxane and bromates;
- Non-targeted screening and suspect screenings of 219 water quality parameters obtained by combining parameters included in the EU directive for emerging
pollutants with the candidate contaminants list n.4 by EPA (USEPA, 2016), using liquid, gas and ionic chromatography coupled with high resolution mass spectrometry (LC-HRMS, GS-HRMS and IC-HRMS);

- Ecotoxicological bioassays, with and without sample pre-concentration, to detect potential impact of the treated water on different biological systems and for different endpoints, namely: toxicity response using Daphnia Magna and Microtox tests, and mutagenicity/genotoxicity response using SOS Chromotest and Comet tests.

**RESULTS**  
Suspect target screening indicated the presence of 13 organic micropollutants (Figure 1.2) in the pilot influent (P2), including pesticides, steroids, contraceptives or compounds of industrial origin, namely: Butylated hydroxyanisole, Di(2-ethylhexyl)phthalate, Diuron, Isoproturon, Quinoline, N-Methyl-2-pyrrolidone, N-nitrosopyrrolidine, Norethindrone, Terbutryne, Perfluoro-octanoic Acid, Aniline, Estriol, Hexahydro-1,3,5-trinitro-1,3,5-triazine) each at ≤ 1 microgram per liter level. None of these pollutants were detected in the local tap water (P0).

![Figure 1.2 Maps of organic micro-pollutants for each of the monitoring point as revealed by suspect screening methods (LC-HRMS, IC-HRMS cat, IC-HRMS, and GC-HRMS) for both physic-chemical and biological trains.](image)

The treatment efficacy against total sum of micropollutants of each unit process was found to be in the following order: RO (99%)> O3/H2O2 (85%)=Carbon biofiltration (85%)>Limestone biofiltration(61%)> UV254/H2O2 (40%)>UF (0%). When assessed as integrated treatment train, the newly developed scheme integrating two AOPs and biofiltration (O3/H2O2 + BAC + UV254/H2O2) was able provide 99% abatement in total micropollutants, with only BHA detected in the effluent (P8). When P8 is compared with P7 (effluent from RO), we can conclude that the BAC-based train can be regarded as promising alternative to MF/UF+RO+ UV254/H2O2 for direct potable reuse. For indirect applications such as managed aquifer recharge and crop irrigation, O3/H2O2 showed excellent performance (85-96% abatement in total micropollutants). Finally, while some of the untreated or partially treated samples showed positive response to ecotoxicological tests, no positive response was recorded for any of the fully-treated samples, even with pre-concentration factors up to 100 times. It is also interesting to examine the molecular size distributions obtained from the different trains. As can be seen in Figure 1.3, carbon biofiltration is able to produce an effluent molecular weight distribution comparable with the one from the control, i.e. local potable water from the tap.

![Figure 1.3 Molecular weight distributions for the effluent from biological train O3/H2O2 + BAC + UV/H2O2 compared against potable water and the tertiary treated wastewater (pilot influent)](image)
In conclusion, this study confirmed that O$_3$/H$_2$O$_2$ + BAC + UV$_{254}$/H$_2$O$_2$ can be regarded as a viable alternative to membrane-based processes such as MF/UF+RO+ UV$_{254}$/H$_2$O$_2$ for direct potable reuse. For less restrictive applications such as indirect potable and agricultural reuse, the O$_3$/H$_2$O$_2$ process, implemented in a multifunctional reactor operated with the MITO$_3$X technology, showed considerable potential given its high performance (85% abatement) and limited capital and operating cost.

REFERENCES
Use of Multi Criteria Decision Making Technique in selection of appropriate Household Water Treatment Technology.

S Savalkar*, MM Ahammed**

*Civil Engineering Department, SV National Institute of Technology, Surat, 395007, India, supriya.e.520@gmail.com

**Civil Engineering Department, SV National Institute of Technology, Surat, 395007, India, mansoorahammed@gmail.com

Abstract: Safe drinking water waives the burden of diarrheal diseases and ensures better health of people in developing countries. Supply of water through piped system is not viable option from the economic point of view in rural background. Thus, household water treatment technologies have emerged as a novel approach that empowers the community to cater their need of safe water by treating and storing water safely at their respective households. Many such technologies are available and selection of an appropriate technology from the set of available alternatives is difficult. Selection of these technologies is often area specific and revolves around many factors. An attempt is made in this paper to present application of Analytical Hierarchy Process (AHP) by incorporating Delphi method and applying VIKOR technique to obtain a compromise solution in selection of a suitable household water treatment technology. Selecting a suitable household water treatment technology is associated with multiple criteria and was constructed as a hierarchy as depicted in Figure 1. The first level of hierarchy depicts the goal to be achieved. The second level decomposes the entire goal accomplishment as a function of criteria considered and finally the third level of alternatives. In the first phase, the criteria and alternatives were fixed and Google form or questionnaire was prepared. In the second phase a questionnaire survey was conducted, wherein we intend to evaluate six adaptation options by obtaining the opinion of 30 experts.

Figure 1 Hierarchy for selection of suitable household water treatment technology
The overall proposed methodology is a rationalized process which will be more relevant in realistic scenarios where multiple stakeholders and priorities are involved in selection of suitable and sustainable household water treatment technology. The entire methodology discussed in this paper is a hybrid technique which combines AHP with Delphi and VIKOR technique in selection of a suitable household water treatment technology where the water is directly used from the source without any pre-treatment. The criteria like reliability, cost, time to treat, efficiency, post contamination and supply chain management were considered for the assessment. Figure 2 depicts the relative weightage of each criterion toward the goal of selection of suitable household water treatment technology. Figure 3 is a radar plot which depicts the behaviour of each household water treatment technology as per the criterion which is the nodes of the plot. If the plot of the technology falls outwards suggests that the technology is better than its counter parts when all criteria weightage are considered on whole. From the results, we can conclude that the panel of experts considered efficiency (29%) followed by reliability (24%) and post contamination (20%) as the main criteria for selecting the suitable household water treatment technique. Figure 4 depicts the global priorities of each household water treatment technology where in chlorination (29.73%) is most preferred by the experts followed by boiling (21.94%) and biosand filter (15.75%). This methodology adopted can be customized for a scenario based approach which is more site-specific. Thus, we can conclude that AHP-Delphi-VIKOR system is a reliable method in selecting suitable and a sustainable household water treatment technology.

Keywords: AHP-Delphi method; Household water treatment; VIKOR.
Quantification of Sustainability Index for the Resource Recovery Technologies Based on the Recovered Resource and Wastewater Stream

E. Topuz*, I. Ozturk**, D. Okutman Taş**

*Department of Environmental Engineering, Gebze Technical University, emeltopuz@gtu.edu.tr  
**Department of Environmental Engineering, Istanbul Technical University

Abstract: Circular city is gaining more and more attention nowadays due to its reuse-recover-recycle applications for circulating the resource. The authorities need decision making support tools to determine which sources can be recovered and what are the best applicable technologies. The aim of the study is to propose a decision making method that calculates Sustainability Index for the resource recovery technologies. SI values provide the communication between stakeholders of circular city by supporting decision making for resource recovery methodologies.

Keywords: Analytical hierarchy process; decision making; circular city

The increase in human population is leading to scarcity in natural sources and placing a pressure on authorities to apply RRR (Reuse-Recover-Recycle) principle for sustainable development (Lazurka, 2018). Recently, the concept of circular city where RRR principle is applied for waste management is gaining attention. The benefits of circular city are not limited only to waste minimization; it also provides circular economy where monetization of waste is possible. Some of the European cities such as Amsterdam and Barcelona are already planning for transition stage to become a circular city ( ). Therefore, authorities of those cities, which are willing to become a circular city, need to make decision how to upgrade the existing facilities and/or establish new ones for resource recovery. Wastewater Treatment Plants (WWTPs) are one of the biggest platform where various sources such as energy, nutrients and water can be circulated in the city. However, a sustainable circulation should be provided for a long life cycle. The main aim of this study is to propose a decision making tool for the selection of proper resource recovery technologies for WWTPs. This tool provides the quantification of sustainability index (SI) for the candidate technologies. The quantification is also beneficial for the communication among stakeholders (i.e. municipality representatives, public, markets) for the valuable resources recovered.

PROPOSED METHOD Analytical Hierarchy Process (AHP) is used for the quantification of SI. AHP provides a systematic approach for decision making problems (Saaty, 1992). The first step is the development of a hierarchy for the calculation of SI. The hierarchy is developed specifically for each source that could be recovered from a WWTP. Waste streams, water and sludge, are considered for the development of hierarchy, as well. For the same resource, a specific hierarchy is
developed for each waste stream. Table 1.1 shows the skeleton of the hierarchy which is used for every source and stream. The concept of sustainability usually involves the technological, economic, environmental and social aspects. In addition to these, characteristics of resource recovered and existing facilities are also critical since they are representing the quality of product and the conditions at the background, respectively.

**Table 1.1** Main and sub criteria (Level I) in the hierarchy developed for the quantification of Sustainability Index

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<th>Main Criteria</th>
<th>Technical Aspects</th>
<th>Economical Aspects</th>
<th>Environmental Aspects</th>
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<td>-Job creation</td>
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By including more sub criteria (levels) in the skeleton of hierarchy (Table 1), specific hierarchies are developed considering the main selected recoverable materials from waste as a model (i.e. bioplastics, cellulose, nitrogen, phosphorus, alginic acid, organic matter, energy). If it is possible to recover a source from both streams (water and sludge), then specific hierarchies are developed for each stream. Details for the calculation of SI is similar to the study of Topuz and van Gestel (2016). Briefly, a scale is determined for scoring the criteria in the hierarchy and the criteria are scored by experts. The criteria in the same level are compared by using Chang’s scale to calculate the priority weight of each criterion. SI is calculated based on the s-cores and the priority weights of criteria. Figure 1.1 shows the flow chart for the application of the proposed method in this study.

Since SI values obtained from the results of the proposed tool in this study provides the comparison of alternatives, the tool supports the authorities to make sustainable decisions about i) which resources could be recovered and ii) which technologies could be used. In addition, SI values might be used to design more efficient hybrid systems for circular cities.

**CONCLUSION** This study provides a systematic quantification tool which is helpful for the communication of stakeholders of circular cities especially between planning committee of city design and decision makers.

**REFERENCES**

Lazurka, A. 2018 Assessing the value of resource recovery and reuse. International Water Management Institute, CGIAR, Germany.

Rethinking Wastewater as a Resource for Irrigation for Musanze Prison, Rwanda

D. Umutangampundu*, C.M. Kanyunge*, J.M. Niyonkuru*, L.L. Atanga**

*Pan African University Institute of Water and Energy Sciences (including climate change), P.O Box: 196 Tlemcen-Algeria, Email: djalia012@gmail.com

Abstract Musanze Prison generates a huge amount of wastewater which, if treated can be reused for agricultural activities. The prison is located in Muhoza sector, Musanze District, in Northern Province of Rwanda where its wastewater is causing problems to the road where it is discharged, to the neighboring community in terms of bad odor generation, to the environment in general and to inmates ‘health in particular. The objective of this project was to quantify, characterize and treat wastewater generated by Musanze prison for irrigation.

To achieve this, wastewater quantity was estimated as equal to 80% of total water consumption. Characterization was done based on checking parameters of importance for irrigation purpose where three samples of grey water were collected and analyzed for TSS, TDS, BOD and coliforms. For the treatment, the design of a decentralized wastewater treatment system (DEWATS) was suggested. DEWATS is a combination of 4 units which are: biogas-digester, anaerobic baffled reactor, planted gravel filter and an aerobic polishing pond.

The analysis found that the wastewater generated is 54.4m³/day. The TSS was found to be 520 mg/l and microorganisms such as E.coli were found to be 80 CFU/100ml, green colonies 160 CFU/100 ml and proteus & salmonella 240 CFU/100ml. Based on water quality standards for irrigation purpose, the study found that grey water from Musanze prison could be reused untreated and irrigate fodder crops or trees for ornament. However, the same water combined with black water could be treated using DEWAT technology and produce water for irrigation as well as energy from biogas. This could also improve aquatic life in Kigombe River where this wastewater ends. So far, this project could be applied from small households to the higher institutions such as hospitals, schools, industries in order to improve sanitation and increase crop production.

Keywords: Musanze Prison, wastewater, crop production, treatment, reuse, irrigation, biogas.
Lab-scale Selection of Lipid Accumulating Bacterium *Microthrix parvicella* from Wastewater Activated Sludge for Biodiesel Production


*marielouise.uwizeye@uni.lu, **zuzana.frkova@uni.lu, , joachim.hansen@uni.lu

Abstract: Information collected from 7 studied wastewater treatment plants (WWTPs) in Luxembourg and from literature has been used to design and test a dedicated methodology to aggregate *Microthrix parvicella* (*M. parvicella*), a lipid accumulating bacterium present in most of the municipal wastewater treatment plants. A pre-test of this methodology to select *M. parvicella* showed that its growth is sustained by short alternating aerobic/anoxic (2min/8min) conditions rather than long alternating aerobic/anoxic (1h/3h) conditions or low dissolved oxygen (DO) continuous aeration.

Keywords: *M. parvicella*; selection; aeration

INTRODUCTION Unlike conventional feedstocks (vegetable oil or animal fat), wastewater-derived lipids represent an important, sustainable and exploitable resource for biofuel production (Muller et al., 2014). Those lipids can be uptaken and stored by specialized microorganisms present in the activated sludge community. *M. parvicella* is one of the lipid-accumulating microorganisms that can contribute to supply future energy demand. *M. parvicella* can in fact store lipids in form of Long Chain Fatty Acids (LCFAs) under anoxic, aerobic and anaerobic conditions (Nielsen et al., 2002). However, *M. parvicella* is associated with solid-liquid separation problems causing foaming and bulking in activated sludge. WWTPs operators adopted different solutions to control the overgrowth of this bacterium. The use of selectors to isolate problematic bacteria has been of common practice in recent years. Such selector may also be used to promote the growth of *M. parvicella* when favourable conditions are selectively ensured. Key parameters affecting *M. parvicella* growth and LCFAs storage have been identified as low temperature, long Sludge Retention Time (SRT) and low Dissolved Oxygen concentrations (DO) (Rosseti et al., 2005; Noutsopoulos et al., 2006). However, other impacting factors are nowadays still not well understood. The aim of this study is to define reliable selection conditions in which targeted *M. parvicella* growth and lipids storage are promoted, and finally design a selection reactor for a targeted aggregation and lipid accumulation.
MATERIAL AND METHODS To better understand the factors that selectively support the growth of *M. parvicella* and its lipids accumulation, a survey on 7 municipal WWTPs in Luxembourg having sludge sedimentation problems in the clarifier have been carried out. Results from questionnaires and conventional microscopic examination of dominant filamentous bacteria highlighted the operational and selection criteria for *M. parvicella*. The study showed that low temperature, intermittent aeration with low DO and low sludge loadings (food/biomass-ratio) promoted the growth of *M. parvicella*. These results together with information gathered from literature provided important input in the design of a selector reactor and different scenarios in which the growth of *M. parvicella* may be promoted. A set of three continuous flow bioreactors operated in parallel fed with synthetic wastewater have been designed and developed. The bioreactors were inoculated with activated sludge rich in *M. parvicella* (filament index of 5) collected in the WWTP of Bettembourg, Luxembourg.

RESULTS AND CONCLUSIONS The first scenario tested was to assess the effect of different aeration modes. The first reactor (R1) was operated under continuous aeration at a low DO (0.5 mg O2/L), the second (R2) under intermittent aeration (on and off for 2 and 8 min respectively, with DO max of 2 mg O2/L), while the third reactor (R3) was operated under intermittent aeration (on and off for 1 and 3h respectively, with DO max 8 mgO2/L). During the experimentation, the temperature has been controlled and kept constant at 12°C and the sludge retention time at > 20 days.

The microscopic monitoring was performed for primary identification of the *M. parvicella* filaments growth. The results from all the reactors showed a decrease in *M. parvicella* filaments (expressed in filament index, FI) at a different extent. While the FI decreased from 5 to 2 in R1 and from 5 to 1 in R3, it slowly dropped from 5 and sustained at 3 in R2. This agrees with Gabb et al. (1996) where *M. parvicella* proliferated in continuously fed with intermittent aeration periods systems (Gabb et al., 1996).

These results show that beside adequate aeration mode other parameters (such as feeding mode, oxygen concentration, temperature and hydraulic retention time) need to be considered for selective growth and lipids accumulation of *M. parvicella*. Thus, in the frame of the Interreg NWE funded project WOW – Wider business opportunities for raw materials from wastewater,
REFERENCES


Phosphate Adsorption by Iron Coated Sand Granules as End-Of-Pipe Solution for the Purification of Drainage Water

N. Lambert*, P. Van Aken*, R. Dewil*

*KU Leuven, Department of Chemical Engineering, Process and Environmental Technology Lab, Jan Pieter De Nayerlaan 5, 2860 Sint-Katelijne-Waver, Belgium, raf.dewil@kuleuven.be

Abstract: In this study, a technology based on phosphate adsorption is proposed as a robust technology for phosphate removal from drainage water. This method has some benefits over the typical metal salt precipitation, including its robustness and lower post-processing requirements. The objective was to translate lab scale experience to good practices and optimal working conditions for field applications. Based on this experimental study, a PO₄-P adsorption capacity of 2 to 6 mg PO₄-P/g sorbent can be expected in full-scale phosphate filter applications, when it is assumed that these filters are fed with drainage water containing an average P concentration of 25 mg PO₄-P/L. Also, bench-scale column adsorption experiments were carried out to verify the adsorption capacity and to investigate whether the PO₄-P adsorption capacity could be augmented by changing the operational conditions of the filter, i.e., attempting to achieve an increased adsorption by the use of intermediate rest periods.

Keywords: Phosphate adsorption; Iron coated sand; Drainage water

INTRODUCTION The agricultural use of fertilizers has been a major source of nitrate and phosphate pollution in Europe. Remarkably, a correlation between the presence of greenhouses, which often grow soilless crops, in a specific region and the exceedance of the nitrate and phosphate standard in surface water is observed. Both high nitrate and phosphate concentrations are present in the run-off water from agriculture and horticulture, i.e., up to 55 mg NO₃-N/L and 25 mg PO₄-P/L. Hence, this nutrient-rich run-off water becomes detrimental when it will overfertilize aquatic plants and subsequently cause an increased eutrophication. To limit their emission, the EU issued the Nitrates Directive (1991), which has been subsequently been integrated in national legislations by the member states. In response to this Directive, vulnerable zones in Flanders (Belgium) were established, in which the standard of 11.3 mg NO₃-N/L and 0.07-0.14 mg PO₄-P/L (depending on the receiving water body) is exceeded. A way to limit the emission of nitrates and phosphates in the environment is the use of good farming practices to avoid the production of nutrient-rich water. Nowadays, exceedances of phosphate discharge standards are still observed despite the good farming practices, forcing the need to retain phosphate before disposed into the environment.

In this study, an adsorption process, which requires less post-processing compared with a conventional physicochemical phosphate removal process, by using Iron Coated Sand (ICS) grains is proposed as end-of-pipe technology. These iron beads are similar to the commercially available Granular Ferric Hydroxide (GFH) and can be used for the adsorption of a variety of pollutants (e.g., arsenic and phosphate) from wastewater (Sperlich, 2010). The potential of the ICS granules to adsorb phosphate from municipal...
wastewater on laboratory scale was already demonstrated by Moelants et al. (2010). The main goal of this research is to demonstrate the feasibility of the phosphate filter to treat nutrient-rich drainage water from horticulture in such a way that the treated water meets the environmental standards and can be discharged in the surface water. Based on batch experiments at lab scale, the influence of granule type (diameter and origin), adsorption kinetics and initial pH was examined. These insights were used to upscale the adsorption columns to a pilot scale application. Special attention is paid to the management and optimal operating parameters of the phosphate filter.

**MATERIAL AND METHODS** The ICS granules are derived from rapid sand filters used for the deferrization in the production of drinking water from groundwater. The drinking water company PIDPA facilitates drinking water production plants at different locations in Flanders (Belgium), e.g., Balen, Grobbendonk, Herentals and Mol. The adsorption isotherms and kinetics are determined by batch tests at ambient temperature (20 °C). 10 g of pre-dried granular substrate material is brought in contact with 100 mL synthetic wastewater sample with different PO₄-P concentrations ranging from 10 to 3000 mg PO₄-P/L.

Continuous laboratory-scale column experiments were performed to verify the kinetics and determine the influence of some operational parameters on the breakthrough time of the column. Each column was filled with a predetermined mass of dry iron granules (100 cm³) and was fed with a phosphate solution with a concentration of 25 mg P-PO₄/l via a membrane metering pump with adjustable flow rate. By performing the rapid small-scale column tests, the breakthrough time of the adsorption column can be estimated.

**RESULTS** There was an attempt to achieve an increased adsorption by the use of intermediate rest periods. In this strategy the column was fed 8h per day and in this way the column was left to stand for 16h per day. In Figure 1.1 it can be clearly established that these rest periods cause a significant improvement of the adsorption capacity, making it possible to reach the maximum adsorption capacity, as determined in the batch experiments on lab scale. The underlying cause can be explained by the interparticle diffusion of PO₄-P towards the core of the granules during the rest periods. This will result in fresh and free adsorption sites, leading to a slower saturation of the granules.

**Figure 1.1** Effect of intermediate rest periods on the adsorption capacity of PO₄-P on the iron granules.

**REFERENCES**


Phosphate Recovery from Iron Coated Sand Granules by Alkaline Desorption

P. Van Aken*, N. Lambert*, R. Dewil*

*KU Leuven, Department of Chemical Engineering, Process and Environmental Technology Lab, Jan Pieter De Nayerlaan 5, 2860 Sint-Katelijne-Waver, Belgium, raf.dewil@kuleuven.be

Abstract: In general, phosphorus (P) is considered as an essential and limiting source of which reuse should be promoted. Agriculture water flows, e.g., drainage water, contain phosphate amounts of unused fertilisers above the standard limits for surface water sources. As end-of-pipe technology, adsorption processes have already showed high potential and efficiency to retain phosphate before discharge. In this study, both regeneration of the saturated sorbents and recovery of phosphorus are the main objectives. A desorption process using alkaline solutions is proposed without harming the sorbent grains. Alkalinity and contact time were varied to obtain optimal process conditions. Considering the investigated process conditions, the highest desorption efficiency, i.e., 60%, was achieved by using a NaOH-solution of 0.1M and a contact time of 48h. In a further stage, the recovery of the phosphate as a precipitate will be investigated.

Keywords: Phosphate adsorption; iron coated sand; drainage water

INTRODUCTION Despite preventive measures and a strict policy, regions with intensive agriculture still have high concentrations of nitrogen (N) and phosphorus (P) in surface water. This leads to algal blooms in our streams, streams and rivers and even off our coasts. Curative steps are needed to improve the situation. This can be done, for example, by applying filter technology to agricultural water flows (e.g. discharge and drainage water). The stricter legislation on fertilisation has not ensured that the water quality in Flanders meets the European standards of 11.3 mg N/L and 0.1 mg P/L. To capture the phosphorus in the drainage water, an adsorption technology using Iron Coated Sand grains is proposed. These grains are a side product of the local drinking water company Pidpa and produced during the deferrization of groundwater. The potential of the ICS granules to adsorb phosphate from municipal wastewater on laboratory scale was already demonstrated by Moelants et al. (2010). Since P is a critical raw material for which supply security is at risk and economic importance is high, it is essential to recover and reuse the P adsorbed on the filter materials.

The main objective of this study is to integrate the filter granules in a circular process. The desorption process of the ‘captured’ phosphates from the grains is investigated. Ideally, the desorption process should be achieved without damaging the pellets, so that the filter material can also be reused as adsorption material. Therefore, an alkaline desorption solution based on NaOH is used to recover P. Process parameters such as the concentration of NaOH and contact time were varied and the purity of the obtained phosphate solution was evaluated. In a further stage, the precipitation of the phosphorus as a phosphate salt will be investigated. The possible presence of impurities can hinder the precipitation process.
MATERIAL AND METHODS The ICS granules are derived from rapid sand filters used for the deferrization in the production of drinking water from groundwater. 5g of pre-dried saturated adsorption material is contacted with 100 mL NaOH-solution (1M, 0.1M, 0.01M & 0.001M) in stoppered sample flasks, resulting in a S/X ratio of 1/20. The desorption experiments are performed at room temperature under constant motion by a horizontal shaker at 100 movements per minute. Afterwards, the solution is separated by the solid materials by decantation and filtered on a 0.45 µm filter prior to phosphate analysis. The residual concentration of phosphate after extraction is determined by ion chromatography. Also, the release of iron or other impurities, as well as the grain structure (SEM), are investigated.

RESULTS The influence of the NaOH concentration and the desorption time on the release of phosphorus is shown in Figure 1.1. By increasing the contact time between the desorption solution and the saturated sorbent, more phosphorus was released from the sorbents. The increased P release at longer desorption times was observed for all investigated NaOH concentrations. However, significant higher P release was noticed by increasing the NaOH concentration. After a contact time of 48 hours, a P release of 0.01, 0.31 and 3.59 mgP/g sorbent was measured at 0.001M, 0.01M and 0.1M NaOH-solution, respectively. Knowing the saturation concentration, i.e., 6 mgP/g sorbent, approximately 60% of the adsorbed P was desorbed at 0.1M NaOH-solution.

![Figure 1.1](image.png)

Figure 1.1 Effect of intermediate rest periods on the adsorption capacity of PO₄-P on the iron granules.

REFERENCES

Which Performance for a Combined C and N Valorisation in Anaerobic Digestion through Sidestream Ammonia Stripping?

F. Vedrenne*, J. Robert**, N. Baffaleuf*, A. Fourçans, J.A. Cacho Rivero*

*Veolia Recherche & Innovation, zone portuaire de Limay, 291 avenue D. Ducas, 78520 Limay, fabien.vedrenne@veolia.com

Abstract: Ammonium and ammonia are the ugly duckling of Anaerobic Digestion (AD) and need to be mastered. The impact of a sidestream stripping, to manage total ammonium nitrogen (TAN) content, on the performance of a mesophilic AD was studied. Daily stripping (55°C, partial vacuum with air) was performed over seven months to reduce the TAN content close to that of a control reactor fed with a lower nitrogen load. Enriching the feed by 35% in protein content produced 25% more biogas and liquid ammonium sulphate. Increasing more protein content in the feed, up to 12 gTN/L, led to the collapse of AD whatever the strategy used: microbiological adaptation or stripping of ammonia.

Keywords: Anaerobic digestion, ammonia stripping

Many solutions to avoid TAN inhibition exist. The stripping of the digestate is being developed as a sidestream positioning, particularly for manure (Yao et al, 2017) and biowaste (Zhang et al., 2017). Conditions varied about temperature, gas and chemicals used for the stripping. Very few data are available on the biological stress occurred by the condition of stripping. This work evaluates the performance of the AD of protein-rich substrates and compares the adaptation of biomass to the use of a sidestream vacuum stripping of ammonia.

Three mesophilic CSTR with 36 days HRT were fed with homemade protein-rich feeds based on 4 high protein feedstocks (18 to 91% on dry solids). Three periods are identified according to the total nitrogen (TN) loads (TN: 7-10-12 gN/L) and the use (wS) or not (woS) of the stripper. The stripping conditions consisted of a partial vacuum, thermophilic, with air, for 3 hours.

Over Period1 (P1), all three reactors were fed with the same mixture with a TN concentration of 7gN/L, in order to establish reproducibility, resulting on similar behaviour of TAN and VFA concentrations (Figure 1.1.A) as well as COD removal, pH and gas production (data not shown). Initial decrease and then increase in TAN up to 4 gN/L was induced by TN content of the feed to allow biomass to acclimatize. VFA only accumulated transitorily at the start of the reactors, validating this choice. The good reproducibility over Period1 and the lack of inhibition allowed starting the Period2 diversifying the operational conditions of each reactor.

Over Period2 (P2), the 1st increase in TN (up to 10 gN/L) was operated for 2 reactors. The sidestream stripper was started and kept steady the TAN content around 4.2 gN/L in reactor TN10wS although TN load was increased by 35% compared to
control reactor (TN7). The Reactor TN10woS gradually accumulated TAN up to 6.5 gN/L. Thus the stripping has steadily reduced the TAN content of the digester by 2 to 2.5 gN/L. The nitrogen mass balance (Figure 1.1.B) is closed with one third of TAN removed by stripping. Stripping condition applied up to 4% of the digester volume per day was safe for the biomass.

Period3 (P3), with upper TN load (up to 12 gN/L) and feedstock characterized by a higher ammonification rate, faced collapses in the performance of both reactors. Acclimation failed with TAN over 10 gN/L, free ammonia up to 0.7 gN/L and VFA up to 55 g/L. With the stripper, the reactor, with TAN at 5 gN/L, benefited from a one-month reprieve before its performance collapsed. Stripping of 8% of the digester volume per day extracted almost 50% of the TAN produced. But the condition of stripping, with quite high TAN content, was recognized as inhibitors of AD.

The impacts of the TAN content and of the stripping on the microbial population were evaluated through the combination of three approaches: F420 observations, cytometry and metagenomics analysis. F420 revealed a slow decrease of the Archaea methanogens (density and diversity) during P2 with and without stripping and whatever the TAN contents. Cytometry pointed out the lytic effect of the stripping with a decrease of cells entirety. High TAN content without stripping also had a lytic effect. Finally, metagenomics highlighted that without stripping, from P1 to P2, the Paludibacteraceae family became the most abundant bacteria. During P3, its content has been replaced by VFA-producers (Bacteroides, Lactobacillus) and methanogen content dropped. The implement of the stripping, to avoid TAN increase, did not significantly impact the microbial mapping from P1 to P2. During P3, an observation similar to that of the reactor conducted without stripping with the highest nitrogen load was performed.

In conclusion, the limits of the coupling of a stripping unit on an anaerobic digester are now defined and confirmed by a complementary process (AD performance) and microbiological approach.


Biomass from Treatment of Food and Beverage Effluents as Microbial Protein Source: Impact of Water Characteristics and Operational Parameters on Biomass Quality


* Siegfried.Vlaeminck@UAntwerpen.be, ** Maarten.Muys@UAntwerpen.be

Abstract: Biomass from aerobic heterotrophic bacteria (AHB) produced on effluents from the food and beverage industry, has potential as protein source in animal feed. The nutritional value and safety were analysed for AHB biomass from 25 treatment plants, not optimized for SCP production. A true protein content of 34±7% dry weight (DW) was observed, which varied notably between companies and within one company through time (up to 49% DW). Variability was also observed in amino acid profiles, which were dependent on process parameters. Additionally, protein content was positively correlated with nitrogen loading rate and negatively with sludge retention time (SRT), indicating that a design tailored towards protein production can increase biomass quality. Finally, safety was guaranteed for most contaminants, however, some pesticides and heavy metals exceeded the animal feed limits. In general, food industry AHB biomass presents a sustainable opportunity to replace traditional feedstuff.

Keywords: Resource recovery; industrial wastewater treatment; microbial protein

To ensure food security in a sustainable way, resource recovery and upcycling from waste streams towards high value single-cell protein (SCP) can provide an important strategy. SCP is the protein-rich, typically dried, biomass of microorganisms. Their near-perfect nutrient conversion efficiency and high volumetric biomass productivity rates, allow their production with a lower environmental footprint compared to conventional crops (Pikaar et al., 2017). Aerobic heterotrophic bacteria (AHB) constitute an important part of the microbial community in activated sludge from typical biological wastewater treatment plants (WWTP). Already in the 80s, AHB were highlighted as a potential protein source in animal feed (Vriens et al. 1989), potentially making nutrient cycling more efficient and generating revenue. However, a major challenge to market AHB as SCP is product consistency and the difficulty to reliably maintain a high protein content and desirable essential amino acid (EAA) profile, while guaranteeing that treated process-wastewater is meeting effluent regulations (Verstraete et al., 2016).

In this study, for the first time a systematic screening was performed of AHB biomass from 25 food processing companies (29 biological treatment units) belonging to the important food industries in Flanders (Belgium). The SCP biomass’ nutritional value, in terms of protein content, EAA profile, and safety was analysed and their relation to process parameters and wastewater characteristics was assessed.

The true protein content of AHB biomass ranged from 21 to 49% DW, of which the higher values can compete with conventional protein sources, e.g. soybean meal (Figure 1.1 (A)). Furthermore, no significant differences in protein content were noticed between different food producing sectors. In terms of EAA profiles expressed
per gram of protein, the sampled AHB biomass is promising with favourable levels of threonine and valine (Figure 1.1 (B)). However, when expressing EAA per biomass dry weight, except for threonine and valine, a deficit was observed compared to soybean meal, mainly due to the lower average AHB protein content of 34±7% DW, compared to the 41%DW true protein in soybean meal (Figure 1.1 (A,C)).

![Figure 1.1](image)

**Figure 1.1** Average true protein, total (AA) and essential amino acid (EAA) content per industrial sector (A), with AA, the sum of non-EAA and EAA. Surplus in AHB biomass EAA content, compared to the content in soybean meal, both per g protein (B) as per g biomass dry weight (C) (the origin means ‘no difference with soybean meal’).

Even though this lower average AHB protein content compared to soybean meal, the observed variability between companies and in one company over time demonstrates potential for process optimization. Indeed, multi-linear regression analysis between biomass nutritional characteristics and WWTP process parameters and processing effluent characteristics, revealed a positive correlation between AHB protein content and biomass specific nitrogen loading rate and a negative correlation with sludge retention time (SRT). This observation paves the way to high-quality protein production through modifying current treatment processes for industrial effluents, resulting in a feed-grade AHB biomass that is on par with soybean meal. These modifications would require systems such as the high-rate activated sludge process applying short SRT in combination with a sufficient biomass-specific N availability. Finally, biomass safety was guaranteed in most AHB in terms of polycyclic aromatic hydrocarbons and antibiotics, however some heavy metals and pesticides exceeded regulatory limits, requiring their elimination from the production process.

Overall, AHB biomass from the food and beverage industry was confirmed as promising sustainable alternative for conventional high-protein animal feed ingredients, switching from carbon and nutrient removal to resource recovery and upgrading. Biomass nutritional value in a broad selection of companies was mapped, while variability over time was assessed for the first time. Most effective design parameters were identified enabling smart process design, increasing biomass quality.

**REFERENCES**


Recovery of the Iron-Phosphate Mineral Vivianite from Anaerobically Digested Sewage Sludge Using Magnetic Separation

W. Wijdeveld*, T.Prot, L. Korving, P. Kuntke, J, Grunig,
* Wetsus, European Centre Of Excellence for Sustainable Water Technology, Oostergoweg 7, 8911 MA, Leeuwarden, The Netherlands, wokke.wijdeveld@wetsus.nl

Abstract: Vivianite (Fe(II)₃(PO₄)₂·8H₂O) is the prevalent iron-phosphate mineral that forms during anaerobic digestion of sewage sludge. Provided that enough iron is present, 70-90% of the total phosphorus can be bound in vivianite. Vivianite is paramagnetic and can be recovered by proven magnetic separation methods that are used in the mining industry. Separation of vivianite was tested on sludge from four different WWTPs using a high gradient magnetic separator. These bench-scale tests demonstrated recoveries of 60-80% of vivianite. The produced concentrate has a vivianite content of 80-90%. Knowledge obtained on the effect of operational parameters on the separation efficiency will be used for optimization of the pilot-scale installation, which is being tested at WWTP Nieuwveer since November 2018.

Keywords: Phosphorus recovery; Vivianite; Magnetic separation

INTRODUCTION Phosphorus (P) is removed from urban wastewater to prevent eutrophication. Phosphate is a critical raw material for food production and countries in Europe are starting to implement legislation demanding P-recovery from sewage sludge. Iron (Fe) is commonly dosed in the treatment process to bind the phosphate. Vivianite (Fe(II)₃(PO₄)₂·8H₂O) is the prevalent iron-phosphate that forms during anaerobic digestion, provided that enough iron is present. 70-90% of the total phosphorus can be bound in vivianite. (Wilfert, 2018) Vivianite is paramagnetic and can be recovered by proven magnetic separation methods that are used in the mining industry. By recovering vivianite from sewage sludge water authorities can comply with phosphate recovery legislation, recover valuable iron and significantly decrease sludge disposal costs.

MATERIAL AND METHODS Sludge from four different waste water treatment plants (WWTPs) in Europe were tested using the SLon-100 magnetic separator. The locations of the WWTPs are in Espoo (FI), Rotterdam (NL), Breda (NL), and Cologne (DE). The sludge samples differed in properties such as dry solids content, viscosity, vivianite content, sludge type and quality.

The Slon-100 is a test unit for High Gradient Magnetic Separation (HGMS). This machine can perform batch-wise separation testing. In a HGMS, by placing a matrix of steel rods in a high intensity magnetic field, many points of high magnetic field
gradient are created which attract the paramagnetic vivianite particles. (Wills & Finch, 2016)

A rectangular rod matrix is placed inside an adjustable magnetic field of up to 1T. A steady flow of water is created over the matrix. Furthermore, pulsation is achieved with a diaphragm acted on by a motor which causes particle dispersion and increases separation efficiency. A sludge sample is fed to the top of the machine, and the sludge is carried over the matrix by the water flow. The magnetic particles stick to the matrix while the non-magnetics are carried out at the bottom of the machine and are collected in a bucket. After about 5 minutes, the water coming out of the bottom is clear and no non-magnetic are coming out. The water flow is then stopped, the magnetic field is turned off and the magnetic fraction is flushed out in a different bucket.

Separation efficiency in terms of recovery and grade (content) was determined by ICP-OES analysis of the elements Fe and P.

RESULTS AND CONCLUSIONS In Table 1.1 the separation results are given in terms of P- and vivianite recovery. These bench-scale tests demonstrated recoveries of 60-80% of vivianite, without any pre-treatment of the sludge or optimization of the separation process. Phosphorus grades of 9-11% were reached in the concentrate (maximum achievable grade (pure vivianite) is 12.35 % P), which corresponds to 80-90% vivianite content. The resulting P recovery depends on the percentage of total P that is bound in the form of vivianite.

<table>
<thead>
<tr>
<th>Sludge source</th>
<th>P recovery max</th>
<th>Fe:P molar ratio</th>
<th>P bound to vivianite (Wilfert 2018)</th>
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<td>29%</td>
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</tr>
<tr>
<td>Nieuwveer</td>
<td>22%</td>
<td>0,74</td>
<td>25-40%</td>
<td>55-88%</td>
</tr>
</tbody>
</table>

The effect of operational parameters on the separation efficiency was investigated. For example, increasing the magnetic field strength results in an increased vivianite recovery and a lower concentrate grade. The opposite will occur when the magnetic field strength is decreased. This knowledge will be applied to optimize the pilot-scale separation process which is being tested at WWTP Nieuwveer since November 2018. This pilot-scale separator can process up to 1 m³ of sludge per hour.

REFERENCES

Investigation of Recovery Potential of Rare Earth Elements from Secondary Sources by Membrane Separation Techniques

A. Yukselkday*, B. Kose-Mutlu**, M.R. Wiesner***, I. Koyuncu****

* Prof. Dr. Dincer Topacık National Research Center on Membrane Technologies (MEM-TEK) & Environmental Engineering Department, Istanbul Technical University, Istanbul, Turkey, yuksekdaga@itu.edu.tr

** Prof. Dr. Dincer Topacık National Research Center on Membrane Technologies (MEM-TEK), Istanbul Technical University & Yeditepe University, Faculty of Engineering, Civil Engineering Department, Istanbul, Turkey, borte.kose@yeditepe.edu.tr

*** The Center for the Environmental Implications of NanoTechnology (CEINT), Duke University, Durham, NC, USA wiesner@duke.edu

**** Prof. Dr. Dincer Topacık National Research Center on Membrane Technologies (MEM-TEK) & Environmental Engineering Department, Istanbul Technical University, Istanbul, Turkey, 

Abstract: Rare earth elements (REE) is a group of elements involves lanthanides, scandium and yttrium have similar physical and chemical properties which make more difficult to separate each other. In parallel to increasing demand to these crucial elements, interest in the recovery techniques from secondary sources becomes even more important. Membrane separation technique stands out as a green technology for REE recovery. For this purpose, boron mining wastewaters and wastes were utilized to recover REEs.

Keywords: Rare earth elements; recovery; membrane separation

Rare earth elements (REE) is a group of elements involves lanthanides, scandium and yttrium. They are called as “Rare Earth Elements” because most of them were originally isolated in the 18th and 19th centuries as the oxides from rare minerals (Emsley, 2001). REEs have various important uses and applications, which make REEs more essential. REEs provide unique spectroscopic and magnetic properties and are needed for a wide variety of products such as catalysts, hybrid vehicles, rechargeable batteries, mobile phones, plasma televisions, disk drives, catalytic converters and fluorescent lamps. The industrial demand for rare earth metals is increasing (Massari and Ruberti, 2013; Tunsu et al., 2014). Since the mining of REEs is difficult and has some economic and environmental disadvantages, recovery from wastewater originated from mining industry a good alternative with its proven REE potential (Borra et al., 2015; Protano and Riccobono, 2002; Verplanck et al., 2004; Zhang et al., 2010; Binnemans et al., 2013). In addition, membrane processes like nanofiltration (NF) and supported liquid membrane (SLM) have been successfully used by researchers to recover REEs from mixtures (Ramakul and Pancharoen, 2003; Prakorn et al., 2005; Murthy and Gaikwad, 2013).
The aim of this study was to execute the REE potential of waste and wastewater and recover REE by membrane separation techniques. These wastewater and waste were supplied from a boron mining plant in Turkey. A microwave digestion system was applied to prepare acidic leaches of solid samples. REE and major element concentrations of these sources were determined by ICP-MS and ICP-OES, respectively. Precisely REE containing acidic leaches and wastewater were concentrated by nanofiltration (NF) process while treating wastewater before supported liquid membrane (SLM) experiments. REE concentration in the feed and permeate phase for NF process and feed and strip phase for SLM process were determined by ICP-MS. Comparison of economic analysis for REE recovery from waste and wastewater should also be investigated.

ACKNOWLEDGEMENT This study was financially supported by The Scientific and Technological Research Council of Turkey (TUBITAK) (Project no.: 117Y357). Authors would like to thank Geochemistry Research Laboratory for XRF analysis.

REFERENCES


Pilot Scale Production of Biological Polyhydroxyalkanoate (PHA) from Cheese Whey for Food Packaging Applications

Carlos Zamalloa*, Lutgart Stragier**, Jeroom Saelens***, Mariane Van Wambeke****, Monica Carvalheira***** Mariane Van Wambeke*****, Maria Reis****** and Willy Verstraete*******.

* Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium, carlos.zamalloa@avecom.be
** Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium, lutgart.stragier@avecom.be
*** Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium, jeroom.saelens@avecom.be
**** Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium, mariane.vanwambeke@avecom.be
***** UCIBIO-REQUIMTE, Department of Chemistry, Faculdade de Ciências e Tecnologia | Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, mic16141@fct.unl.pt
****** UCIBIO-REQUIMTE, Department of Chemistry, Faculdade de Ciências e Tecnologia | Universidade Nova de Lisboa, 2829-516 Caparica, Portugal, amr@fct.unl.pt
******* Avecom NV, Industrieweg 122P, 9032 Wondelgem, Belgium, willy.verstraete@avecom.be

Abstract: Cheese production generates significant amounts of cheese whey wastewater that requires proper valorization. A way of valorizing this industrial side stream, which is highly rich in organics, consist of producing bioplastics such as polyhydroxyalkanoate (PHA). Within the EU-funded YPACK project, an innovative approach of producing PHA-based packing materials will be demonstrated using cheese whey as substrate. A pilot-scale plant was designed and built to evaluate the feasibility of the production of microbial PHA from cheese by implementing fermentation, selection (by applying feast-famine strategy) and accumulation steps. With this integrated approach, it was possible to produce at pilot-scale a microbial biomass rich in PHA with a volumetric productivity of about 1.5 kg CDW/m³.day with a concentration of more than 40% of PHA. This experience shows that there is a high potential of producing biomass rich in PHA from a complex feedstock such as cheese whey. The pilot scale production opens perspectives for elaborating novel implementations of cell biomass rich in PHA.

Although cheese whey contains a high concentration of organic matter, nutrients and minerals, there is a lack of resource recovery focused valorization. Typically cheese whey contains high levels of chemical oxygen demand (COD) up to 100 g/L, nitrogen between 0.2-2 g/L and phosphorus between 0.1-0.5 g/L (Prazeres et al., 2012). Clearly, this substrate has potential for valorization.

Due to the rapid accumulation of plastic waste there is an increasing demand to valorize waste streams such as cheese whey to renewable plastics such as polyhydroxyalkanoate (PHA) via microbial accumulation. In particular the development of more sustainable packaging plastics is of importance due to packaging’s large impact on the environment. Only in the EU about 40% of plastic is used for packaging, accounting for approximately 20 million tons every year (European Bioplastics 2019).

To tackle this problem, a 3-year-long, EU-funded project is aiming to develop and to demonstrate a holistic approach for packaging solutions based on PHBV layers. Within
this project, a 7 m³ demonstration pilot plant was constructed and operated using cheese whey to produce microbial based PHA. The plant process approach consisted of three steps (Figure 1.1); (i) the anaerobic fermentation of cheese whey to produce short chain fatty acids followed by (ii) the selection of PHA accumulation micro-organisms separating the feast from famine stages and (iii) subsequently, subjecting the biomass to a PHA accumulation batch process to produce a microbial biomass rich in PHA.

The anaerobic fermentation process was carried out in a 2 m³ reactor operated in a sequential batch reactor (SBR) mode with a hydraulic retention time (HRT) of 1 day and a volumetric loading rate of 15 kg COD/m³.day. The short chain volatile fatty acid (VFA) produced was stored in a vessel and used in the culture selection and PHA accumulation process. The culture selection was carried out in a 2.5 m³ reactor operated in SBR mode with a feast/famine ratio between 0.2-0.3 in cycles of between 12-24 hours. The microbial biomass used in the selector reactor was carefully selected by Avecom in order to allow the development of a specialized microbiome capable of accumulating PHA. As a final step, the biomass produced in the culture selection process was inserted in the PHA accumulation reactor with a maximum volume of 2.5 m³ for a batch accumulation process. This process consisted of providing different short pulses of VFA rich effluent produced from the anaerobic fermentor using the same conditions as in the culture selection process.

Overall, the biomass productivity in the culture selection reactor was between 1-1.5 kg CDW/m³.day. The PHA accumulation process produced a biomass with a PHA concentration above 40% and a protein concentration of between 30-40%. The major challenge for PHA production is to decrease the overall production cost. The prices of PHA reported in literature are about 3-4 times higher than fossil based polymers such as PP and PE (Prazeres et al., 2012). However the potential for the industrialization of PHA-based plastic is enormous since the PHA market is expected to reach US$93.5 (EUR 82.5) million by 2021 (Markets and Markets 2017).

ACKNOWLEDGEMENT
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REFERENCES
Coupling Effect of Natural Magnetite and Microwave for the Activation of Persulfate in P-Nitrophenol Removal

G. Zhang*, L. Hu**, P. Wang***

*School of Environment, Harbin Institute of Technology, Harbin, 150090, China, gszhanghit@gmail.com
**School of Environment, Harbin Institute of Technology, Harbin, 150090, China, hlmmayday@163.com
***School of Environment, Harbin Institute of Technology, Harbin, 150090, China, pwang73@vip.sina.com

Abstract: Natural magnetite (Fe₃O₄) and microwave (MW) irradiation were applied to activate persulfate (PS) for the degradation of p-nitrophenol (PNP). The characteristics of natural magnetite were systematically analyzed with the aid of X-ray diffraction (XRD), scanning electron microscopy (SEM) and vibrating sample magnetometry (VSM). The Fe₃O₄/MW/PS system showed a high degradation efficiency for PNP (94.2%) within 28 min, which was better than the efficiency of the conventional heating (CH) mode and the MW/PS system at the same reaction temperature. In addition, the active radicals during the degradation process were confirmed to consist of a majority of SO₄•⁻ and a minority of •OH through quenching experiment and electron paramagnetic resonance. Then, the specific Fe₃O₄/MW/PS system investigated herein might open a new path for wastewater treatment.

Keywords: natural magnetite; persulfate; microwave

Water pollution and the scarcity of water resources have become the main factors that restrict global urban construction and economic development. PNP is widespread usage as an important intermediate in the industrial manufacturing of petrochemicals, pesticides, pharmaceuticals, etc. However, because of its high toxicity, persistence and nonbiodegradability, PNP has been considered as a propriety pollutant (Eichenbaum et al. 2009). Sulfate radical-based advanced oxidation processes (SR-AOPs) have attracted increasing attentions due to the high and rapid oxidative capacity of sulfate radicals. In general, PS could be activated to generate sulfate radical with the addition of heating, transition metals, etc. However, their activated capacity was too limit to eliminate the organic pollutant in water. Natural magnetite is one of the abundant mineral resources on earth, which could offer the transition metal source in SR-AOPs. In addition, microwave was introduced due to its unique microwave effect for heating and improvement of the reaction rate.

Magnetite was subjected to a simple pretreatment with water for three times under ultrasonic bath for 2 min to remove impurities from the samples. The degradation process was performed in a microwave reactor with three-neck round flask. In each run, 100 mL of PNP (20 mg L⁻¹) with a certain amount of PS were added into the flask, followed by the addition of pretreated magnetite. The degradation processes started when the temperature increased to the designed level under mechanical stirring.
The characteristics of natural magnetite were analyzed with XRD, SEM, VSM equipment, and the results are shown in Figure 1.1. Clearly, the major diffraction peaks at $2\theta$ matched well with the standard card of 19-0629 and implied that it belong to magnetite. In addition, the morphology of natural magnetite is shown with an irregular rock-like shape. The hysteresis loops demonstrated that the natural magnetite was ferromagnetic in behaviour with a high saturation magnetization value of 81.1 emu·g$^{-1}$, which implied that the sample could be easily separated from solution with the help of a magnet.

![Figure 1.1 XRD pattern (a), SEM image (b), magnetic hysteresis loops (c) of natural magnetite.](image)

In addition, the degradation efficiencies with several conditions were constructed as shown in Figure 1.2a. The degradation efficiency of Fe$_3$O$_4$/MW/PS system reached up to 94.2%, which performed much higher than the rest of the three systems, including MW/PS, Fe$_3$O$_4$/CH/PS and CH/PS. This result meant the coupling effect was performed well in the Fe$_3$O$_4$/MW/PS system. Furthermore, the quenching experiment was carried out to explore the possible active radicals in the system. As shown in Figure 1.2b, the degradation efficiency decreased from 94.2% to 22.6% when increasing the concentration of methanol (MeOH), which is far more distinct for the decrease tendency of the quenching experiment with tert-butyl alcohol (TBA). This result illustrated that MeOH could inhibit the degradation efficiency of PNP, which meant SO$_4$•$^-$ was the dominant species in the system. From Figure 1.2c, definitive peaks of DMPO-OH and DMPO-SO$_4$• (Liu et al. 2017) were found, which confirmed the generation of SO$_4$•$^-$ and •OH in the present system.

![Figure 1.2 Degradation efficiencies of PNP in different systems (a), in quenching experiments with the Fe$_3$O$_4$/MW/PS system (b), and EPR spectra of DMPO trapping in various systems (c). Reaction conditions: [PNP] = 20 mg·L$^{-1}$, [PDS]/[PNP] = 15/1, T = 80 (300 W), [Fe$_3$O$_4$] = 2.5 g L$^{-1}$.](image)

**REFERENCES**


L. Zlatanovic***, O. Bailey***, J. Hofman***, J. Vreeburg****, M. Blokker******, J.P. van der Hoek******

*Sanitary Engineering, Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology, P.O. Box 5048, 2600GA Delft, Netherlands
**Amsterdam Institute for Advanced Metropolitan Solutions, Kattenburgerstraat 5, 1018 JA Amsterdam, Netherlands
***Water Innovation & Research Centre, Department of Chemical Engineering, University of Bath, Claverton Down, Bath, BA2 7AY, UK
****Evides Water Company, Schaardijk 150, 3063 NH Rotterdam, Netherlands
*****KWR Watercycle Research Institute, P.O. Box 1072, 3430 BB Nieuwegein, Netherlands
******Water Cycle Company, Korte Ouderkerkerdijk 7, 1096 AC Amsterdam, Netherlands

Abstract: The design requirements of contemporary engineered urban water cycle have been historically based on public health, comfort, and physical safety. This approach has led to the linear arrangement of the urban water cycle, in which little or even no attention has been paid to the resource recovery concept and closing urban cycles. The emerging need for closing urban water cycles requires a paradigm shift towards reduced drinking water use and generation of concentrated and small wastewater flows which are fit for optimal resource recovery and reuse. This research presents the development and validation of an integrated model for drinking and wastewater transport systems. The model utilises stochastic flow patterns to accurately represent the system dynamics. This integrated model will be used in forthcoming simulations to predict the changes in drinking and wastewater hydraulic and quality parameters which result from implemented resource recovery and water conservation strategies.

BACKGROUND AND PROBLEM STATEMENT The concept of the engineered urban water cycle is more than a hundred years old. It consists of three separate domains: drinking water supply (production, transport and distribution), sanitation (wastewater collection, treatment and disposal) and stormwater management. Historically, this concept has been linearly arranged and has been predominantly based on comfort, public health and physical safety requirements. As such, an adequate consideration for resource recovery within the urban environment has not been a part of the design. Awareness of depleting natural resources has attracted attention worldwide to the lack of circularity in handling natural resources in the urban environment. Therefore, the engineered urban water cycle must be comprehensively reconsidered as an enabler for the circular economy approach and explored for opportunities to recover resources. Harvesting these opportunities, however, will have a huge impact on the collection and transport of waste- water in urban areas and also on the conventional drinking water demand and supply. Rethinking the design and operation of urban water transport systems in the technical context is the core challenge for a sustainable system to recover and reuse resources on a large scale in the urban environment.
METHODOLOGY AND RESULTS This research deals with the development and validation of an integrated model of drinking and wastewater transport systems. This model will be used in forthcoming simulations to understand changes in drinking and wastewater hydraulic and quality parameters which result from the implemented resource recovery and water conservation strategies. Hydraulic drinking water and sewage modelling was conducted using InfoWorks software (Innovyze Ltd, Oxfordshire). InfoWorks WS Pro package was applied for the simulation of drinking water networks while InfoWorks ICM package was used for the simulation of sewer networks in a neighbourhood of Amsterdam, Prinseneilend. The input loading, in terms of demand patterns per household, were generated and incorporated in the model by stochastic water demand model SIMDEUM®. The development of the integrated model has started in mid-January. Early results, shown in Figure 1, indicate that the model is able to accurately forecast the diurnal patterns of both drinking water use and sewage water generation at a household level. A one hour delay between the measured and modelled flows was observed in the morning hours, which can be attributed to the different water consumption behaviours of end-users in the neighbourhood of Prinseneilend. The influence of the resource recovery and water conservation strategies on a household scale will be incorporated in the integrated model in the period March – June.

SIGNIFICANCE OF THE RESEARCH The approach of closing cycles in urban areas is essential to make the transition to a circular economy. The urban water cycle plays an important role as it can integrate water-material-energy flows. However, most resource recovery and reuse alternatives require a new design for urban water infrastructure in order to take full benefit of these options. The final results of this research will be a set of guidelines for the design and operation of a new water transport concept for the urban water cycle. This concept will enable resource recovery, and provide a transition strategy for the period in which the contemporary system and the new system co-exist. Given the worldwide focus on sustainable development, in which circular cities, resource recovery and closed cycles are crucial aspects, the outcomes of the current research may provide a baseline framework for designing and operation of a new generation - resource recovery based urban water transport systems.

![Figure 1.1 Measured and modelled diurnal patterns of drinking and sewage water](image)

REFERENCES


Abstract: The effort to upgrade urban WWTP into bio-refineries capable to recover and produce valuable resources is hindered by the fact that technical, economical and environmental impact analysis are complex and time expensive. In the present work, we present a Decision Support System (DSS) that finds an optimal configuration of a WWTP given a set of resource recovery unit processes. For the case study, we consider seven innovative technologies that are tested into the SMART-Plant H2020 project (No.690323). These technologies are modelled and integrated inside a plant-wide model superstructure. We show how the DSS evaluates all the possible plant configurations and how these configurations are sorted by a Multi-Criteria Decision Making (MCDM) method. Plant design optimization is done under dynamic inflow conditions that depend on the local weather history, sewer characteristics and effluent limitations, while sorting accounts for economic, effluent quality and environmental impact multi-criteria.

Keywords: DSS; wastewater; EBPR

In the last few decades, the wastewater treatment industry has experienced an outstanding rise in the variety of process technologies. Technology selection and benchmarking for plant retrofitting or new design have become more challenging than ever because of the large number of possible plant-designs for a given wastewater treatment problem. On top of this, politic initiatives that promote circular economy motivated the wastewater treatment sector to look for designs that could recover the most of resources from a wastewater stream while still meeting legislation limits. One of the reasons why new technologies for resource recovery are difficult to implement is that a benchmark analysis for a given case study could be very complex. This is a key barrier to their exploitation since it increases the risk aversion of water utilities in moving from conventional technologies to techs with embedded additional benefits from recovery of resources.

DSS tools proposed so far can be classified in two categories: DSS that help the decision maker with a plant design and DSS that improve the management and help to upgrade an existing plant (Guerrero et al (2011), Faria et al (2016), Solon et al (2017) and Torregrossa et al (2017)). For plant design, Comas et al (2003) and Garrido-Baserba et al (2012) proposed a DSS tool that uses a knowledge-based methodology. The main goal of their DSS was to reduce the number of possible plant configurations to a reasonable sub-set of options. Once the sub-set is available, computationally expensive wastewater treatment process design and selection can be performed. Bozkurt et al (2015) build a WWTP superstructure made of static process unit models, that use Mixed Integer (Non)linear Programming (MINLP) for optimal plant design. However, superstructure design optimization studies with dynamic ASM/ADM-type models are very rare. Rigopoulos and Linke (2002) build a superstructure based on the ASM1 model that finds an optimal activated sludge process design for a given constant inflow condition, while Guerrero et al (2013) benchmarked five types of enhanced biological
phosphorus removal (EBPR) configurations with design parameters selected from reference engineering guide-books. However, none of them included inside the study side-stream processes that are known to influence considerably the overall design of the plant.

In order to help water utilities to reduce their risk aversion against new wastewater treatment process units, we propose a DSS that performs an optimal design of hybrid continuous-discrete dynamic plant-wide models. In the following we describe shortly the DSS software architecture which is based on Python and Modelica object-oriented languages. Complex bio-process models are described in MS-Excel sheets, where after a stoichiometric mass balance check, are transformed to Modelica code thanks to a Python auto-code generation routine. Once the process unit models are available in Modelica, the user should build the predefined superstructure functional stages. A stage represents a section inside a WWTP where the goal of operation is common (e.g. pre-treatment, main-stream activated sludge, effluent refinement, side-stream sludge digestion, etc.). At that point, all the possible configurations for a plant-wide model are automatically assembled. OpenModelica simulation environment compiles and simulates the plant-wide model configurations, while post-processing, optimization and results visualization are done from Python. Post-processing consists in computing the multi-criteria index values and sorting the configurations with Order of Preference by Similarity to Ideal Solution (TOPSIS). Python optimization algorithms are employed for design optimization and batch-mode stage (process unit model) calibration. The advantage of automatically assembling independent plant configurations is that it allows computations to run in parallel. On the contrary, in a typical MINLP-type superstructure, connectors between process units are enabled or disabled to emulate a certain plant configuration. This means that there is one big model that is simulated where many dummy units waste computational power and is very difficult to run it in parallel. On the other hand, if configurations are build first-hand, the overall code compilation time is higher but single model configuration simulations run faster, they can run in parallel and ad-hoc solver options for each configuration could be set. Our DSS tries to build on the idea that reliable benchmark analysis of plant designs should be performed within dynamic influent conditions. This is why an influent wastewater model is coupled with the DSS. We take advantage of the E-OBS (Hofstra et al (2009)) weather databases of fine-gridded daily mean values, subsequently disaggregated into hourly values, in order to customize the influent wastewater model output in relation to the location of the plant design. It this way, it is possible to study the influence of local weather conditions on the performance of a plant design configuration.

The case study that we present here is the design of a WWTP bio-refinery that can be assembled from seven resource recovery process units tested during the SMART-Plant H2020 project (No.690323). Those units are a dynamic fine-screen and post-processing of cellulosic sludge (Tech1), a polyurethane-based anaerobic digestion biofilter (Tech2a), a Short-Cut Enhanced Phosphorus and PHA Recovery (SCEPPHAR, Tech2b), a tertiary hybrid ion exchange for N and P nutrients recovery (Tech3), a Short-Cut Enhanced Nutrient Abatement (SCENA) and ordinary digestion (Tech4a), SCENA and CAMBI-enhanced digestion (Tech4b) and a side-stream SCEPPHAR (Tech5). SCEPPHAR and
SCENA are sequential batch reactor technologies based on the ASM2d+N2O model proposed by Massara et al (2018). Tech2a and the digester are modelled by ADM1, modified for co-digestion of primary and waste sludge and for phosphorus release/precipitation. Tech3 is a batch process described with a continuous fixed-bed adsorption column model. The only static model is Tech1, where the TSS separation efficiency depends on influent TSS. In Figure 1.1 is represented the superstructure of the plant-wide model made of four stages. Stage1 could have a conventional primary settler (PS) or Tech1, while Stage2 could be empty or have Tech2a instead. Stage3 could be made of a conventional Anaerobic/Anoxic/Oxic system (A2O) or by the resource recovery process units of Tech2b and Tech3. Stage4 models the whole side-stream. Here the reference benchmark plant configuration is Stage1 with PS, Stage2 empty, Stage3 with A2O and Stage4 with a digester unit. Overall, 48 plant configurations are possible and the main goal is to sort them in relation to their economic, effluent quality and environmental impact performances. For Multi-Criteria Decision Making (MCDM), the Technique of Order Preference Similarity to the Ideal Solution (TOPSIS) will be applied.

Figure 1.1 WWTP superstructure model diagram.

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REFERENCES


Tools for a Circular, Integrated and Symbiotic Use of Water: The Project Ô

Y. Ballesteros Álvarez*, as a representative of the Project Ô Consortium

* Innovation Department, SOCAMEX (Spain): yballesterosa@socamex.com

Abstract: Circular economy is fundamental to guarantee access to resources in the long term, and water is the circular material for excellence. Nevertheless, current models for the management of water are mostly linear, involving acquisition from the source, use and dispose of. Furthermore, elements associated to water are frequently not taken advantage of. In order to foster circular economy, Project Ô (financed by Horizon 2020) addresses resource recovery from a holistic viewpoint, focusing on the recovery of water and elements associated to water through the use of innovative technologies. Project Ô aims to provide stakeholders with a toolkit for planning the use and recovery of water and associated elements for individual situations, at the same time enabling 30% savings in water consumption in industrial sites, as well as 50% energy savings for waste water treatment. The project foresees the implementation of 4 pilots in order to deliver flexible, modular, mobile and low cost systems.

Keywords: resources recovery; innovative water technologies; water re-use

In a context where circular economy is fundamental to guarantee access to resources for the population worldwide, water counts on one of the highest potentials to become the circular material for excellence. Many elements associated to water (e.g. nutrients or materials used to treat waste waters) are also potentially recoverable and reusable. Nevertheless, circular economy is still a very incipiently regulated concern, and many countries have not designed their strategies to match the Communication of the EC (2015) 614 on Circular Economy yet. Following Jeffries (2017), for the specific case of water, there is a need for rethinking water management under the lens of circular economy.

In such a scenario, it is not surprising that models for water management still comply with a linear design, where water is taken from the source, used, and finally disposed of. Other elements in close relation with water (e.g. embedded nutrients, or materials used at treatment plants), on their part, are rarely taken advantage of. The traditional linear model can frequently be found together with the usage of treatment facilities which have been developed for standard situations (instead of specific casuistry), or with the application of big and costly infrastructures.

As a response, Project Ô intends to develop combined solutions of innovative technologies (including HV nanosecond pulsed electric field and active carbon technologies) and management procedures that will enable a circular economy for water and other elements closely related, starting from a holistic perspective which considers water as the recoverable resource for excellence. Through Project Ô, different materials will be recovered, including (among others): 1) high quality water,
which will be reused for various purposes (for industrial processes, as drinking water, for irrigation, or others); 2) nitrogen, which will be recovered through algae production for biofuel; and 3) active carbon from the depuration process, through coupling with auto-regenerative systems. The solutions developed will be compatible with already-existing facilities, and will require low investment.

Besides, proper combinations of the tested technologies will contribute to reduce 30% water consumption in industrial sites, as well as 50% energy consumption associated to waste water treatment.

As a key action to achieve these objectives, the project foresees the implementation of four pilots at different scales, designed according to specific requirements of each demonstration site, in order to address particular, non-generic problems. Table 1 summarizes the specific challenge to be addressed by each pilot, together with the proposed technological solutions to apply to the site.

**Table 1.1** Challenges and opportunities detected in each of the four locations, according to specific local needs.

<table>
<thead>
<tr>
<th>Demosite</th>
<th>Place</th>
<th>Specific challenge to be addressed</th>
<th>Opportunity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Puglia Region (Italy)</td>
<td>Groundwater characterized by EOCs, microbial contamination and high saline content.</td>
<td>Mobile plant based on advanced oxidation and desalination will generate drinking water.</td>
</tr>
<tr>
<td>2</td>
<td>Eilat (Israel)</td>
<td>Water with high salinity, nitrate and microbial content for Oceanographic &amp; Limnological Research centre.</td>
<td>Mobile plant will produce denitrification, disinfection and desalination. Additionally, opportunities for nutrient recovery through algae production will take place.</td>
</tr>
<tr>
<td>3</td>
<td>Almendralejo (Spain)</td>
<td>Accidental spills affecting the WWTP.</td>
<td>Mobile plant based on advanced oxidation control and advanced control unit will timely detect spills and produce water reusable for watering. Active carbon from the depuration process will be recovered.</td>
</tr>
<tr>
<td>4</td>
<td>Croatia</td>
<td>Presence of non-biodegradable organic pollutants in industry (textile sector, pharmaceuticals).</td>
<td>Mobile plant based on advanced oxidation will enable water reuse for industry.</td>
</tr>
</tbody>
</table>

Besides the completion of the technical activities of the project, the implementation of actions to standardize models and technologies, and the creation of new business models, will contribute to improve the access to the market of the project’s outputs.

The project will deliver: 1) innovative water treatment technologies and control systems, which will be flexible, modular, mobile and with low operational costs; and 2) interfacing platforms for decision making; from a participative approach.

The project has an impact on two of the topics addressed by the IWARR 2019: Planning and implementation of next-generation resource recovery, wastewater treatment and sanitation infrastructure-global perspectives (as water, nitrogen and materials coming from the depuration process are recovered for reuse); as well as Cross sectoral links and value chains-enhancing sustainability for society (as the recovery of such materials will contribute to sustainability for society).

The project is financed by the European Commission through Horizon 2020, under grant agreement No. 776816.

**REFERENCES**


Jeffries, N. 2017 Applying the circular economy lens to water. *Circulate*, January 2017 (online article).
Soil Amendment Recovery of Calcite and Hydroxyapatite Mixture from Novel PCF Process in Wastewater


*217, Gajeong-ro, Yuseong-gu, Daejeon, Republic of Korea, lotus900515@nate.com
**283, Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do, Republic of Korea, wjkim1@kict.re.kr

Abstract: To remove phosphorus in wastewater, hydroxyapatite (HAP) crystallization filtration (PCF) process was suggested for phosphorus recovery and sludge utilization. PCF could remove phosphorus remarkably (over 84%) and achieve effluent standard stably in condition of pH 10.0 – 11.0, more than Ca\(^{2+}\) 80 mg/L and 1.8 – 3.0 m/hr of linear velocity. The sludge characteristics were studied by SEM-EDX and XRD. The atomic ratios of sludge indicated its main composition was calcite and HAP mixtures. Also, the formation yields of calcite could be estimated by carbonate alkalinity. Overall, PCF is suggested as a novel alternative to remove and recover phosphorus in wastewater and also sludge mixture of calcite and HAP from PCF is to be utilized as soil amendment resource.

Keywords: soil amendment; calcite; hydroxyapatite

INTRODUCTION In Korea, coagulation with aluminium coagulant is common process to remove phosphorus in wastewater for preventing growth of algae and eutrophication in lakes and rivers. But it generates excessive aluminium mixture sludge that is difficult to find an appropriate reuse. Therefore, hydroxyapatite (HAP) crystallization-filtration (PCF) is devised as an alternative solution for advanced phosphorus removal in wastewater. pH and Ca\(^{2+}\) should be adjusted in pre-treatment step. And then, HAP crystal is precipitated and crystallized on the surface of fixed seed materials. PCF generates sludge containing calcite and HAP in condition of high Ca\(^{2+}\) and dissolved carbonate. Calcite and limestone powder are commonly used as soil amendment for neutralization. In this research, optimal operating conditions and results of PCF pilot plant for wastewater were suggested. Also, sludge characteristics of PCF were reviewed as alternative soil amendment resource.

RESULTS The design parameters and operating conditions of PCF process with 20.0 – 100.0 m\(^3\)/day treatment capacity for wastewater effluent were shown in Fig. 1.1.

![Figure 1.1 Schematic diagram, design parameters and operating conditions of PCF process.](image-url)
The operating results (Jul. 2017 – Sep. 2018) of PCF pilot plant were shown in Fig. 1.2. Average effluent concentrations of T-P and PO₄-P indicated 0.13 and 0.06 mg/L respectively. About 84% of phosphorus had been removed as the form of crystal or sludge. Then, sludge was removed and accumulated in filtration bed.

![Figure 1.2 Operating results of PCF pilot plant during Jul. 2017 – Sep. 2018.](image)

The SEM-EDX analysis and XRD spectrum of sludge were shown in Fig. 1.3. Atomic ratios and XRD peaks of sludge indicated its main composition was calcite, HAP and brucite. Also, alkalinity changes for calcite formation were calculated in Fig. 1.3. More than 50 mg/L of CaCO₃ was generated from carbonate consumption.

![Figure 1.3 SEM-EDX analysis, XRD spectrum of PCF sludge, and alkalinity changes in PCF process.](image)

**DISCUSSION** PCF was suggested as an alternative phosphorus removal process for wastewater. In condition of pH 10.0 – 11.0, more than 80 mg/L of Ca²⁺ and 1.8 – 3.0 m/hr of linear velocity, a pilot plant of PCF was operated successfully. T-P effluent was stably achieved the standard of 0.2 mg/L for Korean water conservation areas. It was revealed that calcite and HAP crystal were main composition of backwashed sludge by EDX and XRD. Moreover, amount of calcite sludge could be estimated by carbonate alkalinity’s reduction. Considering high content of calcite and HAP in sludge, it could be suggested as soil amendment resource.

**ACKNOWLEDGEMENT** This research was financially supported by Korea Institute of Civil Engineering and Building Technology (KICT), project No. 2019-0151.

**REFERENCES**


Recovery of Phosphate from Wastewaters by Vivianite Crystallization: Nucleation and Growth Kinetics


*Beijing Key Laboratory for Source Control Technology of Water Pollution, Beijing Forestry University, Beijing 100083, China, xcheng@bjfu.edu.cn
**Water Research Center, School of Civil and Environmental Engineering, University of New South Wales, Sydney, NSW 2052, Australia

Abstract: Crystallization of vivianite (Fe₃(PO₄)₂∙8H₂O) is a promising approach to remove and recover phosphorus (P) from waste streams while this novel technology is currently far less understood compared to the crystallization of other widely studied phosphates. Crystallization kinetics is one of the major questions that need to be clarified for the real application of vivianite-based P recovery. In this work, we investigated the induction (primary homogeneous nucleation) and secondary nucleation of vivianite under different conditions. Two distinct correlations between induction time and supersaturation ratio ($S_a$) were found with the nucleation being highly $S_a$-dependent for a $S_a > 26$ while substantially less sensitive to $S_a$ when it was below that value. Secondary nucleation rate of vivianite linearly depended on relative supersaturation (σ) with a threshold σ of 24. High supersaturation increased vivianite crystallization rate but resulted in small particle sizes and a wider size distribution.

Keywords: Crystallization; vivianite; kinetics

Crystallization of phosphate as valuable products is a promising technology for the treatment of phosphorus (P)-rich waste streams as it not only removes P from the water for complying with the stringent discharge limit but also recovers P, which is an essential element for all living organisms yet depleting resource. Vivianite crystallization for P removal/recovery has received increasing attention recently because the extremely low solubility ($K_{sp}$: $10^{-37} – 10^{-40}$) of this mineral enables an easily occurring reaction and allows a low-level residual. Compared to struvite-based P crystallization with an optimal pH level of ~9, Liu et al. reported vivianite can form efficiently at pH 7, which is expected to substantially save the chemical cost as many waste streams are at circumneutral pHs. Regardless of the understanding achieved on vivianite formation thermodynamics, crystallization kinetics of this mineral has not been well clarified, which is, however, critical to develop a novel approach of P recovery based on vivianite crystallization, especially for its real application.

By jar tests, induction time of primary nucleation of vivianite was investigated at different supersaturation levels and secondary nucleation examined in a similar way but with seeds. Two distinct linear correlations between induction time and supersaturation ratio ($S_a$) was found for the primary homogeneous nucleation of vivianite. Induction time was highly $S_a$-dependent for a $S_a > 26$ while substantially less sensitive to $S_a$ when it was below that value (Figure 1.1). Secondary nucleation rate was closely correlated with relative supersaturation (σ) with a threshold σ of 24 (Figure 1.2). A high saturation index (SI), in the range of SI7 – 10,
increased the rate of vivianite crystallization but was not favorable to crystal growth as revealed by a reduction in particle size and a wider size distribution (Figure 1.3).

**REFERENCES**

Ammonia Recovery by Gas-Permeable Membranes Enhances Anaerobic Digestion of Swine Manure

I. González-García*, B. Riaño*, B. Molinuevo-Salces*, M. B. Vanotti**, M.C. García-González*

* Agricultural Technological Institute of Castilla y León (ITACyL) Ctra. Burgos, km. 19, 47071 Valladolid (Spain). Phone: +34 983317389. E-mail address: gargonmi@itacyl.es

**United States Department of Agriculture, Agricultural Research Service, Coastal Plains Soil, Water and Plant Research Center, 2611 W. Lucas St., Florence, SC, 29501, USA

Abstract: In this study, gas permeable membrane technology was used to capture ammonia (NH₃) during the anaerobic digestion (AD) process, eliminating one of the main inhibitors of the AD process. The results showed an improvement in the production of biogas from swine manure. The technology also captured nitrogen in the form of an ammonium salt that can be re-used as fertilizer.

Keywords: anaerobic digestion, gas-permeable membrane, ammonia capture.

In many European countries, anaerobic digestion (AD) process is widely used to treat manure. However, the inhibition of methanogens by high ammonia (NH₃) concentration in high-strength manure severely reduces the biogas production using AD process (García-González et al., 2015). A new technology based on gas-permeable membranes (GPM) has been evaluated for NH₃ recovery from manure and anaerobically digested effluents (Vanotti et al., 2015). In the present study, the influence of a GPM system, with the active capture inside an AD reactor, was evaluated both in terms of methane (CH₄) production and biogas composition. Ammonia recovery by the GPM system was also evaluated. For that, batch and semi-continuous AD of swine manure retrofitted with a GPM system were investigated and compared to a control treatment (i.e. anaerobic digestion of swine manure without ammonia recovery).

Two stirred tank reactors with a working volume of 2 L were used (Fig. 1.1): one reactor (R1) was used as a control treatment for AD of swine manure (without NH₃ recovery), and the other reactor (R2) was used for AD of swine manure coupled with a GPM system (with NH₃ recovery). Temperature was kept constant (38°C) in both reactors. The gas-permeable membrane used was tubular (hollow) made of e-PTFE material with a length of 53 cm, an outer diameter of 5.2 mm and a wall thickness of 0.56 mm. Membrane density was 0.95 g/cm³. An acidic solution (150 mL of H₂SO₄...
1N) was continuously recirculated through the inside of the tubular membrane using a peristaltic pump. The acidic solution was used as a trapping solution to recover NH₃ as (NH₄)₂SO₄ solution, which can be used as a fertilizer.

Two sets of experiments were carried out. The first one was a batch AD process, conducted in triplicate. The two reactors (with and without NH₃ recovery) were identically fed with swine manure with a substrate to inoculum ratio of 1:1 (g VS : g VS). Each batch anaerobic experiment lasted 10 days. In the second one, the same two reactors were fed semi-continuously with swine manure at an organic loading rate (OLR) of 2.4 g COD/L d, and at hydraulic retention time (HRT) of 7 d. Mean concentrations were 46.7 volatile solids (VS) g/L and 1.2 g total ammonia nitrogen (TAN)/L in the manure used for batch experiments and 7.4 g VS/L and 2.2 g TAN/L in the manure used for the semi-continuous experiment. The inoculum had a concentration of 16.3 g VS/L. In both experiments, biogas production was measured daily and biogas composition was analysed once per week. Acidic samples from the acid tank were collected daily to monitor pH and TAN concentration. In the batch AD, an increase of specific methane yield of 19% was observed in R2 with NH₃ recovery compared with R1 without NH₃ recovery (Table 1.1). Moreover, the biogas obtained in R2 had a higher percentage of CH₄ (78%) compared to R1 (60%). TAN in the acidic solution of R2 increased up to 540 mg at day 10 with an average TAN recovery rate of 6.33 ± 0.3 g/m² d (Fig 2.A). In the semi-continuous AD, CH₄ productivity in R2 was 106% higher than in R1. Average TAN recovery rate in R2 was 10.69 ± 0.06 g/m² d, with 1944 mg of TAN recovered on day 21 (Fig 1.2.B).

Table 1.1: Effect of the gas-permeable membrane system in AD of swine manure.

<table>
<thead>
<tr>
<th></th>
<th>Specific methane yield (mL CH₄/g VS)</th>
<th>Percentage of Methane (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R1</td>
<td>R2</td>
</tr>
<tr>
<td>Batch</td>
<td>66</td>
<td>77(2)</td>
</tr>
<tr>
<td>Semi-continuous</td>
<td>(11)</td>
<td>31(6)</td>
</tr>
<tr>
<td></td>
<td>15 (2)</td>
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</tbody>
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Figure 1.2: Mass of TAN captured during the experimental time in R2: A) Batch AD; B) Semi-continuous AD.

Results showed a great potential of gas-permeable technology to improve anaerobic digestion of swine manure while recovering ammonia from digester in form of an ammonium salt. This work could be included in the section "Next generation resource recovery - breakthrough technologies and value added products".

This study was supported by FEDER- INIA project: RTA 2015-00060-C04-C01 and project Life+ AMMONIA TRAPPING (LIFE15-ENV/ES/000284).

REFERENCES


Abstract: A metakaolin geopolymer containing 20% of waste from the granite industry was formulated and tested for its capacity to adsorb ammonium from wastewater in batch studies. Batch studies consisted of sets of 250 mL flasks containing known ammonium concentrations, where the effects of medium pH (6-8), adsorbent dose (0.2-15 g/L), influent concentration (10-400 mg/L) and contact time (1 min-24h) were tested while incubation in an orbital shaker at 22 °C. Preliminary results showed ammonium removal efficiencies up to 80% and a maximum adsorption capacity ($q_m$) of about 12 mg/g, being in accordance with literature results for the natural aluminosilicate zeolite. The use of new materials, with a high content of waste, as filter media to recover ammonium from high loaded nutrient effluents is a promising resource recovery technique promoting circular economy.

Keywords: Geopolymer; ammonium; adsorbent

INTRODUCTION

The discharge of nitrogen from untreated wastewater and wastewater treatment plants, as well as by industrial applications or diffuse agricultural pollution from the use of fertilizers to receiving water courses is a widely-recognized problem, since it triggers the eutrophication of water bodies. Eutrophication ends up in oxygen depletion and may potentially cause severe degradation of water quality, thus posing a serious threat to drinking water sources, recreational water bodies and the environment.

The most commonly used methods for ammonium nitrogen removal include biotechnology, breakpoint chlorination, air extraction, reverse osmosis, ionic exchange and sorption. Among them, ionic exchange and sorption have received increasing attention and great emphasis has been put on the development of efficient and cost-effective adsorbents generated from industrial solid waste (Luukkonen et al., 2016). Adsorption of ammonium in inert materials is a promising technique to recover nutrients and use them in agricultural purposes as fertilizers blended with other waste in a proper combination. According to FAO, world demand for total fertilizer nutrients is estimated to grow at 1.8 percent per annum from 2014 to 2018. The demand for nitrogen is forecast to grow annually by 1.4, during the period
MATERIALS AND METHODS In the current study, a metakaolin geopolymer was manufactured at low temperature (60 °C) using 20% of waste from the granite industry for its application on ammonium adsorption from wastewater. The material was crushed and sieved to obtain particle sizes of 4 - 8 mm. After washing, it was dried at +105 °C and desiccated. Batch experiments were carried out in 250 mL Erlenmeyer flasks using deionized water with known ammonium concentrations and geopolymer weights (generally for 24 h, pH = 6, 50 mg NH₄⁺/L and 5 g/L of geopolymer). The effect of variables was measured, including initial water pH (4, 6 and 8), adsorbent dose (0.2 to 15.0 g/L), contact time (from 1 min to 24 h) and initial concentration (10 to 400 mg NH₄⁺/L). Flasks were set at an orbital shaker in dark conditions under 22 °C.

Preliminary results (Figure 1.1) have shown a high sorption capacity of the geopolymer, obtaining removal efficiencies up to 80% and a maximum adsorption capacity (qₑ) of about 12 mg/g. This value is similar to that reported for natural zeolite by Luukkonen et al. (2016). Obtained results will be characterized with Langmuir, Freundlich, Langmuir-Freundlich and Tóth isotherms and to kinetic models to assess the best fitting of the data and obtain an idea of the mechanism involved in its adsorption.

![Figure 1.1 Adsorption of ammonium at various influent ammonium concentrations (Langmuir isotherm)](image)

Batch and column studies are envisaged with a high content ammonium leachate of a landfill using the geopolymer as sorption material to assess the scale-up of a filter system to pilot scale in a landfill facility to recover nutrients following a circular economy approach.

REFERENCES

Efficient Fertilizer Production from Urine – Separate Degradation of Organic Matter with a Membrane Aerated Biofilm Reactor (MABR)

A. Heusser*, B. Etter*, C. Doll*, K. Udert**

*Eawag, Swiss Federal Institute of Aquatic Science and Technology, Überlandstrasse 133, 8600 Dübendorf, Switzerland, aurea.heusser@eawag.ch
**Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland, and ETH Zürich, Institute of Environmental Engineering, 8093 Zürich, Switzerland, kai.udert@eawag.ch

Abstract: The VUNA process allows the production of an agricultural fertilizer from source separated urine. The nitrogen that is released to water bodies and the atmosphere in common WWTPs is captured with this process. Heterotrophic and autotrophic bacteria compete for oxygen and space to grow in the nitrification reactor where the urine is stabilized. An MABR is installed to degrade the organic matter in a separate treatment step and therewith enhance the overall process performance. The pH of 9 in stored urine inhibits the nitrifiers and allows a separation of the processes. The nitrification rate can be doubled using the MABR for the pre-treatment of urine. The long-term behaviour has to be monitored further because the biomass in the reactor decreases. Nitrogen losses are around 5% of the incoming nitrogen and could be recovered, reintroducing the off gas of the MABR as aeration for the nitrification reactor.

Urine contains most of the nutrients getting to the waste water treatment plant (WWTP). Decentralized treatment of source separated urine makes the recovery and recycling of nutrients possible (Fumasoli, Etter, Sterkele, Morgenroth & Udert, 2016).

The VUNA process converts source-separated urine into an agricultural fertilizer recycling the nutrients e.g. nitrogen. The nitrification stabilizes the urine followed by a granulated activated carbon column removing the micropollutants and a distillation reducing the volume and hygienizing the fertilizer (Fumasoli, Etter, Sterkele, Morgenroth & Udert, 2016). In the nitrification reactor, ammonia is oxidized by nitrifying bacteria via nitrite to nitrate and organic matter is degraded by heterotrophic bacteria. The different microorganisms compete for oxygen and space to grow.

For this study the VUNA process located in the pilot test facility Water Hub in the NEST building in Dübendorf was equipped with a membrane aerated biofilm reactor (MABR) for...
separate degradation of organic matter. The separation aims to support the following nitrification process by reducing the competition for space and oxygen by heterotrophic bacteria. A scheme of the process is shown in Figure 1.1. The MABR (Oxymem, Ireland) consists of gas permeable polydimethylsilocane tubes aerated with ambient air. On the outer surface of the tubes a counter diffusional biofilm forms. The oxygen is gradient regulated and energy for aeration can be saved using an MABR thanks to the high oxygen transfer rate compared to bubble aeration (Suzuki, 1993).

The operation of the MABR showed that the nitrifiers are inhibited at a pH of 9 present in stored urine. The COD removal depends on the residence time of urine in the reactor but COD removal over 70% was achieved at high flow- and loading-rates.

Figure 1.2 shows the nitrification rates when fed with urine and the effluent of the MABR. The feeding of the nitrification reactor with low COD loadings (MABR effluent) caused an immediate increase of the nitrification rate. This strong effect was observed only right after the change. The nitrification rate levelled at 130 mgNL⁻¹d⁻¹, being around 60 mgNL⁻¹d⁻¹ without the pre-treatment of urine as shown in Figure 1.2. It was observed that the biomass in the reactor decreased over time. This may be due to the lack of heterotrophic bacteria being important for the floc formation.

For the fertilizer it is essential to keep the nitrogen during the process, therefore the different sources of nitrogen losses are located and quantified. Sources of nitrogen losses include the scouring of the reactor, the sludge removal as well as the off gas of the membranes. The nitrogen losses generated by sludge removal and by the scouring are less than 1% of the incoming nitrogen and can therefore be neglected. The continuous loss of nitrogen generated by the ammonia diffusion into the gas permeable tubes is highly variable. The losses are found to be around 5% depending on the throughput of the reactor. The off gas of the membranes still contains about 17% oxygen, using the off gas for the aeration of the nitrification reactor would allow to recapture the nitrogen.

Our experiments show that integrating an MABR in the VUNA process can reduce the reactor volume by 17%. The power demand for aeration can be reduced by 20%. A further advantage is that the heterotrophic bacteria are more resistant to toxic shocks, the MABR could function as a pre-treatment in case of unexpected contaminants in the process.

REFERENCES

Reuse of Treated Wastewater as Technical Grade Water in Industrial Symbiosis

K. Hoyer*

*VA SYD, Sjölunda Wastewater Treatment Plant, Spillepengsgatan 15-17, Malmö, Sweden, kerstin.hoyer@vasyd.se

Abstract: Due to increased water stress and water scarcity and a wish for a more sustainable water management, reuse of treated wastewater is gaining interest also in Sweden. We have studied the interest and possibility to reuse treated wastewater from Swedish municipal wastewater treatment plants for industrial and agricultural use, focusing on the integration in the wastewater treatment plants.

Keywords: Water reuse; industrial symbiosis; technical grade water

Reuse of wastewater has long been discussed in the world. Lately, also in Sweden, a country with generally good water supply, reoccurring dry summers and local challenges of water supply have put the topic on the agenda.

Techniques to treat wastewater for reuse in different applications have been studied in general. In order to implement reuse of treated wastewater in industry and agriculture (for irrigation purposes), besides technical surveys and studies, business concepts based on the local conditions at different wastewater treatment plants are needed. In this project, eight municipal water and wastewater organizations in Sweden corporate to study which applications for wastewater reuse are interesting for industry and agriculture in connection to the participating wastewater treatment plants. This approach gives a better understanding of the potential for treated wastewater for different applications, mostly in symbioses between water and wastewater organizations and industry or agriculture. Interesting applications for industrial reuse of wastewater are identified and studied further. The focus on industrial symbiosis between the wastewater treatment plants and industry and agriculture leads to results which can be implemented in connection to wastewater treatment plants within the near future.

The project covers a compilation of the potential for reuse of treated wastewater in industry and agriculture, identification of treatment processes needed for the identified applications focusing on the integration in the wastewater treatment plants as well as an economic analysis. The results will be presented at the conference.
Investigation on Microbial Activity Response to Organic Loading Rates in Anaerobic Membrane Bioreactors Using Metagenomics and Metatranscriptomics Approaches

M.J. Lee*, H. Kim**, K.G. Song***, J. Park****

* Department of Civil and Environmental Engineering, Yonsei University., Seoul 120-749, Korea
amjay0629@yonsei.ac.kr

** Department of Civil and Environmental Engineering, Yonsei University., Seoul 120-749, Korea

*** Korea Institute of Science and Technology, Seoul 136-791, Korea

**** Department of Civil and Environmental Engineering, Yonsei University., Seoul 120-749, Korea
parkj@yonsei.ac.kr

Abstract: Anaerobic processes have the advantages compared to aerobic treatment in terms of resource recovery and energy efficiency in wastewater treatment plants. In this study, a novel anaerobic membrane bioreactor (AnMBR) with rotary disks and floating media was used to reduce electricity use in reducing biofouling formation. At laboratory scale, their treatment and biofouling control performances were examined in response to different organic loading rates (OLRs), and shot-gun metagenomic investigation was conducted to explore the effects of OLRs on the dynamics of microbial populations and genes in the AnMBR. As OLR was increased (0.53, 1.07, and 2.13 kg COD m-3d-1), net energy recovery via gas-phase methane was increased. In addition, the metagenomics response to the varying OLRs was investigated in the microbial communities in which Methanoseta was found to be the major methanogens, and methyl-CoM reductase was the most abundant gene in methanogenesis pathway.

Keywords: Anaerobic membrane bioreactor; methane recovery; microbial activity

Countries all over the world have recently paid attention on energy resource recovery from organic waste or wastewater. In the current wastewater treatment plants using activated sludge or its modified aerobic processes, electric power for air supply and stirring accounts for over 40% of the total power consumption. Not only to reduce the operational cost from aeration and sludge treatment but also to recover energy resources from wastewater organic matters, anaerobic process has been proposed to treat municipal wastewater treatment plants. Applying anaerobic membrane bioreactor (AnMBR) process to treat domestic wastewater has been suggested because it reduces maintenance costs, and also recovers energy from wastewater organics (McCarty et al., 2011; Smith et al., 2012). Notwithstanding the strengths of the AnMBR, membrane fouling has emerged as one of the biggest problems of AnMBR (Skouteris et al., 2012). To reduce energy consumption for biofouling control, a new AnMBR combined with a rotary disk and floating media was suggested (Kim et al., 2014). In our previous study, methane recovery and biofouling formation were examined in response to different organic loading rates (OLRs) to assess the applicability of the new AnMBR system in domestic wastewater treatment. As OLR was increased (0.53, 1.07, and 2.13 kg COD m-3d-1), net energy recovery via gas-phase methane was increased while biofouling formation was increased. In this study, It is identified which populations and genes are
involved in high methane conversion. The effects of different OLRs on the dynamics of methane-producing populations and genes were investigated using shot-gun metagenomics sequencing.

Samples were taken from Anaerobic membrane bioreactors with rotary disks and floating media operated with three different organic loading rates (2.13, 1.07 and 0.53 kg COD m-3d-1). Each sample was collected for DNA and RNA extraction. For metagenomics and metatranscriptomics investigation, metagenomics DNA fragments and RNA fragments from the reactors were sequenced by Illumina HiSeq 2000.

The results of shot-gun sequencing of microbial communities revealed that microbial population and functional gene compositions were more influenced by different OLRs than different habitats (suspended versus media-attached growth). In the archaea communities, the major genera member was Methanosaeta, and as the OLR increased, the relative abundance of Methanospirillum, Methanoregula and Methanofolis, which are hydrogenotrophic methanogenic archaea, also increased (Fig 1.1). The results of methanogenesis genes analysis showed that methyl-CoM reductase gene was the most abundant. The functional diversity result indicated that Methanoregula is the important species which involved in methane production. Microbial community analysis showed various changes, but there was no significant difference in microbial functional analysis results depending on OLRs and growth habitats.

Figure 1.1 Relative abundances of microbial communities in genus level.

REFERENCES


Interactions among Quorum Sensing, Microbial Communities and Granule Properties during Aerobic Granulation Induced by Low Organic Loading

A. Li*, H. Chen**, F. Ma***

*State Key Laboratory of Urban Water Resource and Environment, School of Environment, Harbin Institute of Technology, Harbin 150090, People’s Republic of China, li.ang@hit.edu.cn
**State Key Laboratory of Urban Water Resource and Environment, School of Environment, Harbin Institute of Technology, Harbin 150090, People’s Republic of China, chenhanhit@126.com
***State Key Laboratory of Urban Water Resource and Environment, School of Environment, Harbin Institute of Technology, Harbin 150090, People’s Republic of China, mafang@hit.edu.cn

Abstract: This study comprehensively investigated the formation mechanism of AGS fed with ammonium-rich wastewater at a low OLR of 0.15 kg COD (m³ d)⁻¹ and focused on quorum sensing (QS) and microbial communities. The results showed that the AGS appeared within 90 days, and the mature granular size was over 700 μm with strong settleability and ammonium removal ability. C10-HSL and C12-HSL gradually became dominant during the formation of AGS. EPS producers and autotrophic nitrifiers were successfully retained in the AGS under the low OLR condition. The contents of 3OC6-HSL, C10-HSL, C12-HSL, S-AHL and total AHL had strong positive correlations with PS, PN, EPS, the PN/PS ratio, granular size and settleability. The correlations of bacterial genera with AGS properties and AHL-mediated QS were complicated under low OLR. These results indicated the key formation mechanism of AGS under low OLR from the perspective of AHL-mediated QS.

Keywords: Aerobic granular sludge; quorum sensing; low organic loading rate

Aerobic granular sludge (AGS) is a promising technology for wastewater treatment due to its excellent settling property, small footprint demand and low operation costs. As a key influencing factor, the organic loading rate (OLR) has been proven to affect the formation and characteristics of AGS (Ni et al., 2009). AGS has been obtained at a wide range of OLRs. Nevertheless, the feasibility and granulation process of AGS under low OLR are rarely reported. Extracellular polymeric substances (EPS) play critical roles in bacteria aggregation and aerobic granulation. N-acyl-homoserine lactones (AHLs) secreted and sensed by Gram-negative bacteria have been reported extensively to regulate EPS secretion during aerobic granulation (Chen et al., 2018). However, the spatial and temporal distribution of diverse AHLs under low OLR is still rarely reported during the process of aerobic granulation. In addition, investigating the correlation of AHL-mediated QS with microbial community during aerobic granulation is rarely performed under low OLR. This study comprehensively investigates the formation mechanism of AGS fed with ammonium-rich wastewater at an OLR of 0.15 kg COD (m³ day)⁻¹ and focuses on the characteristics of QS and microbial community.

Obtaining a stable AGS with satisfactory settleability and ammonium removal ability at a low OLR of 0.15 kg COD (m³ d)⁻¹ is feasible, while the granulation
process is prolonged due to the lack of organic substrates. C10-HSL and C12-HSL are critical in AGS-mediated QS under low OLR. The low OLR affects the allocation of limited organics by regulating the diversity and composition of the microbial community, which favours the retention of EPS producers and autotrophic nitrifiers under harsh selection pressures. AHL-mediated QS regulates the EPS production with three AHLs including 3OC6-HSL, C10-HSL and C12-HSL. Autotrophic nitrifiers may perform interspecific communication with C10-HSL under low OLR. The correlations of bacterial genera with AGS properties and AHL-mediated QS are complex under low OLR in that the composition of the microbial community fluctuates dynamically, and many factors in the mixed-culture system may interfere with the AHL-mediated QS. The findings of this work may supplement the formation mechanism of AGS under low OLR from a microbial viewpoint.

Figure 1.1 Variation tendency of AHLs during aerobic granulation.

Figure 1.2 This is a style for Figure legends.


Assessment of the Alternative Sanitation Systems in Urban Environment – Case Hiedanranta in the City of Tampere, Finland

R., Malila*, S., Lehtoranta**, E.-L. Viskari***

*Finnish Environment Institute SYKE, riikka.malila@ymparisto.fi  
**Finnish Environment Institute SYKE, suvi.lehtoranta@ymparisto.fi  
*** Tampere University of Applied Sciences, eeva-liisa.viskari@tuni.fi

Abstract: The potential of wastewater nutrients are rarely utilized as resources. However, source-separation offers an option to recover nutrients effectively and more pure. Sanitation systems based on a vacuum toilet and urine-diverting toilet systems were compared to reference system with centralized wastewater treatment in Hiedanranta area. Multiple amounts of nutrients could be recovered with separating systems. At the same time both carbon footprint and eutrophication impact were reduced significantly. The results will be exploited in NutriCity project and in the planning of a practical implementation of a circular economy super block, a residential block, which aims to recover resources as efficiently as possible.

Keywords: nutrient recovery; wastewater; LCA

Recycling of nutrients is recognized as one of the key elements of the circular economy and is identified in several targets and programs globally. The diminishing global phosphorus reserves and highly energy intensive nitrogen fertilizer production has brought up the need to seek for more sustainable ways to use, reuse and produce fertilizers. In addition to various side streams from e.g. food industry, nutrients of the wastewater could be utilized for fertilizer production. Source-separation, i.e. separate collection of urine, feces and grey water from the households, offers an option to recover nutrients effectively and retain the fertilization characteristics of each fraction.

In Finland, approximately 4,000 t of phosphorus and 27,000 t of nitrogen are supplied to wastewater treatment plants (WWTP) annually. However, a major part of the nutrients is lost during the wastewater treatment process or transforms into poorly soluble form. At the same time, wastewater treatment process causes a significant carbon footprint, which could be reduced by lowering the need of e.g. nitrogen removal. In addition, industrial wastewaters affect negatively on the quality of the sludge produced in the WWTPs since they contain more hazardous substances than plain household wastewaters. Subsequently, WWTP sludge acceptance as agricultural fertilizer is low.

Utilization of source-separation of human excreta for the recovery of nutrients on an urban scale requires major structural changes in infrastructure and practices. However, in new residential areas it is easier to introduce novel technologies. Hiedanranta is a new residential area in the city of Tampere, Finland, which is opened
as an innovation platform for novel solutions of sustainable city development. The construction of the Hiedanranta begins in the next decade and there will be 25,000 inhabitants and 10,000 jobs. In order to evaluate alternative sanitation solutions for the area, a life cycle assessment (LCA) was carried out.

Source-separating toilet systems, including a vacuum toilet (A1) and urine-diverting toilet (A2) systems were selected for evaluation and compared to the current sanitation system with centralized WWTPs (A0). In separating systems, grey water and faeces or grey water only, was assumed to be treated in centralized WWTP like in the current system. In separating alternatives, further treatment of urine and toilet water was assumed to be carried out locally in Hiedanranta. Construction of the necessary infrastructure was taken into account, but the end use of materials and supplies as well as infrastructure was excluded.

By applying sanitation systems based on urine or blackwater separation in Hiedanranta, over 3 to 10 times more nitrogen could be recovered compared to the current system. If the nutrient potential of the reject water of the digestion, formed as a side stream of further processing in A1, would be exploited, the recovery rate would be even higher. For phosphorus, the recovered amount would be at the same level in all the alternatives. However, the quality and applicability of phosphorus is higher in the separating systems.

Concerning the lifecycle environmental impacts, the carbon footprint will reduce to about a quarter and eutrophication impact to one third (Figure 1.1). Wastewater treatment in WWTPs causes a major part of the greenhouse gas and eutrophic emissions. The urine transport, storage and application to the field are also significant sources of emissions in the alternative A2. The proportion of emissions avoided in separating systems is also significant, as in the further processing of toilet wastewater energy is produced and/or the inorganic fertilizers are replaced by the produced nutrients.

The study will continue in the future in a NutriCity project financed by the Ministry of Environment Finland, in which the functionality, technical implementation and acceptability of the alternative systems as well as the quality of urine and blackwater produced will be evaluated. Some new technologies, which are currently under development, for the upgrading of the collected urine and blackwater to fertilizer products will be piloted as well. The results of the pilots and tests in Hiedanranta will be exploited in the planning of a practical implementation of a circular economy super block, i.e. a residential block, which aims to recover resources as efficiently as possible.

![Figure 1.1 Environmental impacts of the alternative systems.](image-url)
Use of Different Types of Gas-Permeable Membranes in the Ammonia Recovery from the Air

M. Sánchez-Báscones*, M. Soto-Herranz†, J. M. Antolín, D. Conde-Cid

Agroforestry Sciences Department, Valladolid University (UVa), ETSIIAA, 34004 Palencia, Spain.

*Corresponding authors.
Tel. +34 653 421 030
E-mail address: mercedes.sanchez@uva.es

Abstract:

**Keywords:** Ammonia trapping, ammonia recovery, gas-permeable membranes (GPM)

The agricultural sector, and specifically the farmer, is directly related to the emission of different types of gases into the atmosphere, one of the most important being NH3 (Beusen *et al*., 2008), which is generated by the decomposition of urea and uric acid contained in the excreta. The importance of NH3 lies in its ability to form aerosols, to acidify soils, ground and surface water and its potential for eutrophication. In addition (Bouwman *et al*., 2002), NH3 is an irritant gas of the respiratory tract, its excessive accumulation in the air can directly affect the welfare of animals and workers. Finally, it contributes to the formation of PM 2.5 particles, which are harmful to people since they attack the cardiovascular system (Erisman *et al*., 2008). In Europe, the largest source of NH3 emissions remains the agro-livestock sector, with a contribution of 92% of total emissions (EEA, 2018), although they have been reduced by 10% since 1990 as a result of the reduction of livestock and changes in the management and management of livestock waste and fertilizers. In this vein, a new European Directive was proposed in 2016 to improve the quality of the air. In Spain, the reduction commitment for NH3 annual emissions accounts for 3% for any year from 2020 to 2029 and for 16% for years from 2030, compared to 2005, which was selected as the base year (EU, 2016).
We work with prototypes based on the technology of hydrophobic membranes permeable to gases. The process is based on the ability of NH₃ to cross the membrane and can be recovered in an acid solution on the other side of the membrane. Once the NH₃ is concentrated in the acid solution, it combines with the H⁺ ions to form non-volatile ammonium (NH₄⁺) ions, becoming an ammonium salt that can be used as a fertilizer. The efficiency of the process is dependent on the pH and temperature in the manure, which determines free NH₃ concentration.

The objective of this experiment is to evaluate the effect of two different types of membranes (ZM and PM), with different diameter and thickness, in the recovery of ammonia by capturing it with an acid solution. The membranes are same diameter and different physical characteristics on the recovery from ammonia gas emitted by a synthetic solution (59.4 g L⁻¹ NH₄Cl + 108.5 g L⁻¹ NaHCO₃ + 10.0 mg allylourea L⁻¹) using an acid solution (H₂SO₄ 1N) as ammonia capture solution. Experiments were performed in duplicate and simultaneously over a period of 7 days at a flow of 40 L d⁻¹ of acid solution.

The recovered ammonia (determined as total nitrogen) was 3242.9 ± 403.3 mg of NH₃-N for PM and 4204.6 ± 391.6 mg of NH₃-N for ZM. The nitrogen recovery efficiency was 63% and 66% for PM and ZM, respectively. The ammonia absorption per unit area and day was 1.6 ± 0.2 g m⁻² d⁻¹ for PM and 2.1 ± 0.2 g m⁻² d⁻¹ for ZM. The elimination efficiency of ammonia in air, under similar conditions of emission and capture, was slightly higher in systems that used the ZM membrane.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>ZM</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (cm)</td>
<td>104.0</td>
<td>104.0</td>
</tr>
<tr>
<td>Outer diameter (mm)</td>
<td>8.6</td>
<td>8.6</td>
</tr>
<tr>
<td>Width of the Wall (mm)</td>
<td>0.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>21.8</td>
<td>5.6</td>
</tr>
<tr>
<td>Polymer density (g/cm³)</td>
<td>0.4</td>
<td>0.95</td>
</tr>
<tr>
<td>Absorption surface (cm²)</td>
<td>522.8</td>
<td>522.8</td>
</tr>
</tbody>
</table>

**REFERENCES**


EEA. Air quality in Europe. Informe EEE nº 12/2018

Bioelectrochemical System Accelerated Methane Production Rate in Anaerobic Digestion of Waste Activated Sludge


* State Key Laboratory of Urban Water Resource and Environment, School of Environment, Harbin Institute of Technology, 73 Huanghe Road, Harbin, Heilongjiang Province 150090, China
** Department of Chemical Engineering, National Taiwan University, Taipei 106, Taiwan;
*** Department of Chemical Engineering, National Taiwan University of Science and Technology, Taipei 106, Taiwan;
† Correspondence to Chuan Chen. E-mail: cchen@hit.edu.cn

Abstract: Methane production rate (MPR) is usually limited by the complex organic matter degradation in waste activated sludge digestion processes. A lab-scale digester, which integrated anaerobic bioreactor with microbial electrolysis (MEC-AD), was operated under three voltages (0V, 0.6V, 0.8V) at 35 ± 1°C in order to examine the contribution of bioelectrochemical system on accelerating MPR of waste activated sludge digestion processes. The time required for COD and protein degradation of the MEC-AD at 0.6V and 0.8V were shortened more than 7 days compared to 0V. At the end of the reaction, the concentration of sugar and protein in the MEC-AD at both 0.6V and 0.8V were 300 mg/L and 200 mg/L lower than that at 0V, respectively. Compared to 0V, the MPR at 0.6V of MEC-AD increased nearly 50%, indicating that the applied voltage was a very effective way to achieve high-efficiency anaerobic digestion of WAS.

Keywords: Bioelectrochemical; anaerobic digestion; methane production rate; waste activated sludge

INTRODUCTION Waste activated sludge (WAS) was considered an important renewable biomass energy source because it is rich in organic matter and has a large annual emissions. Anaerobic digestion (AD) is a worldwide method for sludge reduction and stabilization as well as energy recovery(Appels et al., 2008; Rulkens, 2008). However, methane production rate (MPR) rate in AD is low (digestive cycle and usually takes from 20 to 30 day) due to the limited of intracellular biomolecular hydrolysis, which is one of the main bottlenecks of the technology. Therefore, one of the main ways to improve MPR is to promote the decomposition of intracellular biomolecules and enhance their biodegradability. The microbial electrolysis cell (MEC) can produce hydrogen by using organic substances such as volatile acids, and hydrogen acts as a substrate for methanogens to facilitate the growth of hydrophilic methanogens, which could quickly eliminate the inhibition of volatile acid accumulation and enhance the efficiency of WAS to produce methane by AD(Lippert et al., 2018).

MATERIALS AND METHODS A lab-scale digester with 1L volume, which integrated anaerobic bioreactor with microbial electrolysis (MEC-AD), was operated under three voltages (0V, 0.6V, 0.8V) at 35 ± 1°C. Acetate was used as carbon source for MEC-AD startup. WAS taken from secondary sedimentation tank of the Taiping Municipal Wastewater Treatment Plant (Harbin, Heilongjiang Province, China) was used as seed sludge and substrate for methanogenesis after heating in a water bath at 75°C for 9 hours.
RESULTS AND DISCUSSION As shown in Figure 1.1, in the MEC-AD system, the VFAs produced by the pretreated WAS is acetic acid, propionic acid, n-butyric acid, isovaleric acid, isobutyric acid and n-valeric acid. Overall, the concentrations of these VFAs all increased first and then decreased under different voltage conditions. At 0.6V and 0.8V, the concentrations of these VFAs in the bioreactor was lower than those in the no-voltage one. Under no-voltage condition, the concentration of VFAs other than propionic acid gradually increased in the first 3 days, then decreased slowly, and complete degradation took around 12 to 15 days. When the voltage of MEC was 0.6V, the time required for the VFAs degradation was shortened to less than 10 days. When the voltage increased to 0.8V, the time required for the VFAs degradation was shortened to within 7 days. It is speculated that with the voltage applied, macromolecular organic matter and VFAs directly were decomposed into carbon dioxide, omitting the hydrolysis acidification step, thereby the VFAs concentration in the system were lower and degradation rate were increased.

As shown in Figure 1.2, the total volume of gas was about 1577 ml, the total yield of CH₄ was about 38 mmol, and the yield of CO₂ was about 12 mmol, regardless of whether the voltage was applied to MEC-AD or not. However, at 0.6V, the methanogenesis cycle decreased from 15 days at 0V to 7 days at 0.6V, and the MPR increased by 50%. It is speculated that the voltage of MEC might increase the MPR by promoting the direct use of carbon dioxide to produce methane.

The efficiency of MPR by WES could effectively reduce the cost of excess sludge treatment and disposal, and at the same time realize resource and energy. Through the exchange of meetings, it is expected to achieve this goal as soon as possible, and the process can be extended to other aspects of water treatment and energy recovery.

REFERENCES


Investigation of the environmental performance of a polyfoam high rate up-flow anaerobic biofilter system treating municipal wastewater


* Brunel University London, Uxbridge UB8 3PH, UK, vasilia.vasilaki2@brunel.ac.uk
** Institute of Applied Research–The Galilee Society, Israel and AgRobics Ltd, mahdi.hs@hotmail.com
*** Institute of Applied Research – The Galilee Society, Israel and AgRobics Ltd., nedal@gal-soc.org

Abstract: The aim of this study is to assess the concentrations of methane in the biogas and dissolved methane in the effluent of a pilot-scale poly foam-based high rate up-flow anaerobic system treating municipal wastewater. The trade-offs between energy consumption, biogas production and permeate dissolved CH\textsubscript{4} concentration under different environmental and operational conditions were investigated. The average COD removal efficiency of the system was 47% with peaks up to 70%. The average solids removal was 53% with average CH\textsubscript{4} content in the biogas equal to 70%. In total, ~52% of CH\textsubscript{4} generated in the reactor was recovered as biogas, whereas ~48% belonged to the dissolved CH\textsubscript{4} concentration in the effluent. The average electricity consumption was ~18 kWh/day resulting in a net-positive energy balance. The current work investigates the operating conditions that result in minimization of the dissolved CH\textsubscript{4} concentration and maximization of the biogas yield.

Keywords: Polyfoam-based anaerobic reactor; mainstream wastewater treatment; sustainability trade-offs

Introduction: Mainstream anaerobic processes in wastewater, have been identified as a sustainable alternative to aerobic treatment and have been linked to reduced costs, low energy requirements and low solids generation (Verstraete et al., 2009). Additionally, a portion of the organic matter is degraded to methane (CH\textsubscript{4}), which can be converted to energy, while the nutrients preserved, can be recovered or treated energy-efficiently in subsequent treatment steps (Dai et al., 2015). However, significant dissolved CH\textsubscript{4} concentrations in the permeate of anaerobic processes have been reported in the literature (up to 38 mg/L) (Shin et al., 2014). The objective of this work is to quantify the concentrations of CH\textsubscript{4} in the biogas and dissolved CH\textsubscript{4} in the effluent of a pilot-scale advanced anaerobic treatment (AAT) reactor treating municipal wastewater. The trade-offs between energy consumption, biogas production and permeate dissolved CH\textsubscript{4} concentration was investigated under different environmental and operational conditions.

Materials and Methods: The AAT system utilizes a “bio-stabilized”, polymer-based matrix with large surface area and high capacity (Massalha et al., 2015), impregnated with high amount of anaerobic microorganisms (Sabbah et al., 2016). The volume of the anaerobic reactor is equal to 25 m\textsuperscript{3} (liquid height: 4.4 m) with active volume of 21 m\textsuperscript{3}. Raw (after mechanical separation) wastewater from Karmiel wastewater treatment...
plant (Israel) was pumped in the reactor; the flow-rate was equal to $5 \, \text{m}^3/\text{h}$ (HRT=4.2 h). Wastewater temperature ranged from 17 to 27 ºC. 24 h composite samples were collected biweekly from the influent and effluent of the system. The samples were analysed in terms of pH, chemical oxygen demand (COD), total nitrogen (TN), soluble COD (sCOD) and total suspended solids (TSS) according to standard methods (APHA, 2005). Dissolved CH$_4$ was sampled and quantified based on Souza et al., (2011). Energy consumption was monitored online.

**Results and Conclusions:** Table 1.1 shows the influent and effluent concentrations of the system during the monitoring period. The average COD removal efficiency was 47% with peaks up to 70%. The average influent TSS concentration was $638.8 \pm 219 \, \text{mg/L}$ with solids removal equal to 53%.

**Table 1.1** Mean concentrations and standard deviations of influent and effluent characteristics of the AAT reactor

<table>
<thead>
<tr>
<th></th>
<th>Influent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>N$_{\text{tot}}$ (mg/L)</td>
<td>80.9 ± 9.9</td>
<td>731.5 ± 185.5</td>
</tr>
<tr>
<td>TSS (mgTSS/L)</td>
<td>638.8 ± 219.3</td>
<td>731.5 ± 185.5</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>1335.3 ± 311.9</td>
<td>277.4 ± 53.5</td>
</tr>
<tr>
<td>sCOD (mg/L)</td>
<td>378.5 ± 70.8</td>
<td>277.4 ± 53.5</td>
</tr>
<tr>
<td>pH</td>
<td>7.3 ± 0.2</td>
<td>7.2 ± 1.0</td>
</tr>
</tbody>
</table>

Figure 1.1 shows the boxplots of the daily dissolved CH$_4$ loads in the effluent of the AAT reactor, the daily CH$_4$ load in the biogas and the daily energy consumption of the system. In total, ~52% of the generated CH$_4$ in the system was recovered as biogas, whereas ~48% belonged to the dissolved CH$_4$ concentration in the effluent. The average electricity consumption was ~18 kWh/day.

**Figure 1.1** Boxplots of the daily dissolved methane loads in the effluent of the AAT reactor, the daily CH$_4$ load in the biogas and the daily energy consumption of the system.

The analysis showed that the AAT system can be an energy-positive alternative to primary treatment at a WWTP. This study provides insights on the operational conditions (i.e. loads, temperature) that affect the dissolved CH$_4$ concentrations, the trade-offs between energy consumption and CH$_4$ generation and guides towards the mitigation of dissolved CH$_4$ loads.

**ACKNOWLEDGMENTS**

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**REFERENCES**

Verstraete, W., Van de Caveye, P. and Diamantis, V., 2009. Maximum use of resources present in domestic “used water”. Bioresource technology, 100(23), pp.5537-5545.


Achieving Sustainable Wastewater Treatment by Mitigating the Nitrous Oxide (N₂O) Emissions

T.M. Massara*, V. Vasilaki*, A. Nafay*, E. Katsou*

*Department of Civil and Environmental Engineering; College of Engineering, Design and Physical Sciences; Institute of Environment, Health and Societies, Brunel University London, Uxbridge Campus, Middlesex, UB8 3PH, Uxbridge, UK.

Authors’ email addresses: Theoni.Massara2@brunel.ac.uk (T.M. Massara); Vasileia.Vasilaki2@brunel.ac.uk (V. Vasilaki); Abdulnafay261@hotmail.co.uk (A. Nafay); Evina.Katsou@brunel.ac.uk (E. Katsou)

Keywords: N₂O emissions; Wastewater treatment; Municipal WWTP; Full-scale modelling

INTRODUCTION
Climate change pressures have urged an increasing focus on the control and minimization of greenhouse gas emissions (GHG) from wastewater treatment plants (WWTPs). Having a global warming potential 265 times higher than CO₂ in a 100-year period (IPCC, 2013), N₂O gains importance. During nitrification and denitrification, N₂O can be produced and emitted under the occurrence of various conditions such as increased nitrite (NO₂⁻) concentration and/or low dissolved oxygen (DO) levels at the nitrification stage, etc. (Law et al., 2012). Hence, the development of mathematical models estimating the level of N₂O production and emission in WWTPs is of high interest. A common practice is to follow the widely accepted structure of the IWA Activated Sludge Models (ASM) (Henze et al., 2000) for the description of chemical oxygen demand (COD) and nutrient removal in WWTPs. Nevertheless, the original ASM versions contain no mention of the N₂O production and quantification. The aims of this work are to: (i) develop an ASM-type N₂O model describing the operation of an existing full-scale municipal WWTP, (ii) calibrate and validate the model with real time emission data, and (iii) suggest effective mitigation measures for the optimal plant operation.

WWTP
This study describes the operation of a full-scale municipal WWTP located in Midlands (UK). The WWTP treats an average daily flow of 27 ML d⁻¹ to a standard of: 10 mg L⁻¹ biochemical oxygen demand (BOD), 5-10 mg L⁻¹ ammonia (NH₃) and 2 mg L⁻¹ phosphorus (P). The energy demand of the plant is 9,000 kWhr d⁻¹, whereas the energy production is around 15,000 kWhr d⁻¹. The treatment works in the plant include preliminary treatment (6mm screening and grit removal), primary settling, secondary treatment with bio-filters for 30% of the flow and activated sludge for the remaining 70%, and, finally, tertiary treatment with sand filters. The dewatered sludge is recycled to local farmlands after being treated in anaerobic digesters. The biogas produced by the anaerobic digesters is utilized to produce heat and electricity.
MATERIALS AND METHODOLOGY The model developed for the purposes of this study is based on the ASM1 structure (Henze et al., 2000). Henze et al. (2000) modelled the biochemical processes that occur within the biological reactors that treat wastewater. Considering that the initial ASM1 form excludes the description of N₂O generation, the development of ASM1-type N₂O models is of particular interest (Massara et al., 2017). Hence, the model presented in this paper is based on the ASM1 but coupled with the two-pathway model of Pocquet et al. (2016) to include the N₂O production by AOB. Moreover, the heterotrophic denitrification steps have been imported by Hiatt and Grady (2008). The kinetic model is currently being developed in MATLAB and altered to support real emission data of the WWTP. The stoichiometry of the model is designed to include 18 processes and 18 components (Table 1.1). Amongst the model components, there are certain which are focused upon: i.e. NO₂⁻, NH₂OH, nitric oxide (NO) and nitrate (NO₃⁻), all of which are significantly correlated with the N₂O emissions in WWTPs. For example, studies have shown that the NH₂OH oxidation process can importantly contribute to the N₂O emissions (Wrage et al., 2001). Another study by Colliver and Stephenson (2000) suggests that increased NO₂⁻ concentration during nitrification can lead to increased N₂O generation. Tallec et al. (2006) showed that the use of 10 mg L⁻¹ of artificial NO₂⁻ resulted in 4 to 8-fold increase in the N₂O production. Thus, the ASM1-N₂O model under development has been accordingly adapted to include such parameters as well as the impact of changes in their concentrations. N₂O stripping is modeled using the dissolved N₂O concentration and the volumetric mass transfer coefficient (kLa). A coefficient expressing different levels of participation of the kLa to the N₂O stripping named ‘stripping effectivity’ is also being applied.

Table 1.1 List of the 18 processes considered in our ASM1-type N₂O model for 4-step nitrification-denitrification combined with a 2-pathway model for N₂O production by AOB.

<table>
<thead>
<tr>
<th>Process Number</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Hydrolysis</td>
</tr>
<tr>
<td>2</td>
<td>Aerobic Hydrolysis</td>
</tr>
<tr>
<td>3</td>
<td>Anoxic Hydrolysis (NO₃⁻→NO₂⁻)</td>
</tr>
<tr>
<td>4</td>
<td>Anoxic Hydrolysis (NO₂⁻→N₂)</td>
</tr>
<tr>
<td>5</td>
<td>Anaerobic Hydrolysis</td>
</tr>
<tr>
<td>6</td>
<td>Aerobic Growth on Ss</td>
</tr>
<tr>
<td>7</td>
<td>Anoxic Growth of Heterotrophs on Ss (NO₃⁻→NO₂⁻)</td>
</tr>
<tr>
<td>8</td>
<td>Anoxic Growth of Heterotrophs on Ss (NO₂⁻→NO)</td>
</tr>
<tr>
<td>9</td>
<td>Anoxic Growth of Heterotrophs on Ss (NO→N₂O)</td>
</tr>
<tr>
<td>10</td>
<td>Anoxic Growth of Heterotrophs on Ss (N₂O→N₂)</td>
</tr>
<tr>
<td>11</td>
<td>Lysis</td>
</tr>
<tr>
<td>12</td>
<td>NH₃ oxidation to NH₂OH with oxygen consumption</td>
</tr>
<tr>
<td>13</td>
<td>NH₂OH oxidation to NO coupled with oxygen reduction (AOB growth here)</td>
</tr>
<tr>
<td>14</td>
<td>NO oxidation to NO₂⁻ coupled with oxygen reduction</td>
</tr>
<tr>
<td>15</td>
<td>NO reduction to N₂O coupled with the NH₂OH oxidation to NO₂⁻ (N₂O from NH₂OH oxidation pathway)</td>
</tr>
<tr>
<td>16</td>
<td>Aerobic Growth of NOB</td>
</tr>
<tr>
<td>17</td>
<td>HNO₂ reduction to N₂O coupled with NH₂OH oxidation to NO₂⁻ (N₂O from nitrifier denitrification pathway)</td>
</tr>
</tbody>
</table>

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The model under development will further expand to include several parameters influencing the N$_2$O emissions in the WWTP. Emission data of 2 weeks will be used for the calibration and validation steps. The produced results will be studied and thoroughly analysed before being presented at the conference. It is hoped that sustainable suggestions will be drawn to design strategies for the mitigation of N$_2$O emissions in the full-scale municipal WWTP under investigation.

REFERENCES
Novel Solutions for Water and Nutrient Recovery from Non-Conventional Water Resources: The Project FIT4REUSE

S. Lavrnić*, S. Bleich**, R. Declercq***, F. Fatone****, A. Jaouani*****; Ö. Karahan Özgün******; A. Lorenzo******; S. Malamis*******; G. Monacelli********; A. Toscano*

*Alma Mater Studiorum - University of Bologna, Department of Agricultural and Food Sciences, Viale Giuseppe Fanin 50, Bologna 40127, Italy (stevo.lavrnic@unibo.it; Attilio.toscano@unibo.it)
**MEKOROT, WaTech division, Israel (sbleich@mekerot.co.il)
***Ecofilae, rue Alfred Nobel 425, 34000 Montpellier, France (remi.declercq@ecofilae.fr)
****Marche Polytechnic University, Department of Material, Environmental and City Planning Science and Engineering, Via Brecce Bianche 12, Ancona 60100, Italy (f.fatone@staff.univpm.it)
*****University of Tunis El Manar - Higher Institute of Applied Biological Sciences of Tunis, Tunisia (ajaouani@yahoo.fr)
******Istanbul Technical University, Department of Environmental Engineering, TR-34469 Maslak, Istanbul, Turkey (ozlem.karahan@itu.edu.tr)
*******Bioazul S.L., Severo Ochoa 7, Malaga 29590, Spain (alorenzo@bioazul.com)

Abstract: High treatment costs, possible negative effects and actual low public acceptance can hinder and restrict the safe usage of non-conventional water resources (NCWR, i.e. treated wastewater and desalinated water) that can help the Mediterranean region to overcome water scarcity in agriculture. FIT4REUSE aims to tackle these challenges through three areas: i) optimisation and innovation of wastewater treatment and desalination technology to offer sustainable and low-cost solutions, ii) application of NCWR for irrigation or aquifer recharge through direct and indirect water reuse schemes and iii) analyse economic, social and environmental impacts of the solutions proposed. FIT4REUSE will achieve its goals by the inclusion of research, governmental and industrial partners from different parts of the Mediterranean region.

Keywords: Treated wastewater reuse; Desalinated water; Irrigational reuse

FIT4REUSE is a 3-year project recently funded by the PRIMA (Partnership for Research and Innovation in the Mediterranean Area) foundation. The consortium is formed by 9 partners from 7 countries (Italy, Spain, France, Greece, Israel, Tunisia and Turkey) with the main goal of providing a sustainable water supply for the Mediterranean agricultural sector by the use of non-conventional water resources. The overall concept and rationale of FIT4REUSE (Figure 1.1) are identified with the three main pillars of the project: i) innovation of treatment technologies, ii) application of non-conventional water resources in simulated/relevant environment, and iii) assessment and regulation.

The innovation pillar will concentrate on wastewater treatment and desalination technologies, and offer novel and sustainable solutions. Several combinations will be
tested to achieve the required quality for municipal wastewater agricultural reuse. In particular, optimised constructed wetlands, advanced anaerobic treatment systems and nano-materials will be innovatively combined in order to provide practical solutions tailored for maintaining nutrients only when needed, while removing pathogens and emerging compounds for a safe wastewater reuse. Furthermore, a novel integrated algae-based system will be implemented to effectively treat brines produced by the desalination process and extract salts and struvite from it.

Figure 1.1 Overall FIT4REUSE concept.

Once a suitable water quality is achieved, the application pillar will study its use in irrigation, fertigation and aquifer recharge. Different drip irrigation systems and practices will be tested to prevent and decrease emitter clogging, avoid any adverse health effect on farmers and consumers, and reduce soil degradation and nutrient leaching. The application pillar will also concentrate on aquifer recharge with treated municipal wastewater, in order to find the best way to preserve aquifer quality and its ecological balance. Moreover, considering the potential danger that non-conventional water resources can present (i.e., presence of pathogens, toxic and emerging contaminants), guidelines for water reuse safety (risk management) planning in the Mediterranean area will also be developed, in order to minimise these threats and support further regulation and water policies.

Finally, the assessment and regulation pillar will assess the sustainability of the entire water reuse value-chain to identify hotspots and different scenarios to improve the sustainability of the diverse treatment and application systems. In addition, it will identify and evaluate the relevance of the factors driving community to alternative water resources application. This activity will be performed by a specific holistic methodological framework, taking into account environmental, social, and economic aspects through LCA/E-LCC/S-LCA/CBA tools. A special focus will be given to the exploitation of FIT4REUSE results to develop scenarios that will inform and actively involve policy makers, citizens, and market actors, train selected stakeholders, and increase public acceptance of non-conventional water resources.

Therefore, apart from water recovery from non-conventional water resources, FIT4REUSE will also develop scheme for nutrient recovery and their use in agriculture in order to reduce the need for industrial fertilisers.
Holistic Economic Assessment of the Integration of Nature-Based Solutions in Small Scale Decentralised Water Cycles

M. Ghafourian*, P. Stanchev**, E. Katsou***

*Brunel University London, Kingston Lane, Uxbridge UB8 3PH, ghafourian_m@hotmail.co.uk
** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, peyo.stanchev@brunel.ac.uk
*** Brunel University London, Kingston Lane, Uxbridge UB8 3PH, evina.katsou@brunel.ac.uk

Abstract: The nature based solutions (NBS) are low-cost alternative green infrastructures with a lower environmental impact than the conventional grey infrastructure, particularly suitable for water-scarce and remote decentralised areas. However, there is still the lack of an evidence regarding their system wide economic benefits which is a main barrier of overtaking the nonconventional solutions. The aim of this paper is to develop a holistic framework for assessing and evaluating the wide economic performance of nature-based solutions for small scale decentralised water management. The proposed evaluation framework is based on the joint application of different assessment tools such as Material Flow Cost accounting, Life Cycle Costing, cost-benefit analysis and True Cost Accounting. The approach has been demonstrated on a real eco-tourist facility implementing several NBS solutions for water management.

Keywords: Circularity and cost effectiveness assessment; nature-based solutions; life cycle costing

INTRODUCTION Water scarcity and climate change are main drives that push researchers towards more nature-based solutions (NBS) rather than ecosystem-based approaches in order to adjust and mitigate the impacts from climate change (Cohen-Shacham et al., 2016). During the early stages of water system decision making, it is desirable to have reasonably accurate cost estimates of water supply projects. The important concerns that cannot be solved yet is assessing the impacts of NBS within and across Economic challenge. Lack of a comprehensive approach that taking into account all the costs of construction, operating, maintaining, and disposing capital assets over their life cycle is noticeable (Rathnayaka et al., 2016). This research develops a holistic framework that evaluates the economic benefits of nature based solution through value added in the loops. With the additional value built into these systems from agriculture and energy, and the savings that can be made on fertilisers and wastewater treatment, the NBS solutions will have a shorter payback period and give a clear estimation with respect to cost from economic point of view that can be used by decisionmaker for plan and implement the system (Valentina Marchionni & Nuno LopesLuis MamourosDidia C, 2014). Therefore, the objective of this study is to assess the economic performance of NBS by proposing suitable tool to evaluate the product within extended supply chain using life cycle costing.

MATERIALS AND METHODS The proposed methodology for cost modelling has been based on existing methods such as Material flow cost accounting, Life Cycle Costing, Cost-benefit Analysis, Extended cost benefit assessments and social cost benefit analysis. The results from these tools have been used to develop target cost
functions and economic indicators to describe the value performance of the NBS solutions. Case Study: The proposed methodology has been demonstrated on a real case study of an Eco-touristic facility in an island in Mediterranean called Tinos Island, Greece. Results and Discussion: The proposed economic assessment framework proved to be a valuable tool for mapping and evaluating the multiple economic benefits of NBS. Measuring the added value of the water management loops helps the decision makers and stakeholders to see advantages of the NBS solutions over the conventional systems. The results showed that the NBS performs equal or even better than the conventional system. It has a similar cost, and it provides additional benefits like attracting more tourists to the area by running recreational park and supporting wildlife. The analysis showed that local citizens are willing to pay around three times more for a green infrastructure than for a grey infrastructure, and pay more if it is surrounded by a recreational park.

CONCLUSIONS This paper proposed an integrated methodology for evaluation of wide economic benefits of NBS solutions for water management. The results showed that the inclusion of the economic value added the NBS by-products and the avoided external costs into the calculations, resulted in significant reduction of the payback period compared to traditional grey infrastructure solutions.

REFERENCES

Cohen-Shacham, E. et al. 2016 Nature-based Solutions to address global societal challenges. IUCN, Gland, Switzerland


Rathnayaka, K., Malano, H. & Arora, M. 2016 Assessment of sustainability of urban water supply and demand management options: A comprehensive approach, Water (Switzerland), 8(12).


Life Cycle Assessment of an Ion Exchange Technology for Nutrient Removal and Recovery from Municipal Wastewater


* Berlin Centre of Competence for Water, Cicerostraße 24, 10709 Berlin, Germany
lea.conzelmann@kompetenz-wasser.de
** Cranfield Water Science Institute, Cranfield University, Beds, Cranfield MK43 0AL, UK
*** Severn Trent, 2 St John's Street, Coventry CV1 2LZ, UK

Abstract: Recovery of nutrients as well as the requirement to meet low effluent values are recent challenges for municipal wastewater treatment plants (WWTP). Therefore, an ion exchange process (IEX) was developed, which is integrated in the secondary effluent of a WWTP to eliminate and recover ammonium and phosphate. This study compares a simple WWTP without targeted nutrient removal in combination with a downstream IEX and a generic reference WWTP with biological nutrient removal in their environmental impacts, using the Life Cycle Assessment method. Preliminary results suggest that an IEX can be beneficial due to upstream energy savings in the WWTP. The results strongly depend on the technical solution for recovery of the IEX regeneration solution.

Keywords: Nutrient recovery; municipal wastewater, high effluent quality; Life Cycle Assessment;

INTRODUCTION

Because WWTPs are a point source of nutrients (N and P) in surface water bodies, water authorities pursue to tighten the limits for effluent quality. Additionally, nutrient recovery is targeted to get closer towards a circular economy and become more independent of phosphorus imports. New technologies are coming up to meet these targets. Life Cycle Assessment (LCA) can help to compare the environmental footprint of new technologies with conventional processes to see if material recovery is associated with environmental benefits in a holistic perspective. This study investigates ion exchange (IEX) as an innovative process for nutrient removal and recovery with LCA, comparing it to a conventional WWTP.

METHODS

New technologies such as the IEX for municipal wastewater are associated with environmental impacts and benefits. To gain a distinct overview of these effects, two different scenarios for small and large WWTPs with a corresponding baseline (a generic conventional WWTP) are defined in Table 1.

| Table 1.1 Overview of the configuration and targets of the two LCA scenarios. |
|--------------------------------------|--------------------------------------|--------------------------------------|
| **Small WWTP (10,000 pe)** | **Large WWTP (100,000 pe)** |
| **Targets** | Nutrient recovery | Nutrient recovery and effluent polishing |
| **Effluent quality** | 1-2 mg/L TP, 10 mg/L NH$_4$-N | 0.5 mg/L TP, 3 mg/L NH$_4$-N |
| **Baseline WWTP** | • Trickling filter | • Nitrification for NH$_4$ removal |
| **Setup of Baseline WWTP** | • Chemical P removal (Fe dosing) | • Chemical P removal (Fe dosing) |
| **Setup of WWTP-IEX combination** | • Sand filtration for N removal and P removal after Fe dosing | • Post-treatment with sand filtration and Fe dosing |
| | • BOD removal plant | • BNR plant (N and P removal) |
| | • IEX for nutrient recovery | • IEX for polishing |
Both setups fulfil the same limits of the WWTP effluent and the sewage sludge is applied in agriculture. The system boundaries of this Life Cycle Assessment (see Figure 1.1) include:
- Direct emission of WWTP and IEX to air, surface water and ground,
- relevant background processes for operations of sewage treatment plant and IEX, such as electricity, heat, chemical and polymer demand,
- sludge treatment including sludge digestion, biogas valorisation within a CHP and the return load from thickening and dewatering,
- transportation of dewatered sludge and application in agriculture,
- infrastructure,
- credits for produced goods such as electricity via CHP or incinerator and
- credits for avoided fertilizer production due to recovered nutrients.

This study follows the method of Life Cycle Assessment (ISO 14040 2006). All used process data concerning the IEX is based on technical scale testings of Cranfield University in the H2020 innovation action SMART-PLANT (Grant No. 690323) and data concerning the effects on the upstream WWTP is provided by Severn Trent.

REFERENCES

Cellulose recovery from municipal wastewater and reuse in cement mortars: efficiencies and functional performances

Giulia Cipolletta1, Anna Laura Eusebi1, Alessia Foglia1, Francesca Tittarelli1, Chiara Giosuè1, Silvia Palmieri1, Nicola Frison2, Carlo Pastore3 and Francesco Fatone1

1Department of Materials, Environmental Sciences and Urban Planning - SIMAU, Università Politecnica delle Marche – INSTM Research Unit, Ancona, 60121, Italy
2Department of Biotechnology, University of Verona, Verona, 37129, Italy
3Istituto di Ricerca Sulle Acque, Consiglio Nazionale delle Ricerche, Viale F. De Blasio 5, Bari, 70132, Italy

Abstract: In the context of circular economy, an innovative application could be represented by the recovery of cellulose fibres from municipal wastewater. Recovered cellulose fibres could have a positive effect on the construction sector by reducing the amount of non-renewable raw materials and increasing sustainability. Rotating belt filter was used to recover cellulosic sludge from real urban wastewater. Recovered cellulosic material (cellulose, hemicellulose and lignin) reached values up to 26.59 g/m³ for solids removal efficiency of 74%. The cellulosic material content was averagely 87% of the total composition. Recovered fibres were analysed and used in mortar mix design to understand possible impact of the fibre in the building sector and the effect on the properties of hydraulic lime-based mortars, as microstructure and mechanical strength. Improvement of the mortar’s performance in terms of increased lightness, flexural strength and hygrometric properties were obtained with recovered fibre addition.

Keywords: Wastewater, Cellulose recovery, Sustainable building sector

INTRODUCTION Enhanced primary separation of cellulosic sludge may improve the energy and carbon footprint of wastewater treatment and allow for cellulose fibres reuse in construction materials sectors [1]. In particular, fibres can be used as reinforcing component in binder-based materials [2] in the building sector. In this field benefits derived from the use of cellulose fibres from other industrial activities were investigated [3], but the effects deriving from the use of recovered cellulose from wastewater treatment plant are still unknown.

MATERIALS AND METHODS Rotating belt filters (RBF) were used to separate a cellulose-rich sludge in two real wastewater treatment plants (WWTPs) in Falconara Marittima and in Carbonera. Experimental tests were conducted at different operating conditions (flowrate, belt porosities and hydraulic levels) to investigate their influence on the separation yields of the cellulosic material in the sludge. Solids removal efficiencies (E%TSS) were related to the Solids Loading Rate SLR [kgTSS h⁻¹ for m² of filtration area]. The amount of cellulosic material Ychl (cellulose, hemicellulose and lignin) was determined by analysing sludges separated from the RBF after washing and sieving. In a second phase, recovered cellulose fibres were added, at different percentages (from 0 to 20% by volume), to mortar blends (prepared according to UNI EN 1015-11:2007) to analyse their effect on the mechanical properties of mortars.
Fibres and mortars have been morphologically investigated by a Scanning Electron Microscope (SEM-EDAX). Effects of different fibres addition were analysed in terms of mortars workability, according to UNI EN 1015-3:2007, and of compressive and flexural strength ($R_c$ and $R_f$), on 28-days hardened mortars according to the UNI EN1015-11:2007.

RESULTS AND DISCUSSIONS Efficiencies of solids removal (E\%TSS) varied in the range 11-74%. Specifically, the efficiency was: 11% for SRL in the interval of 0-10 kg TSS m\(^{-2}\) h\(^{-1}\); 35%±13 for SLR 10-20 kg TSS m\(^{-2}\) h\(^{-1}\); 31%±22 for 20-30 kg TSS m\(^{-2}\) h\(^{-1}\); 55%±13 for 30-40 kg TSS m\(^{-2}\) h\(^{-1}\); 49%±22 for 40-50 kg TSS m\(^{-2}\) h\(^{-1}\); 59%±23 for 50-60 kg TSS m\(^{-2}\) h\(^{-1}\); 75% for 90-100 kg TSS m\(^{-2}\) h\(^{-1}\). Further, lower porosity of the RBF belt led to an improvement of separation yields (E\%TSS of 37±19% for 350 µm mesh and of 74±2% for 90 µm mesh). Hydraulic level into the filtration chamber affected the TSS removal, highlighting averagely E\%TSS of 48±22% for Hmax/Hmin of 260/240 mm and 57±17% on average for Hmax/Hmin equal to 220/200 mm. Cellulosic material content of washed and sieved sludge samples was averagely 38 ± 6% of cellulose, 9 ± 1% of hemicellulose and 40 ± 3% of lignin and humic compounds. The average amount of cellulosic material $Y_{chl}$ varied from 0.4 g cellulosic material m\(^{-3}\) for E\%TSS up to 12.6±8.8 g cellulosic material m\(^{-3}\) for E\%TSS in the range 60-80%. $Y_{chl}$ reached values up to 26.59 g cellulosic material m\(^{-3}\).

Recovered fibres (CREC) analysed by SEM appeared rough, with tubular shape and with diameter of 11.1 µm on average (Figure 1). Fibres are well dispersed into the mix and a significant number of binders paste particles adhered to the surface of CREC fibres, highlighting a well-developed Interfacial Transition Zone (ITZ). Furthermore, addition of cellulose fibres led to an increase of the number and diameter of pores up to 34% (for 20% of fibre addition). Regarding physical and mechanical properties, density of mortars varied from 1703 kg/m\(^{3}\) for 5% addition to 1574 kg/m\(^{3}\) for 20% addition; the compressive strength $R_c$ of the composites decreased up to 46% of the initial value (0% of fibre addition) when fiber addition increased from 0% to 20%; flexural strength $R_f$ increased up to 200% from addition 0% to 20%, thanks to the bridging effect of fibre that increased the resistance to crack propagation in mortars [4]. Concerning the hygrometric behaviour, water vapor permeability increased and water vapor resistance factor $\mu$ decreased from 10.2 to 9.7 for fibre addition respectively of 5% and 20%.

Furthermore, a simplified assessment was conducted to highlight the feasibility of production (expressed as sacks per day) of pre-mixed mortar with 20% and 5% of CREC fibres by volume. Results showed that large size WWTP (e.g. 150.000 PE) can supply a daily production from 305 to 1069, respectively with 20% and 5% of fibre addition.

REFERENCES
The Wast4Bioplast Turning Wastewater into Valuable Bioplastics

E. Ficara*, S. Turri**, N. Frison***

*Politecnico di Milano, Department of Civil and Environmental Engineering (DICA), Piazza Leonardo da Vinci 32, 20133, Milano, elena.ficara@polimi.it
**Politecnico di Milano, DICA, Piazza Leonardo da Vinci 32, 20133, Milano, stefano.turri@polimi.it
***Università di Verona, Strada Le Grazie 15, 37134 Verona, Italy, nicola.frison@univr.it

Abstract: The objective of Wast4Bioplast project is to demonstrate the feasibility of producing high-quality bioplastics, biofillers and biofertilisers from wastewater while reducing wastewater treatment costs. This is achieved by integrating several technological bricks in the sludge line of existing WWTPs including: the culturing of microalgal biomass on the CO2 from biogas upgrading and nutrients in blackwater from digestate S/L separation, the fermentation of waste sludge (or its co-fermentation with the algal biomass), struvite recovery and PHA accumulation and extraction. Algal biomass will also be tested as a biofiller. Also, microalgae produce oxygen by photosynthesis reducing the energy demand for aeration. This approach overcomes the well-known difficulty of maintaining pure/selected algae/bacteria cultures in open systems fed on wastewaters and will achieve synergies with existing infrastructures and trained manpower.

Keywords: Microalgae; PHA; biofiller

To this aim, a chain of additional processes are to be integrated into existing wastewater treatment plants will be proposed including:

- microalgal culturing, thus converting available nutrients and CO2 rich streams into algal biomass via photosynthesis
- fermentation of the waste streams (sludge and microalgae) to produce a volatile fatty acid (VFA) mixture with optimal composition in terms of relative abundance of acetic, propionic and butyric acids
- separation of the nutrients (N and P) released during the fermentation process to produce struvite, a slow release fertilizer
- biological conversion of VFA mixture into bioplastics (PHA) by using hyper-accumulating bacteria, and recovery from the bacterial biomass

In addition, the direct use of microalgal biomass as renewable and functional biofillers for biopolymers in different technological sectors will be also tested.

The amount of microalgal biomass can be estimated in 5 gDM/(PE·d) based on the available area for cultivation (assumed to be 0.5 m²/PE) and from an algal productivity of 10 gDM/(m²·d) using approx. 10 gCO₂/(PE·d) from biogas upgrading. The amount of N assimilated by algal growth is 5x0.07 gN/gDM = 0.35 gN/(PE·d). The amount of N that can be nitrified (Nnit) is calculated from the N in blackwater Nnit = 1.8-0.35 = 1.45 gN/(PE·d). This corresponds to an oxygen request of 1.45x4.3 gO₂/gN = 6.3 gO₂/(PE·d), covered by the oxygen made available by photosynthesis, that implies an energy saving in the activated sludge tank of 6.45 Wh/(PE·d) (approx. 7% of the overall WWTP energy demand). Assuming a harvesting efficiency of 70%, a VFA production from MA biomass of 0.2 gVFA/gDM (Gusmini et al., 2018), and a VFA recovery as PHA of 10%, the expected PHA production is 5x0.7x0.2x0.1 = 0.07 gPHA/(PE·d). Furthermore, biogas is produced from algal residues: (0.6 LCH₄/(PE·d), from methane yield tests). Finally, the amount of precipitated struvite estimated from a preliminary test on algal biomass is assumed as 0.14 g/(PE·d). Similarly, expected PHA production can be computed from waste sludge: PHA = 0.67 gPHA/(PE·d); CH₄ = 10 LCH₄/(PE·d); STRUVITE = 0.41 gSTRUV/(PE·d)).

The proposed technology is suitable for a fast uptake in existing WWTPs, as well as to new plants. The obtained biopolymers and biocompounds will be fully characterized in their composition and structural features as a function of the production process. A variety of model formulations will be developed covering possible use cases in the field of thermoplastics, rubbers, and coatings.

![Figure 1.1 Integration of the new value chains into existing WWTPs.](image)

REFERENCES
A Particular Phenomenon: Loss of Intermediate Products

Causes a Decrease in pH in an Anammox System

M. Jinyuan, G. Hui, W. Kaijun
State Key Joint Laboratory of Environment Simulation and Pollution Control, School of Environment, Tsinghua University, Beijing 100084, PR China

Abstract Anaerobic ammonium oxidation is an alkali-producing reaction. Usually, the pH of the system will increase after anammox reaction is completed. However, in an anammox system operating in a novel manner that by reducing the drainage frequency and adding concentrate of ammonium and nitrite to maintain stable operation of the anammox system, an amazing phenomenon was found: Although more than 95% of the total nitrogen in the system is removed by the anammox pathway, which is determined by the microbial community structure and the ratio of nitrite consumed and ammonium consumed and of nitrate produced and ammonium consumed in the system, However, the pH of the anammox system not only does not continue to rise, but instead shows a process of increasing-stable-lowering, which is an interesting and surprising phenomenon. Actually, because the cycle culture mode is adopted, our operating mothed is a concentration process of products in water phase and gas phase, we are conduct research from solid phase (mud), water phase and gas phase, respectively. Firstly, the water and mud from the anammox system in pH drop stage were taken out to conduct batch experiments, in which, However, the pH Instead began to rise, which ruled out the influence from water phase; The possibility of anaerobic acid production was ruled out by the result of microbial community structure analysis and small molecule organic acid determination. Finally, it is founded that the pH value is positively correlated with the N₂O concentration in the gas during the whole process, which indicates that the pH anomaly in the system is related to gas composition. Further research found that once the accumulated concentration of N₂O in the system is higher than 1200ppm, it will cause the pH of the system to decrease. We speculate that the N₂O accumulated in the system causes an abnormality of proton consumption in anammox pathway. The specific mechanism is still under study.

Keywords: ANAMMOX, pH, nitrous oxide
Figure 1.1 The molar ratio of nitrite consumed and ammonium consumed and of nitrate produced and ammonium consumed in the system.

Figure 1.2 Nitrogen conversion balance analysis in the anammox system.

Figure 1.3 The relationship between pH in water and N₂O accumulated in gas in the anammox system.
Ettringite Precipitation from Mine Water with Electrochemical Aluminium Dosage


*University of Oulu, Research Unit of Sustainable Chemistry, P.O.Box 4300, FI-90014 University of
Oulu, Finland, emma-tuulia.nurmesniemi@oulu.fi
**University of Oulu, Research Unit of Sustainable Chemistry, P.O.Box 4300, FI-90014 University of
Oulu, Finland, tao.hu@oulu.fi
***University of Oulu, Research Unit of Sustainable Chemistry, P.O.Box 4300, FI-90014 University of
Oulu, Finland, kyosti.rajaniemi@oulu.fi
****University of Oulu, Research Unit of Sustainable Chemistry, P.O.Box 4300, FI-90014 University of
Oulu, Finland, ulla.lassi@oulu.fi

Abstract: When the pH of sulphate rich mine water is raised to approximately 12 with calcium oxide/calcium hydroxide and aluminium is added, ettringite (Ca₆Al₂(SO₄)₃(OH)₁₂·26H₂O) precipitates. Typically, aluminium salts including sodium aluminate, aluminium hydroxide, aluminium chloride, aluminium nitrate and polyaluminium chloride are used as the source of aluminium. However, in this research electrochemical dosing of aluminium was investigated. In addition, leaching of the precipitated solids was investigated. The results indicate that electrochemical dosing of aluminium could be an alternative to aluminium salts in ettringite precipitation.

Keywords: Ettringite; electrochemistry; wastewater treatment

Sulphate precipitation as ettringite is a modification of the high pH (>11) lime precipitation process (Geldenhuys et al., 2003). With precipitation as ettringite it is possible to reach residual sulphate concentration of less than 200 mgL⁻¹ which is less than the drinking water guideline in Finland (250 mgL⁻¹) (Tolonen et al., 2016a, Tolonen et al., 2016b, Nurmesniemi et al., 2018). In ettringite precipitation the pH of the sulphate containing mine water is raised to approximately 12 with lime. Thereafter, aluminium salt is added, leading to precipitation of ettringite. The emergence of circular economy thinking has sparked interest towards recovery of industrial by-products and precipitation of sulphate as ettringite offers one possible way. The recovery of ettringite sludge is more cost-efficient than recovery of gypsum sludge formed in the traditional mine water treatment with lime. The formed ettringite could possibly be used as sorbent for pollutants such as arsenite (Tolonen et al., 2016a, Tolonen et al., 2016b, Nurmesniemi et al., 2018, Myneni et al., 1998).

In this research aluminium was dosed electrochemically instead of typical dosing as aluminium salt. To our knowledge, research on the use of aluminium electrodes for sulphate precipitation as ettringite has not yet been published in the scientific literature. Although, a patent exists for the use of electrocoagulation for sulphate precipitation as ettringite, aluminium sulphate hydroxides and/or iron-aluminium sulphate hydroxides (Van der Meer et al., 2014). Batch electrochemical ettringite precipitations and batch chemical ettringite precipitation experiments were conducted and the results were
compared. A schematic illustration of the experimental systems is shown in Fig. 1.1. Additionally, the stability of the precipitated solids was investigated by leaching experiments based on standard SFS-EN 12457-2. The precipitated solids were characterised with X-ray diffraction. Al, Ca and S concentrations were analysed by ICP-OES from the effluents.

**Figure 1.1** Schematic illustration of the a) electrochemical and the b) chemical ettringite precipitation experimental systems.

The results indicate that electrochemical ettringite precipitation could be a promising alternative for chemical ettringite precipitation. Using aluminium electrode as the aluminium source offers easier handling.

**REFERENCES**


Microalgae: A Sustainable and Efficient Adsorbent for Indium Recovery from Liquid Process and Waste Streams


* Laboratory of Analytical Chemistry and Applied Ecochemistry, Department of Applied Analytical and Physical Chemistry, Ghent University, Coupure Links 653, 9000 Ghent, Belgium
** GEMMA – Group of Environmental Engineering and Microbiology, Department of Civil and Environmental Engineering, Universitat Politècnica de Catalunya-BarcelonaTech, c/ Jordi Girona 1-3, Building D1, 08034 Barcelona, Spain
*** Center for Microbial Ecology and Technology, Department of Biochemical and Microbial Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

* Corresponding author (E-mail: NinaRicci.Nicomel@UGent.be)

Keywords: Indium; microalgae; biosorption

Indium (In) is listed as one of the 27 raw materials critical for the European Union (EU) in the most recent report of the European Commission (2017). The supply risks associated with the concentration of reserves and production in particular countries are accompanied by low substitution and recycling rates (European Commission, 2017). For these reasons, there has been a growing interest in the recovery of In from alternative secondary sources, such as leachates from polymetallic sludge produced by hydrometallurgical zinc processing (Kinnunen, 2017). Conventional methods for In recovery are either economically or environmentally disadvantageous, and thus, biosorption is of interest because of its low-cost and eco-friendly approach. Among widely available biosorbents, microalgal biomass possesses relatively high binding capacities for several metals (Wilde and Benemann, 1993; Aksu, 2002). This is explained by the presence of carboxylic, hydroxyl, amino, phosphate, and sulfhydryl groups in the microalgal cell wall that can act as metal binding sites (Suresh Kumar et al., 2015). To date, the potential of using microalgal biomass to remove and/or recover In from aqueous solutions has not been investigated.

In the present work, the use of microalgal biomass was studied for the removal and recovery of In from aqueous solutions. Different process parameters, which include pH, contact time, initial indium concentration and presence of competing ions, were...
studied to assess their effects on In biosorption. In addition, the desorption of In ions adsorbed by the microalgal biomass was investigated.

The results indicate that In removal increases with increasing pH. The maximum In adsorption (94.7% of initial In) was obtained at pH 2.4. This is an advantage for the application in real wastewater or leach solutions since most of these have an acidic pH. The In adsorption rapidly increased during the first 30 min of the process, reaching up to ca. 80% of the initial In. Fast kinetics are important for process scale-up. With rapid adsorption, smaller reactor volumes are required to ensure efficiency (Aksu, 2002). The correlation coefficients suggest that the Freundlich isotherm model fits the data better than the Langmuir model. This can be an indication that In was adsorbed in multilayers onto the active sites of the microalgal biomass surface with lateral interaction between the adsorbed molecules. The maximum adsorption capacity ($q_{\text{max}}$) of the microalgal biomass was estimated from the Langmuir model. The estimated $q_{\text{max}}$ value was 16.4 mg/g, which is in the same order as those of chemically modified adsorbents reported in literature. However, these modified adsorbents are costly, complicated to synthesize, and less environmentally sustainable, making microalgae more advantageous.

The competing effects of Cu, Zn, Sn, Al, and Fe on indium biosorption were also examined. Selectivity of In was observed over Cu, Zn, and Al, which is remarkable considering that the biosorbent was not treated or modified. Several desorbing agents (i.e. HCl, HNO₃, NaCl, CaCl₂, and EDTA) were tested to assess the regenerability of the microalgal biomass. Considering efficiencies and economic feasibility, HCl was chosen as the optimum desorbing agent for the regeneration experiments with up to 80 % desorption efficiency. HCl works as a desorbing agent through the exchange of In for protons. Although adsorption efficiencies decreased by 28 % over the three adsorption-desorption cycles because of a decrease in available adsorption sites (Figure 1.1), these processes proved to be useful in concentrating In ions.

Overall, this study demonstrates the potential of microalgal biomass for In biosorption from aqueous solutions. This potential should now be further explored using real In-containing wastewaters and leachates. Furthermore, it provided some insight into the adsorption behavior and mechanism of In adsorption on microalgal biomass. This information can now be used as input data for subsequent continuous adsorption experiments involving a lab-scale column.

![Figure 1.1](image1.png)

**Figure 1.1.** Three cycles of In adsorption – desorption using 0.1 M HCl as desorbing agent.
REFERENCES


Phythase Enhanced Phosphorus Recovery in Soybean Processing

Wim H.M. Moereman
*NuReSys Hoestraat 3  8540 Deerlijk Belgium – wm@nuresys.com

Abstract: Soybean import is source of livestock feed and is also used abundantly for human food production. A specific feature of soybean is that it contains most of it’s phosphorus as phytic acid. During processing of wastewater from soybean the anaerobic degradation of this phytic acid is limited which hampers the use of struvite crystallisation to recover the phosphorus as fertilizer. The approach investigated was to evaluate if adding phytase enzyme could enhance phosphorus recovery potential. Adding of phytase enzyme to raw influent at low levels of 10 µg/g COD resulted in an increase of available PO₄³⁻-P from 69 PO₄³⁻-P mg/l up to 107 PO₄³⁻-P mg/l on a total P-level of 156 mg P/l. Raw influent also contained high level of potassium (1200 mg K/l) and magnesium (160 mg Mg/l) resulting in phosphate being the limiting parameter for struvite formation after anaerobic treatment. Full scale sample analysis showed that operating the anaerobic treatment at relatively low pH (6.8 – 7.0) opens the possibility to produced struvite by simple pH increase. Samples showed a combination of both PO₄³⁻-P and pH of accordingly: pH 7.0 and 80 mg PO₄³⁻-P /l; pH 7.5 and 38 PO₄³⁻-P mg/l and finally pH 8.3 and 22 PO₄³⁻-P mg/l. Both phytase pre-treatment of the raw wastewater and pH controlled struvite formation were shown to significantly increase phosphorus recovery potential for soybean processing industry. The work down also demonstrates the risk of unwanted struvite clogging when operating anaerobic stage at elevated pH levels.

Keywords: Phosphorus recovery, phytase, soybean processing
Improving the Sustainability of Nutrient and Energy Recovery Facilities: Optimization of Treatment Train Performance and Economics Using a New Process Model Library

C. Vaneeckhaute*, E. Belia**

*BioEngine, Université Laval, 1065 ave. de la Médecine, Québec, QC, Canada, G1V0A6
celine.vaneeckhaute@gch.ulaval.ca
**Primodal Inc., 145 Rue Aberdeen, Québec, QC, Canada, G1R 2C9, belia@primodal.com

Abstract: This paper presents the use of a new nutrient recovery model (NRM) library to establish the operational settings of a sustainable and cost-effective treatment scenario with maximal resource recovery and minimal energy and chemical requirements. To this end, an economic analysis was programmed in the process model library and the operational settings of a pre-configured treatment train were optimized for pig manure as a case study. Under the optimized conditions and assumptions made, potential financial benefits for a large-scale anaerobic digestion and nutrient recovery project were estimated at an average of ± 2 m³ y⁻¹, equivalent to 40 $ ton⁻¹ total solids y⁻¹, over 20 years.

Keywords: bio-based fertilizers; circular economy; sludge treatment; nutrient recycling; resource recovery.

INTRODUCTION In order to hasten the implementation of optimal, cost-effective and sustainable treatment trains for resource recovery, a nutrient recovery model (NRM) library has recently been developed and validated at steady state (Vaneeckhaute et al., 2018a). It includes dynamic mathematical process models for anaerobic digestion (biogas recovery), struvite crystallization (phosphorus recovery), and NH₃ stripping and acidic air scrubbing (ammonium sulfate recovery). The models are based on detailed chemical solution speciation and reaction kinetics. To facilitate numerical solution, a highly efficient PHREEQC-WEST (DHI) software interface has been established and verified. Important generic insights in the interactions between process inputs and outputs were obtained through global sensitivity analyses (Vaneeckhaute et al., 2018b). Based on the results, it was possible to define an optimal sequence of unit processes in a treatment train for energy and nutrient recovery aiming at the production of high-quality fertilizers at minimal cost (Figure 1.1).

This paper presents the use of the NRM library to establish the operational settings of a sustainable and cost-effective treatment scenario with maximal resource recovery and minimal energy and chemical requirements. An economic analysis was programmed in the process model library, and the operational settings of the below treatment train were optimized for pig manure as a case study.
METHODS The operational settings of the configured treatment train (Figure 1.1) were optimized in order to maximize resource recovery and minimize energy and chemical requirements in a cost-effective way. The operational envelope involves: i) the operational temperature, liquid flow rate, and amount of alkalinity dosing for the anaerobic digester, ii) the fraction of non-settleable precipitates and particulate organics for the phase separation unit, iii) the amount of base dosing, the concentration of seed material in the input flow, and precipitate extraction rate for the precipitation unit, iv) the operational temperature and gas flow rate for the stripping unit, and v) the acid dose and liquid recycle flow rate for the scrubbing unit. The operational costs for the optimized scenario were then calculated and included in the overall economic balance, in addition to labor, material and maintenance costs, revenues from CO₂-emission reduction credits, as well as capital costs. Capital costs (including equipment and construction costs) for each unit process were obtained from technology providers who delivered design reactor dimensions for the treatment train set-up. The complete treatment train was also implemented in CAPDET (Symantec, 2014) in order to estimate other important direct and indirect construction costs, not included in the unit process cost estimations, such as land costs, legal costs, inspection costs, costs for lab and administration buildings, and miscellaneous costs.

RESULTS AND CONCLUSIONS Assuming an average discount rate of 6% and a depreciation period of 20 years for all unit processes (Symantec, 2014), except for the NH₃ stripping unit, for which a depreciation period of eight years was assumed, the nutrient recovery project presented above would have a positive net present value (NPV) in year 7 of operation in the best case. This value is at the lower end of the range of payback times for existing anaerobic digestion plants without nutrient recovery in the US, i.e. 6.9-8.9 years based on a survey of 24 plants. The NPV after 20 years amounted to about 3.5 M $, resulting in average net financial benefits of $ 2 M $ m⁻³ manure yr⁻¹ (40 $ ton⁻¹ total solids (TS) yr⁻¹) over 20 years. The internal rate of return (IRR), i.e. the discount rate that makes the NPV equal to zero, after 20 years in this case was 18%, which is about the same as the estimated best-case IRR (including subsidies) after 20 years for an operational full-scale resource recovery facility in the Netherlands, i.e. 19-21% (Gebrezgabher et al., 2010). In the worst-case scenario, the
IRR after 20 years was only 5%. Based on the analysis (worst vs. best case), it can be stated that the feasibility of implementing a resource recovery project depends greatly on the heat recovery potential, the marketing potential of the fertilizers, as well as the subsidies obtained.

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**REFERENCES**


Comparative Analysis of Sustainable Acid Alternatives for Ammonia Recovery from Anaerobic Digestate


* BioEngine – Research Team on Green Process Engineering and Biorefineries, Department of Chemical Engineering, Université Laval, 1065 Avenue de la Médecine, Québec City QC, Canada.
** Anaergia Inc., 4210 South Service Road, Burlington ON, Canada.
*** CentrEau, Université Laval, 1065 Avenue de la Médecine, Québec City QC, Canada.
+ Corresponding author’s email address: celine.vaneeckhaute@gec.ulaval.ca

Abstract: This work compares the performance of organic acids that could be utilized for ammonia recovery from anaerobic digestate. Citric and acetic acids were tested in a bench-scale stripping-scrubbing experimental setup. Citric acid was found to give excellent recovery performance equivalent to that of the most commonly applied sulfuric acid, but required double the acid dosage due to its partial dissociation characteristics. Acetic acid performed satisfactorily at low temperature and was susceptible to vaporization due to stripping effect in the scrubbing unit. Economic and safety comparisons among the acids demonstrated that citric acid could be feasible for full-scale applications given competitive material cost and extended classification of organic fertilizer to include ammonium citrate in its product market.

Keywords: Anaerobic digestion; ammonia stripping; acid air scrubbing

INTRODUCTION The impact of climate change, waste disposal crisis and eutrophication of water bodies are key drivers in the development of circular economy frameworks. In this context, the implementation of anaerobic digestion technology in landfill diversion policies and wastewater treatment plants has enabled the generation of renewable energy and other resources. In anaerobic digestion and resource recovery facilities, air stripping of ammonia is typically integrated with a sulfuric acid scrubbing unit to produce ammonium sulfate, a chemical-based inorganic fertilizer. Sulfuric acid, while the most commonly applied and least expensive scrubbing agent, is prohibited in some regions due to safety and environmental concerns. This study evaluated the ammonia scrubbing efficiency using organic citric and acetic acids for the synthesis of bio-based ammonium citrate and ammonium acetate fertilizers.

MATERIALS AND METHODS Air stripping of ammonia from anaerobic digestate with subsequent acid scrubbing was performed in a bench-scale lab setup of one litre working volume. A moisture trap was placed between the stripper and scrubber to collect condensation in the tubing system. Digestate derived from sewage sludge with a total ammonia-nitrogen (TAN) of 695±80 mg L⁻¹ was aerated at 4.72 L min⁻¹ for ammonia removal. The mass of acids needed to scrub the ammonia was calculated based on an average of 85% ammonia removal efficiency achieved. Stripping and scrubbing temperature was maintained between 67–70 °C while the digestate pH was raised to above 8.5 through a simultaneous ammonia and CO₂ stripping.
RESULTS AND DISCUSSION The ammonia scrubbing performance of the acids is summarized in Table 1.1. The resulting ammonia product solutions were colourless and particle-free. Approximately 90% ammonia recovery was achieved when acids were provided in access, although a low operating temperature (15–18 °C) was required for acetic acid to perform comparably. In these cases, ammonia recovered in the moisture trap due to condensation in the form of ammonia water was in the range of 5.91–6.89%, whereas loses to the atmosphere accounted for 3.21–3.50% of the ammonia stripped. It is noted here that 99.9% ammonia recovery is achievable with the provision of effective excellent mass transfer area in a full-scale scrubber design. Only 70% of the stripped ammonia was recovered when acetic acid scrubbing temperature was set to around 36–40 °C, and the recovery dropped to less than 30% at 66–70 °C. These results can be explained by the Henry’s volatility constant of acetic acid (2.50×10⁻² m³ Pa mol⁻¹) that is at least 1000 times higher than that of sulfuric (7.69×10⁻¹⁴ m³ Pa mol⁻¹) and citric (3.33×10⁻¹⁷ m³ Pa mol⁻¹) acids (Sander, 2015). Stripping effect caused by bubbling ammonia-rich air flow in the scrubbing unit vapourized the acetic acid molecules, resulting in substantial losses of acid at high temperatures. It was also observed that the pH of ammonium sulfate and ammonium citrate product solutions at the end of experiments were below neutral due to the presence of residual H⁺ ions from the non-reacted acid molecules. In all acetic acid scrubbing tests, the final pH of ammonium acetate product solutions was around neutral, hence indicating a concurrent scrubbing reaction and loss to the surrounding of the acid molecules. Following the 90% ammonia recovery efficiency, acid consumption (i.e. scrubbing capacity) was determined by providing sufficient acids that resulted in ammonium product solutions that were pH neutral. Every sulfuric acid molecules dissociated completely to produce double H⁺ ions, leading to lower acid consumption in comparison to its organic counterparts.

Table 1.1 Ammonia recovery performances.

<table>
<thead>
<tr>
<th>Acids</th>
<th>NH₃ recovery (%)</th>
<th>Product solution</th>
<th>Acid consumption (mg acid/mg NH₃)</th>
<th>Moisture trap (%)</th>
<th>Atmosphere (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Citric acid</td>
<td>90.88 ± 3.42</td>
<td>2.37</td>
<td>5.91 ± 0.86</td>
<td>3.21 ± 4.28</td>
<td></td>
</tr>
<tr>
<td>Acetic acid (15–18 °C)</td>
<td>90.12 ± 3.56</td>
<td>5.02</td>
<td>6.58 ± 0.54</td>
<td>3.29 ± 3.01</td>
<td></td>
</tr>
<tr>
<td>Acetic acid (36–40 °C)</td>
<td>89.61 ± 0.63</td>
<td>5.25</td>
<td>6.89 ± 0.98</td>
<td>3.50 ± 1.61</td>
<td></td>
</tr>
<tr>
<td>Acetic acid (67–70 °C)</td>
<td>70.32 ± 0.06</td>
<td>n/a</td>
<td>6.24 ± 0.74</td>
<td>23.4 ± 0.68</td>
<td></td>
</tr>
<tr>
<td>Acetic acid</td>
<td>29.83 ± 0.12</td>
<td>n/a</td>
<td>6.40 ± 0.43</td>
<td>63.7 ± 0.31</td>
<td></td>
</tr>
</tbody>
</table>

Through elemental analysis, only Ca, Na and Mg were detected in the ammonium product solutions, and these are macronutrients essential for plant growth. Since air stripping does not remove trace metals, their varying concentrations in the product solutions were presumably originated from the raw acids used or carry over of fine mists of the digestate at almost undetectable levels. A safety review demonstrated that citric acid remains in its liquid form while reacting with ammonia. It also offers storage and handling advantages because its crude anhydrous form is nontoxic and has low reactivity. Acetic acid, however, releases strong pungent odour during handling and operation, and poses critical safety and operational concerns due to its high volatility. An economic analysis showed that the production of ammonium citrate product is feasible given competitive acid cost and profitable product value in organic farming business. This study, therefore, put forth the concept of producing nitrogen-rich organic fertilizer through nutrient recovery from anaerobic digestate.

REFERENCES
Solar Drying in the Vineyard: A Sustainable Technology for the Recovery of Nutrients from Winery Organic Wastes


* GIRO Program, Institute of Agrifood Research and Technology (IRTA), Torre Marimon, E08140 Caldes de Montbui, Barcelona, Spain. francesc.prenafeta@irta.cat; laura.burgos@irta.cat; joan.noguerol@irta.cat; belen.fernandez@irta.cat

** Bodegas Torres, Familia Torres, Carrer de Miquel Torres i Carbó 6, E08720, Vilafranca del Penedès, Barcelona, Spain. mmmercader@torres.es

*** EMA Depuració i Enginyeria de l’Aigua, SL. Avda. Sant Jordi, 176 Bajos, E17800 Olot, Girona (Spain). adm@edepura.com

Abstract: The present study describes a pilot-scale experimental validation of a dynamic solar dryer, combined with a biofilter for controlled atmospheric emissions, which was applied to the dehydration of sewage sludge from a biological plant treating process wastewater in a commercial winery (Penedès designation of origin, Catalonia, Spain). Experiments were performed after the harvest, from September onwards, during the peak generation of sludge. Gaseous emissions were monitored and the final product was characterized for its suitability as an organic fertilizer.

Keywords: Circular economy; organic waste; sewage-sludge; solar-drying.

INTRODUCTION Wine has generally been regarded as a traditional handcrafted product, with strong cultural implications and a reputation as a beverage that contributes to the preservation of historical landscapes. Organic wastes generated during winemaking can be valorised into organic fertilizers, thus improving the environmental, economic, and social sustainability of the vineyard. However, waste processing by conventional methods, such as anaerobic digestion or mechanical dewatering, is usually complex and expensive in wineries since their organic wastes generation is strongly seasonal.

Solar drying has already been applied successfully for the industrial dehydration of agricultural/food products (Singh et al., 2018) but, to our knowledge, there are no reports on the application of this technology for treating winery wastes. Here a pilot experience on the application of a greenhouse-based dynamic solar drier, which also integrated an air biofilter to control atmospheric emissions, is described for the treatment of sewage sludge from the winery wastewater treatment plant.

MATERIALS AND METHODS The greenhouse was designed as a Quonsep shape (LWH: 8.4×1.2×0.7 m). A structural frame of PVC tubes supported a 200 µm low density PET sheet, and a 400 µm PET sheet at the basis for sludge containment. The greenhouse was thermally isolated from the concrete floor by a geotextile cover. Indoor and outdoor temperature (T) and relative humidity (RH), as well as the weight of a sludge sample inside the greenhouse, were monitored online (30 min reading pace). Air from the greenhouse was extracted with a fan (66 W; 1 m³ min⁻¹ nominal flow) and forced into a biofilter. The fan was activated upon the following regime: (i)
turn on at 8:00 and off at 20:00, and (ii) activate only if the indoor RH>50%. The biofilter bed (packed volume 113 L) was a mixture of ripe compost and pine bark (1:5 mass ratio) and was encased in a PVC tube (diameter 31.5 cm). Fresh and dried sludge samples and gas samples taken during the drying process were characterized in physicochemical terms (APHA, 2005).

RESULTS The solar drier was installed at Bodegas Torres (Vilafranca del Penedès, Spain), and operated in two phases. The first experiment was initiated at mid-September 2018 and lasted for 10 days. The greenhouse was loaded with sludge (27.8 kg m⁻²). Subsequent weather conditions were generally sunny and warm (daily average T=18-25°C; RH=59-81%), so that daily maximum indoor temperatures often peaked above 40°C. An average drying rate of 2.2 kg m⁻² d⁻¹ was measured through online weight measurements (Fig. 1.1), but global mass balances yielded an average drying rate of 1.5 kg m⁻² d⁻¹. This difference might be explained by the heterogeneity due to the formation of sludge aggregates (the crust prevented the drying of the core) and by the strong drying gradient along the greenhouse (areas close to the air inlet were drier than those from the exhaust). The emission of methane and ammonia was relatively low, with peak values up to 12 mg m⁻³ after 4-9 days of operation. The emission of VOCs during this period was in average of 76 mg m⁻³ (mainly hydrocarbons, organohalogenes, mercaptans, and phenols). The effectivity of the biofilter in reducing methane was practically null, but ammonia and VOCs were reduced in average by 56% and 19% (this low VOCs removal efficiency might be explained by the emission of the biofilter organic bed).

The drying experiment was extended in a second phase that lasted 28 days, from mid-November to December 2019, during which the TS of the sludge increased up to 86%. The average drying rate during this stage was 0.93 kg m⁻² d⁻¹. The obtained product had a N:P:K ratio of 4.30:1.44:0.04, which is comparable to a that of a typical compost. The dry basis content of copper (112 mg kg⁻¹) and zinc (287 mg kg⁻¹) was below the threshold for Category B stabilized biosolids (according to the Spanish legislation). On the other hand, mass balances demonstrated that total nitrogen loses due to volatilization of NH₃ and N₂O were lower than 6% of the initial total nitrogen.

ACKNOWLEDGEMENTS This research was funded by the Agència Catalana de Residus (project RAÎM). The support of the CERCA Programme/Generalitat de Catalunya and of the Consolidated Research Group TERRA (ref. 2017 SGR 1290) is also acknowledged.

REFERENCES
LIFE- Newbies: Nitrogen Extraction from Water by an Innovative Electrochemical System

F. Ferrari*,**, S. Molenaar***, P. van den Brink****, M. Pijuan*,**, J. Radgenovic**, P. Kuntke*****
* Catalan Institute for Water Research (ICRA), Emili Grahit Street, 101, 17003 Girona, Spain
** University of Girona, 17003 Girona, Spain.
*** W&F Technologies, Noordhaven 88a. 4761 DC Zevenbergen
**** Evides Industriewater, Schaarijk 150, 3063NH Rotterdam, The Netherlands
***** Wetsus, European centre of excellence for sustainable water technology, Oostergoweg 9, 8911MA Leeuwarden, The Netherlands

Keywords: Electrochemical system; nitrogen recovery; wastewater

INTRODUCTION This abstract presents the concept of the recently awarded LIFE NEWBIES project (2018-2021, LIFE17 ENV/NL/000408), a project on the subject of “Environment and resource efficiency” funded by the LIFE-programme. The LIFE NEWBIES project aims at validating nitrogen extraction from water by an innovative electrochemical system for different waste streams. The NEWBIES system was designed and built as a containerized pilot system, which can be deployed at any suitable location for the recovery of nitrogen from process and wastewaters. During this project, the NEWBIES pilot system is being tested and evaluated at several geographical locations. The main objectives of the project are:

- To recover 1 kg of ammonia-nitrogen/day (e.g. as N-based fertilizer) from 3 different waste streams in various geographical locations: rejection water (Girona, ES), urine (Leeuwarden, NL), and landfill leachate (Nieuwdorp, NL).
- To show the feasibility of recovering nitrogen at equal or lower costs and with lower environmental impacts than state-of-the-art nitrogen removal technologies.
- To demonstrate that a useful nitrogen product can be recovered which can be sold to an existing market.
- To bind stakeholders that enable a large scale demonstration project, as a follow-up to the LIFE-NEWBIES project.

This demonstration project is considered necessary to mobilize a wider uptake of the NEWBIES technology. The partners of the project are WETSUS, ICRA, W&F Technologies, and Evides.

MATERIAL AND METHODS
concentrated ammonia-containing stream. Ammonia is recovered from this stream via transmembrane chemosorption/membrane distillation. The effluent of the pilot is a wastewater depleted of ammonia and the final product an ammonium salt solution.

RESULTS The pilot plant will start its operation in July 2019 treating reject wastewater produced in the anaerobic digesters from Girona WWTP. Preliminary results will be presented at the conference. After the successful run in Girona, the pilot will be operated on urine (Leeuwarden in 2020) and on landfill leachate in Nieuwdorp (2021) (Figure 1.2).

ACKNOWLEDGEMENTS This project is funded by the Life Program through the project 2018-2021, LIFE17 ENV/NL/000408
Assessment of the production of biodiesel from urban wastewater-derived lipids

Zuzana Frkova*, Patrick Herr**, Silvia Venditti***, Marie-Louise Uwizeye****, Joachim Hansen*****

*zuzana.frkova@uni.lu
**patrick.herr@remondis.de
***silvia.venditti@uni.lu
****marielouise.uwizeye@uni.lu
*****joachim.hansen@uni.lu

Abstract: By adopting a Circular Economy Package in 2015, European Commission aimed at stimulating transition towards a stronger and more circular economy where waste (including sewage) is no longer recognized as waste, but as a valuable resource of raw materials. This review study assesses the existing methodologies to produce biodiesel from wastewater-derived lipids. Depending on the stage of wastewater treatment where biodiesel would be extracted, it may cover up to 20% of the current European biodiesel demand. Further studies in regards to the biodiesel quality, legislative conditions and techno-economic assessment towards respective transition are needed.

Keywords: Wastewater derived lipids; biodiesel; wastewater valorization

1. Introduction

Due to growing population and increasing prosperity, resources are getting scarce and the necessity for efficient reuse of raw materials increases. Production of biodiesel will remain one of the most important European targets in terms of renewables in transport fuels for future (1).

Industrially today, biodiesel (fatty acid methyl esters; FAMEs) is produced by processing vegetable oil or animal fat. These feedstocks are expensive and to some extent part of the ongoing food vs. fuel discussion. The current recovery and reuse of wastewater-derived lipids (fat, oil, grease; FOG) is limited to biogas production in digesters. The residual (majority) of the lipid potential in sewage is currently not utilized, it is dissolved and gets partially degraded or is being disposed (incineration or deposition in landfill), which brings additional cost to the wastewater treatment plants (WWTPs).

Biodiesel processes commonly use base-catalysed transesterification, where triacylglycerol reacts with 3 molecules of methanol to form three FAME molecules (2) it requires low operating temperature achieving high conversion within couple of hours. However, if the free fatty acid content exceeds 1%, acid-catalyzed transesterification takes place. Although it is much slower, it prevents soaps formation hindering otherwise transesterification and downstream purification (3).
2. Materials and methods

Articles reporting biodiesel extraction from urban wastewaters were reviewed (5–14). It is important to highlight the scarcity of literature presenting both the biodiesel yield and its acid composition. The maximum extraction yields at different stages of wastewater treatment were compared. The assessment of potential supply by biodiesel from urban wastewater-derived lipids was calculated based on facts that i) 30-40% of COD (120 g/d/PE) in urban wastewater influent is FOG (15), ii) population number (EU-28) in 2018 was estimated to 512,710,966 (16), iii) 80% of population (EU-15) is connected to WWTPs (17), and iv) considering the average possible biodiesel production at different stages of wastewater treatment.

3. Results and conclusions

As lipids are readily removed by mixed microbial populations in WWTPs, total FAME yield showed decreasing trend along the treatments: almost 60% originated from EWC (sludge from oil-water separator, considered as hazardous material), 9-15% primary sludge, 6-23% scum from floatation tank, and 0.5-6% from the secondary sludge. At the first glance, fatty acid composition collected from various WWTPs in different countries and stages of treatment did not propose a substantial difference; the content of palmitic (C16:0) and oleic acid (C18:1) were maximal, with stearic (C18:0) and palmitoleic acid (C16:1) behind. However, analysis of variance revealed the type of wastewater, meaning the stage of treatment samples were taken, to be highly significant for some acids (Figure 3.1).

Figure 3.1 Composition of fatty acids in total FAMEs yield in samples collected at different stages of urban wastewater treatment (EWC from oil-water separator, primary sludge, scum and secondary sludge, 1., 2.-3., 4.-10., 11.-16. column respectively). ANOVA significance levels <0.01 and <0.001 are depicted with two and three asterisks, respectively.

The assessment results on potential annual market supply indicated 2.6 – 310.4 10^4 tons (min for secondary and max for EWC sludge) of extractable biodiesel from wastewater. Considering the expected biodiesel demand 14.8 10^6 tons (18), and prospect to transform WWTPs into biorefineries, we may cover in average by 1.2, 5.3, 4.4 and 20.9% (from secondary, scum, primary and EWC sludge, respectively) the European biodiesel market from the wastewater-derived lipids. Such amount cannot be ignored, and if efficiently implemented, it could represent an exploitable resource for biofuel production, an important and desired step towards the circular economy (19, 20).

This study addresses challenges and potential of transition in the urban water cycle; from a linear approach where drinking water is produced, consumed and discharged as wastewater, to a circular approach where lipids are recovered from WW and used as bio-based products. The circular use of raw materials from wastewater demands from the WWTP operators a different way of thinking and working. Within the Interreg-NWE WOW! project (12 partners from 6 countries) we are trying to optimize recovery of carbon-based products and scaling up to real conditions (supported by pilot-plant investigations), equally important is to involve the industry and market parties to use recovered material for bio-based products.
REFERENCES
Exploitation of Solar Energy for Ammonium Sulfate Recovery from Anaerobic Digestate of Different Origin

F. Battista*, D. Bolzonella

Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona.
*Corresponding author: email federico.battista@univr.it

Abstract: Digestate represents the semi-liquid byproduct of the Anaerobic Digestion process. Digestate composition includes a stabilized organic matter content between 20 and 50 g/L, a high content of nitrogen compounds (2-8 g/kg) and of phosphorous compounds (up to 3 g/kg) (Bolzonella et al. 2018). In particular, ammonia presence in digestate is interesting for ammonium sulfate production, a fertilizer which favours plants’ growth (Zarebska et al., 2015). This work investigates the exploitation of solar energy to evaporate the liquid phase of digestate in a lab-scale greenhouse. Digestate vapours, rich in ammonia, are sent in a Drechsler trap, filled with 38% w/w sulfuric acid solution, through three solar air fans. The process has been tested on digestates differing for TS content and origin. It emerged that the process is favoured by digestates with high ammonia content, as those originated from manure, and a TS content of about 10% w/w, which allowed to obtain an ammonium sulfate concentration of about 2 M in the final solution.

Keywords: Digestate; nitrogen nutrient recovery; solar energy

i) Agricultural digestate at wet condition (ADWC), which derived from a biogas plant treating a mixture of bovine manure, chicken manure and rice straw and operating at mesophilic conditions in wet conditions (TS content after AD of about 8% w/w);

ii) Agricultural digestate at dry condition (ADDC), which derived from a biogas plant treating a mixture of bovine manure, chicken manure and rice straw and operating at mesophilic conditions in dry conditions (TS content after AD of about 18% w/w);

iii) Civil wastewater sludge (CWS) from a digester treating a mixture of primary and secondary civil sludge at mesophilic condition. The TS content after the AD was of about 2.50 % w/w;

iv) OFMSW digestate from a reactor working at mesophilic condition. The TS content of digestate after AD was of about 6.00 % w/w.

The digestates were located in a transparent greenhouse exposed to solar irradiation, provided by three solar air fans to favour the aqueous phase evaporation and the
ammonia rich vapours’ addressing to a Drechsler trap filled with 38% w/w sulfuric acid solution (Figure 1.1).

![Solar air-fans, Section shrinkage, Drechsel trap with 38% w/w sulfuric acid solution]

Figure 1.1 The solar greenhouse and its main components.

It emerged that the drying digestate is clearly influenced by weather conditions (temperature and sunny days) but also by the TS content of digestate. In fact, a TS concentration higher than 5% w/w induced to a superficial crust layer which prevented the below aqueous phase evaporation and required an occasionally mixing of digestate. In addition, a too high TS (15-20% TS w/w) content favoured ammonia adsorption on the substrates, reducing the amount potentially recovered and converted in ammonium sulfate. Instead, a low TS content, as in activated sewage sludge digestate, was neither convenient because it meant, consequentially, low initial ammonia concentration too. A good compromise resulted to be a TS concentration of about 10% w/w. Regarding the ammonium sulfate recovery, it was essentially influenced by the origin of digestate. In particular, high protein substrates, rich in nitrogen and ammonia, such as animal manure and food wastes resulted in good ammonium sulfate recovery, with a concentration in the Drechsler trap of about 2 M. On the contrary, digestate rich in inert materials, as OFMSW, or poor TS content, as activated civil sludge, emerged in low or null ammonium sulfate recovery.

The positive results of this study encourage a scale-up of the project with the realization of a new greenhouse provided also by a floor grating to better separate liquid phase of digestate, increasing the drying speed of the process. In addition, the solar fans will be provided by a solar battery to assure a continuous working of the fans, even when solar irradiation misses.

REFERENCES

The cascade biorefinery approach for the valorization of the Spent Coffee Grounds

Federico Battista*, Marco Andreoli, Serena Zanzoni, David Bolzonella

Department of Biotechnology, University of Verona, Verona, 37134

*Corresponding author: federico.battista@univr.it

Abstract: Coffee is one of the most appreciated beverage around the world with a global consumption of 9.3 tons during the 2016/2017 (Pettinato et al., 2019). It has been estimated that 1 kg of coffee generates about 2 kg of wet Spent Coffee Grounds (SCG), for an annual amount of 6 tons generated at international level (Mata et al., 2018). This study will investigate on the cascade biorefinery application for the SCG valorization in high added value products and biofuels.

SCG have been treated with different solvents in order to recover an oil rich in molecules having applications in cosmetic, pharmacological and food industries. Then, the high content of cellulose and hemicellulose make the extracted SCG profitable for bioethanol production by Saccharomyces Cerevisiae fermentation with a preliminary stage of enzymatic hydrolysis for the cellulose conversion in fermentable sugars. Lastly, the solid residues from bioethanol production will be exploited for biogas production by Anaerobic Digestion.

Keywords: Spent Coffee Grounds, cascade biorefinery, added value compounds.

Spent Coffee Grounds (SCG) are among the food wastes most produced in the world (Pettinato et al., 2019). Currently SCG are mainly incinerated or simply collected with the Organic Fraction of the Municipal Solid Wastes (OFMSW) and disposed in landfill. In the last decade, the emerging of the circular economy concept favoured alternative uses for SCG, encouraging the scientific community to investigate the bioenergy production (bioethanol and biogas). Anyway, the new EU Waste Framework Directive supports the “cascade biorefinery approach” for agro-food wastes, where the extraction of valuable biomolecules (even in small quantities) for pharmaceutical, chemical, cosmetic, agronomic applications and the production of high added value compounds are priority. The European Commission, therefore, specifies that bioenergy production should be approached only after these processes, while the wastes disposition in landfill should be avoided (Directive EU 2018/851, 2018.
Hatzakis, 2019). Moreover, SCG have high content of polyphenols compounds, in particular of chlorogenic acid which, with its isomers and derivatives, are known to be antioxidants, to have effects against inflammation, to reduce the risk of cardiovascular and of liver diseases (Pettinato et al., 2019). Linoleic acid is also present in high concentration in SCG. It has an 18-carbon chain with two double bonds in cis configuration, belonging to the polyunsaturated omega-6 fatty acids family. Linolenic acid prevents skin cancer and diseases of the heart and blood vessels (www.webmb.com). This study will investigate on the cascade biorefinery application for the valorization of SCG (Figure 1).

Figure 1. The cascade biorefinery approach for the SCG valorisation

SCG will be firstly used for the extraction of high economic value molecules, through different polar (ethanol, ethanol-water mixture, methanol) and no polar (hexane, chloroform, octane, toluene and their combination with water) solvents in a Soxhlet apparatus. Preliminary tests allowed to recover a 10% \textit{w/w} coffee oil from SCG by hexane solid/liquid extraction. H NMR analysis found the presence of linoleic acid (25% \textit{w/w}), Cafestol (12% \textit{w/w}) and Kahweol (10\% \textit{w/w}) in the extracted coffee oil. The extracted SCG have been used for the bioethanol and biogas productions. The residual SCG showed a bioethanol concentration and a methane yield of 9.50 g/L and 210 L/KgVS\textsubscript{0}, respectively.

REFERENCES
The Cascade Biorefinery Approach for the Valorization of the Spent Coffee Grounds

F. Battista*, M. Andreolli, S. Zanzoni, D. Bolzonella

Department of Biotechnology, University of Verona, Verona, 37134
*Corresponding author: federico.battista@univr.it

Abstract: Coffee is one of the most appreciated beverage around the world with a global consumption of 9.3 tons during the 2016/2017 (Pettinato et al., 2019). It has been estimated that 1 kg of coffee generates about 2 kg of wet Spent Coffee Grounds (SCG), for an annual amount of 6 tons generated at international level (Mata et al., 2018). This study will investigate on the cascade biorefinery application for the SCG valorization in high added value products and biofuels.

SCG have been treated with different solvents in order to recover an oil rich in molecules having applications in cosmetic, pharmacological and food industries. Then, the high content of cellulose and hemicellulose make the extracted SCG profitable for bioethanol production by *Saccharomyces Cerevisiae* fermentation with a preliminary stage of enzymatic hydrolysis for the cellulose conversion in fermentable sugars. Lastly, the solid residues from bioethanol production will be exploited for biogas production by Anaerobic Digestion.

Keywords: Spent coffee grounds, cascade biorefinery, added value compounds

Spent Coffee Grounds (SCG) are among the food wastes most produced in the world (Pettinato et al., 2019). Currently SCG are mainly incinerated or simply collected with the Organic Fraction of the Municipal Solid Wastes (OFMSW) and disposed in landfill. In the last decade, the emerging of the circular economy concept favoured alternative uses for SCG, encouraging the scientific community to investigate the bioenergy production (bioethanol and biogas). Anyway, the new EU Waste Framework Directive supports the “cascade biorefinery approach” for agro-food wastes, where the extraction of valuable biomolecules (even in small quantities) for pharmaceutical, chemical, cosmetic, agronomic applications and the production of high added value compounds are priority. The European Commission, therefore, specifies that bioenergy production should be approached only after these processes, while the wastes disposition in landfill should be avoided (Directive EU 2018/851, 2018).

Different solid/liquid extraction have been tested polar and no-polar solvents allowing to recover a coffee oil from SCG, whose commercial value is higher than coffee itself. Coffee oil is mainly composed by lipids but contains important bioactive compounds. Between them, two coffee-specific diterpenes, Cafestol and Kahweol, are particularly important for health, being anticarcinogenic substances. Due to the peculiar taste and flavoring, they are used as fundamental molecules for the production of many food products, such as candies, cakes, and beverages. Consequentially, Cafestol and Kahweol find several application in pharmaceutical and food sectors (Williamson and Hatzakis, 2019). Moreover, SCG have high content of polyphenols compounds, in particular of chlorogenic acid which, with its isomers and
derivatives, are known to be antioxidants, to have effects against inflammation, to reduce the risk of cardiovascular and of liver diseases (Pettinato et al., 2019). Linoleic acid is also present in high concentration in SCG. It has an 18-carbon chain with two double bonds in cis configuration, belonging to the polyunsaturated omega-6 fatty acids family. Linolenic acid prevents skin cancer and diseases of the heart and blood vessels (www.webmd.com). This study will investigate on the cascade biorefinery application for the valorization of SCG (Figure 1).

![Figure 1.1 The cascade biorefinery approach for the SCG valorisation](image)

SCG will be firstly used for the extraction of high economic value molecules, through different polar (ethanol, ethanol-water mixture, methanol) and no polar (hexane, chloroform, octane, toluene and their combination with water) solvents in a Soxhlet apparatus. Preliminary tests allowed to recover a 10% w/w coffee oil from SCG by hexane solid/liquid extraction. H NMR analysis found the presence of linoleic acid (25% w/w), Cafestol (12% w/w) and Kahweol (10% w/w) in the extracted coffee oil. The extracted SCG have been used for the bioethanol and biogas productions. The residual SCG showed a bioethanol concentration and a methane yield of 9.50 g/L and 210 L/KgVS0, respectively.

REFERENCES


Williamson K., Hatzakis E., 2019. NMR analysis of roasted coffee lipids and development of a spent ground coffee application for the production of bioplastic precursors. Food Research International, IN PRESS.
Nutrients Recovery from Wastewater by Struvite precipitation: Influence of pH and Temperature


*Universidad de Antioquia UdeA, calle 70 No. 52 - 21 Medellín-Colombia.
carolina.gonzalez@udea.edu.co; francisco.molina@udea.edu.co; diana.lopez@udea.edu.co;
carlos.pelaez@udea.edu.co.
** IRTA, Torre Marimón E08140 Caldes de Montbui, Barcelona, Spain. belen.fernandez@irta.cat
*** University of Leeds, Leeds LS2 9JT, UK. M.A.Camargo-Valero@leeds.ac.uk

Abstract: Struvite was produced in batch reactors from municipal centrates, under three pH (8, 9 and 10) and three temperatures (25, 33 and 40°C) regarding the optimization of its particle size, to enhance its agronomic properties. The results showed that the optimum pH and temperature to obtain large precipitates (78 µm) were 9 and 25 °C, respectively. The temperatures of 33°C and 40°C are not recommended because at 33°C the amount of amorphous material increased and at 40°C ammonia losses were induced due to volatilisation.

Keywords: Struvite crystallisation; nutrient recovery; municipal wastewater treatment plant.

INTRODUCTION The precipitation of struvite (MgNH4PO4·6H2O) represents an opportunity for resource recovery (N and P) from nutrient-rich liquid wastes (i.e., centrate from wastewater treatment plant (WWTP)). Struvite is considered a slow-release fertiliser, ideal for agriculture as it reduces nutrient run-off and subsequent impacts on water bodies (Guadie et al. 2014). In order to increase nutrient uptake by plants and crops, the particle size of struvite crystals should be large enough (2 mm) to have a longer effect on soils (Tarragó et al., 2016) and increase the crushing strength (Muhmood et al. 2019). Previous works conducted on the pH and temperature effect on struvite particle size are so far inconclusive (Ariyanto et al., 2017; Hutnik et al. 2013); therefore, the aim of this work was to identify the optimum pH and temperature values for struvite crystallization process, focused on its use in agriculture.

MATERIALS AND METHODS Centrate samples, collected in a municipal WWTP (Bradford, UK), were characterized for their pH (7.8), reactive phosphorus (2.5 mgP-PO4³⁻ L⁻¹), ammonium (1.080 mgN-NH4⁺ L⁻¹), calcium (92 mgCa²⁺ L⁻¹), and total alkalinity (4.6 gCaCO₃ L⁻¹). Tests were performed in a standard jar tester for: (i) temperature (25, 33 and 40 °C; water bath); and (ii) pH (8, 9 and 10; NaOH addition). Tests comprised 3 hours of reaction time, followed by 10 hours of sedimentation. Reactants MgCl₂·6H₂O and NaH₂PO₄ balanced the P: N: Mg molar ratio of centrates to 1:8:1.7 and 1:21:1.3 in temperature and pH tests, respectively. Precipitates were air-dried scanning electron microscopy (SEM) characterisation, being the crystals size measured with ImageJ software.

RESULTS AND DISCUSSION Table 1.1 and Figure 1.1 summarize the removal efficiency, the precipitates quantity and size. The effect of temperature and pH on particle size was confirmed, finding the largest particle size at pH 9 (mean 76µm) (20°C) (Fig.1A) and at 33°C (mean 58µm) (pH 9) (Fig.1B).
Due to the high N: P and Mg: Ca ratios, struvite precipitation was favored in comparison with the formation of amorphous calcium and magnesium phosphates. A higher NH₄⁺ removal than expected was found as pH and temperature increased, which could be explained by NH₃ volatilization. Although larger particle sizes were obtained at 33°C (58 µm) and 40°C (49 µm), 33 °C is not recommended for the high formation of amorphous material and 40°C is only recommended if the crystallization process is linked to a system to remove ammonium via ammonia stripping, to avoid environmental risks caused by losses due to ammonia volatilization. The greatest removal of Mg occurred at 33 °C. At this temperature, a combined Mg precipitation as struvite and other salts was possible: the struvite solubility increased as temperature increased until 35°C (then it is decreased; Ariyanto et al., 2017) which left available Mg to form other salts like Mg(OH)₃. This was verified by SEM: a large amount of amorphous material was observed at 33°C. However, the small removal of Ca, that increased as pH increased, may be due to the formation of calcium carbonate (CaCO₃), explained by the alkalinity increase (Capdevielle et al., 2013). Considering the high amount of amorphous materials and ammonia volatilisation at T> 33°C, it is recommended to work at an optimum pH of 9 and temperature of 25°C for the crystallization of 78 µm size struvite particles.

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REFERENCES
Promoting Circular Economy In The Chemical Sector: Resource Recovery From Industrial Brines

S. Meca 1*, X. Martínez1**, A. Casadellà1, D. Ribas1, S. Sahuquillo2, M. Marín2, M. Cano3

* sandra.meca@eurecat.org
** xavier.martinez@eurecat.org
1 Eurecat, Manresa (Spain)
2 TYPSA, Barcelona (Spain)
3 Industrias Químicas del Ebro (IQE), Zaragoza (Spain)

Abstract: This work is focused on the technical demonstration of an innovative process to treat brines produced in silica industry. The new process is based on: a) first Nanofiltration stage using tailor-made membranes produced by regenerating end-of-life reverse osmosis (RO) elements from desalination plants whose fate was a landfill; b) treatment of the concentrate stream produced in the first stage by eutectic freeze crystallization to achieve Zero liquid Discharge. A pilot plant able to treat 2m³/h of the effluent is being operated in a silica industry to demonstrate the technical viability of the process. First results demonstrate that the treatment will allow to recover 70% of water that will be reused in the silica production process and near 20 kg of Na₂SO₄·10H₂O per m³ of brine treated.

Keywords: Industrial brines, end-of-life membrane, eutectic freeze crystallization, resource recovery, circular economy

Brine effluents are currently a big management problem for many industries, due to the high environmental impact and an elevated cost associated to their management. The need for a solution addressing this issue led to the development of zero liquid discharge (ZLD) systems that eliminate brine disposal through the conversion of brine to water and salt, thus treating the brine not as a waste, but as a resource. This approach will reduce operational costs and minimise the environmental impact of industrial operations thorough brines.

Silica industry generates high amounts of saline wastewater (Table 1.1), currently discharged to wastewater treatment plant (WWTP), causing operational problems due to the high concentration of sulphates. Sodium sulphate is a potential by-product; however, as it is stated in the BREF of inorganic chemical industry sector (EC, 2007), the concentration of sodium sulphate in wastewater is too low for its recovery to be economically viable and present problems with the available methods (spry drying, precipitation of gypsum, etc.). In this context, there is a need of a new treatment for these streams in order to manage them in a more sustainable way.

Table 1.1 Mean composition of saline wastewater generated in silica industry.

<table>
<thead>
<tr>
<th>Conductivity (mS/cm)</th>
<th>Turbidity (NTU)</th>
<th>Cl (mg/L)</th>
<th>NO₃ (mg/L)</th>
<th>SO₄ (mg/L)</th>
<th>K (mg/L)</th>
<th>Na (mg/L)</th>
<th>Ca (mg/L)</th>
<th>Mg (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.8</td>
<td>27.3</td>
<td>67.4</td>
<td>1,760</td>
<td>11.8</td>
<td>16,470</td>
<td>434</td>
<td>7,320</td>
<td>38.5</td>
</tr>
</tbody>
</table>
This work, conducted within the ZERO BRINE project, is focused on the technical demonstration of an innovative process to treat brines produced in silica industry. This process is based on: a) a first Nanofiltration process using tailor-made membranes produced by regenerating end-of-life reverse osmosis (RO) elements from desalination plants whose fate was a landfill; b) treatment of the concentrate stream produced in the first stage by Eutectic Freeze Crystallization (EFC) to achieve Zero liquid Discharge. The use of regeneration membranes can reduce the operation cost of the treatment scheme by reducing the cost of membrane acquisition. In addition revenues from Na₂SO₄·10H₂O selling will contribute to make the process economically feasible. Sodium sulphate has a wide range of applications as powered detergent or as raw material in glass industry and pulp&paper industry.

In September 2018, a prototype for membrane stage evaluation with a capacity of 2m³/h was installed in a silica industry located in Zaragoza (Spain) and will be operated until end 2019. It is expected to install EFC prototype on May 2019.

Before pilot plant installation, a pre-treatment was defined in order to avoid scaling problems due to Si, Al and Iron precipitation. The pre-treatment consists in pH increase to 7, to precipitate Fe and Al, followed by UF to remove solids. In addition, before nanofiltration, pH is adjusted to 9 to increase Si solubility.

Regarding regenerated membranes production, the optimal protocol for membrane regeneration was first assessed at lab scale, testing different chemicals and operation conditions to finally obtain membranes able to achieve a suitable quality of water, equivalent to the current quality in the industry, and to achieve a high saline concentrate to be treated by crystallization. Two types of membranes were produced: a) Type I with permeability higher than commercial SW-RO membranes and a rejection similar to BW-RO membranes; b) Type II with permeability higher than commercial NF membranes and a rejection above the lower limit for permeate (water) to be reused. Both types of regenerated membranes will be tested at the pilot plant.

For nanofiltration stage, first results demonstrate good membrane performance, obtaining permeability and rejection comply with the limits established for their reuse at industry level. In addition, high water recovery near 70% is obtained and consequently a concentrated stream able to feed crystallization process.

Finally, EFC is being evaluated by combining modelling tools with lab-scale experiments. Sodium sulphate purity and recovered water quality will be the key points to be addressed during experimentation. Benefits of this technology, as lower energy consumption in comparison with forward feed evaporation, will be demonstrated.

This work will address the topic “Implementation of resource recovery in demo and full-scale”. Results presented will demonstrate the technical and economical viability of the implementation of a resource recovery strategy in the silica industry allowing to reduce water consumption in the company and recover sodium sulphate that can be valorized in several applications.

REFERENCES
Overcoming Sewage Sludge Management Issues Through the Synthesis of Sludge-Based Biochar and Its Use for Sorption of Organic Micropollutants in Wastewater


*Department of Chemistry “Ugo Schiff”, University of Florence, Via della Lastruccia 3 – 50019 Sesto Fiorentino, Florence, Italy (e-mails: ayoub.elghadraoui@unifi.it; bakari.zaineb@gmail.com; cscordo@unifi.it; serena.orlandini@unifi.it; alexandra.antal@stud.unifi.it; lapo.renai@unifi.it; massimo.delbubba@unifi.it)

** GIDA S.p.A., Via di Baciacavallo 36, 59100 Prato, Italy (e-mails: d.fibbi@gida-spa.it, r.camisa@gida-spa.it)

Abstract: The disposal of sewage sludge, nowadays, is a crucial problem for urban and industrial wastewater treatment plants (WWTP). The main strategies for sludge management consist in landfilling, incineration and spreading on agricultural land. However, all these management strategies involve important environmental, logistical and economic problems. In this study, a "zero waste" alternative is proposed for overcoming the problem of sludge management, through the production of sewage sludge-based biochars and plant biomass.

Keywords: sewage sludge reuse; biochar; waste recovery.

The aim of this research is the development of a "zero waste" circular strategy to manage sewage sludge through a thermal-conversion process for biochar production and its utilization as sorption media for wastewater purification.

Sewage sludge disposal is a global environmental issue, which has become crucial in the Italian scenario for urban and industrial wastewater treatment plants (WWTP). The most common methods of sludge disposal are the reuse as soil amendment in agriculture, landfilling and incineration (Kelessidis, A et al 2012). However, all these strategies have a number of drawbacks and limitations, such as high cost and possible environmental impacts (Lombardi et al.). Furthermore, in Italy, recent judgments issued by the regional administrative courts have made the management of sludge even more complex, requiring for the spreading in the soil the satisfaction also for the sludge of contamination threshold concentrations defined in the Legislative Decree 152/2006 (Sentenza). It should also be remarked that there is a lack of specific treatment facilities, especially in Tuscany (Italy).
supports 4,500 €/d for its sludge treatment line and 650,000 €/y for haulage and research of new landfilling destinations.

The use of sewage sludge, mixed with vegetal biomasses for biochar’s production, is an economically advantageous alternative for WWTP compared to traditional solutions. Biochar can be turned into a competitive renewable alternative to traditional activated carbon.

In this research, a comprehensive strategy was performed to overcome the sludge management problem. The effect of the simultaneous variation of biochar synthesis variables on its physicochemical properties and adsorption performance was assessed by the Quality by Design (QbD) workflow. The simultaneous variation of two biomasses (oak and poplar) mixed with different percentages of sludge (from 0 to 30%), deriving from two different wastewater treatment plants, different pyrolysis temperatures (450, 650, 850 ºC) and different contact times (60 and 120 min) was performed by an asymmetric screening matrix. Biochar, in comparison with a commercial activated carbon, have been characterized by porosity indexes, BET surface area and pore size distribution. Furthermore, water-extractable metals and polycyclic aromatic hydrocarbons were measured according to EN 12915-1/2009. Adsorption performances of the synthetized materials were tested, applying Langmuir and Freundlich isotherms, on real effluent wastewaters to simulate actual treatment process conditions. This goal was achieved by investigating priority and priority-hazardous substances, belonging to different chemical classes and characterized by with a range of polarity as estimated by their log KOW values.

REFERENCES
Extraction and Quantification of Bioactive Compounds in Vitivinivulture Residues


*cristiane.lisboa@posgrad.ufsc.br; **jeanmenezes@gmail.com; ***beatriz.lskd@hotmail.com; ****Fernanda.megiolaro@unoesc.edu.br; *****maria.lobo@ufsc.br; ******maria.eliza@ufsc.br.

Abstract: The cultivation of the grape in Brazil is an important economic source of funds, that moves the national and international market. Together with the expansion of this culture, the generation of residues by the viticulture sector has increase. The main residues generated are grape stems, pomace or marc and seeds. The grape stems are separated from the fruit, when they are intended for in nature consumption, as well as for the production of their derivatives. This material has no commercial value and is generally discarded as residues. In this context, the aim of this work was to extracted and to quantify tannic substances present in this material, aiming at its use for the production of new tannin base products. The extraction process of the tannins was carried out in an extractor and a quantification of the compounds by spectrophotometry in 510 and 725nm. The results indicated that the grape stems consist of 16% of condensed tannins and 3.84% of hydrolysable tannins.

Keywords: grape stems, residue recovery, tannin.

The grape culture is one of the largest and oldest in the world. In the year 2018, Brazil produced approximately 1.4 million tons of fruit (EPAGRI, 2018). Amongst the residues generated by the consumption of natural fruit and the production of its derivatives, stems or peduncles are the least valued (Barros et al., 2015). However, its composition indicates this material as an important source of phenolic compounds that may be promising for the transformation industry. The aim of this work was to extract and to quantify tannic substances present in grape stems of specie Vitis labrusca. The Vitis labrusca variety was chosen for being widely spread in Brazil. Acquired in the farm's, the grape stems (Figure 1.1) were oven dried at 60 °C for a period of 12 hours. After this period, they were macerated.

![Figure 1.1 Grape stems.](image)

The process of tannin extraction, which lasted 36 hours, was carried out in a soxleht extractor (Figure 1.2) using water and ethanol as solvents.
The quantification of condensed tannins by spectrophotometrically in 510nm, based on reference curve constructed with different concentrations of catechin. This standard was used because condensed tannins contain only phenolic nuclei and are formed by the condensation of two or more flavonoids, as catechin, epicatechin and leucocyanidin, or a mixture of these. For the hydrolysable tannins, the Folin-Ciocalteu method was used, with the reference curve constructed with different concentrations of tannic acid, in 725nm. The tannic acid standard was used as a hydrolysable tannin; it is probable that this reagent is the best commercially available tannin standard. As from linear equations (Figures 1.3 (a) and 1 (b), the tannin concentrations extracted from the grape stems were calculated.

The samples analyzed presented a percentage of 16.4% of condensed tannins and 3.84% of hydrolysable tannins. This composition is very interesting for industrial processes leather manufacture, adhesives, in particular wood adhesives, ore flotation agents, cement superplasticizer, medical and pharmaceutical applications (Pizzi, 2008). The results herein reveal that grape stems represent a rich source of high added-value compounds with high concentrations of tannin. The dynamics of the use of agricultural by-products promotes economic growth and at the same time contributes to the preservation of the environment.

REFERENCES


Olive Mill Wastewater Valorization through Polyphenol Adsorption and Anaerobic Digestion of the Dephenolized Wastewater

D. Pinelli*, G. Rubertelli*, A. Ragini*, F. Arous**, D. Frascari*

*Dept. of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Italy, davide.pinelli@unibo.it
**Institut Supérieur des Sciences Biologiques Appliquées de Tunis, Université de Tunis El Manar, Tunisia, ajaouani@yahoo.fr

Abstract: Due to their high content in phenolic compounds (0.5-18 g/L) and COD (20-200 g/L), Olive Mill Wastewaters (OMWs) can be valorised as a source of chemicals and energy. The goal of this work is to develop an OMW valorisation multi-step process which comprises: i) the microfiltration of the OMW, ii) the recovery of phenolic compounds by adsorption/desorption and, finally, iii) the anaerobic co-digestion of the dephenolized OMW and the solid obtained from the microfiltration to produce methane. The important co-objective of the process is to produce a treated wastewater suitable for irrigation according to the ISO 16075 standard.

Keywords: anaerobic digestion; polyphenol adsorption; olive mill wastewater

RESULTS A microfiltration system was successfully and effectively applied to pre-treat the OMW and separate the suspended solid. The plant includes: i) a 50 L feed reservoir, ii) a membrane pump, iii) a ceramic circular filter with pore-size average of 0.2 μm. The microfiltration step on the OMW yielded a 98% suspended solid removal with an acceptable loss in polyphenols (9%).

4 neutral sorbents and 1 anionic ion exchange (IE) resin were tested. The polyphenol adsorption was studied by conventional isotherms (21 °C, figure 1) that could be fitted with a Langmuir and that allowed an estimation of the adsorption capacities. AMBERLITE XAD16 with an adsorption capacity of 80 mg polyphenols/g dry resin and IE resin IRA958 with its low cost and high selectivity for polyphenols were selected for the continuous flow tests.

The plant for OMW treatment consisted of: i) a 1-m modular adsorption column, ii) a vacuum distillation unit for the recovery of the desorption solvent (ethanol + HCl 5·10⁻⁴ M) and iii) a 30-L continuous-flow anaerobic digester. The plant was fed with an actual OMW (polyphenols 1.2 g/L, COD 70 g/L, suspended solids 2 g/L). Step disturbance tests were conducted on the adsorption column to assess the packed bed effective porosity (0.89) and longitudinal dispersivity (0.029 m). Adsorption breakthrough tests aimed at completing the resin selection process and optimizing the superficial velocity (1-4 m/h) and bed length (0.5-2.0 m) were performed for both the selected resins. The XAD16N performed better than IRA958 with a higher operating capacity. On the other hand, the characterization of the desorbed products showed very similar and good phenolic compound purities and antioxidant capacities.
Anaerobic digestion tests were conducted on both the dephenolized WW and on the untreated OMW. A 38% OMW dephenolization determined a 33% increase in methane production yield and a 40% increase in methane production rate, with a consequent increase of the revenues from electricity production and decrease in capital cost (smaller digester required). A full characterisation of the final water produced after the polyphenols recovery and the biomethane production was carried out and a tertiary aerobic treatment is necessary to reduce the BOD below the concentration allowed for the use of the treated WW as irrigation water.

CONCLUSIONS This study represents the first attempt to develop an integrated OMW treatment process that includes high-added value product recovery and anaerobic digestion, with the final aim to produce an effluent reusable in agriculture.

**Figure 1.1** Comparison of the polyphenol isotherms of the 5 adsorption resins tested in this work.

**Figure 1.2** Comparison of the adsorption performances (breakthrough) of the two selected resins.

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Extraction of Amorphous Silica from Residue of Mineral Coal Combustion


*felipe.ghedin@posgrad.ufsc.br; **cristiane.lisboa@posgrad.ufsc.br; ***crislaine.maccari@gmail.com; ****jeancarlomenezes@gmail.com; *****maria.eliza@ufsc.br

Abstract: The mineral coal is one of the most widely used sources for electric power generation in the world. Its combustion generates thousands of tons of ash, which are often discarded as residue. This study aimed to extract amorphous silica from fly ash from the combustion of mineral coal from a thermoelectric plant using the alkali fusion process followed by acid leaching. The effectiveness of the silica extraction process was confirmed by X-ray diffraction analysis. The diffractogram fly ash presented crystalline and amorphous phases, the most important being hematite and quartz. In the silica extracted from the ashes, an amorphous band was observed in the 2θ region between 20 and 40°, which is related to the predominantly amorphous state of the silica.

Keywords: Amorphous silica; fly ash; mineral coal

The mineral coal represents an important source of energy, accounting worldwide for 27.1% of the energy matrix (IEA, 2018). However, the main restriction of the use of this source is associated with the strong socio-environmental impact, regarding the degradation of the area explored by the mining, the emission of gases and the generation of coal combustion products (CCPs) during the combustion. The world production of CCPs in 2010 was 780 million tons, largely composed of fly ash and heavy. In Brazil, coal-fired power plants produce an average of three million tons of ash a year, 65-85% of fly ash and 15-35% of bottom ash, being characterized as an environmental impact with potential harmful to the environment, oftentimes this material is disposed of in landfills and in deactivated mines (Levandowski; Kalkreuth, 2009; Heidrich; Feuerborn; Weir, 2013; Robl; Oberlink; Jones, 2017; Toniolo; Boccaccini, 2017). This study aimed to extract amorphous silica from fly ash from the combustion of mineral coal from a thermoelectric plant using the alkali fusion process followed by acid leaching.

The fly ash was collected in a thermoelectric plant, operated by Companhia Carbonífera do Cambuí - situated at the city of Figueira-PR, Brazil. The silica extraction was carried out by the alkaline melting process followed by acidic leaching. In the alkaline melt, at 20g portion of ash was macerated along with 10g of Na2CO3. This mixture was melted at 950 °C for 90 minutes. The material passed through a maceration process until particles of size 500 μm. Then, the acid leaching process was applied, where the samples were given the addition of a 6 molar HCl solution. The mixture was maintained under stirring at 300 rpm, over a period of 90 minutes. After, in 44 μm membranes, the samples were filtered and held at rest until complete formation of a resistant gel. This process lasted approximately 24 hours. The
gel was kept in an oven at 105 °C for 6 h and after cooling, it was washed successively with 10% HCl solution, for the removal of residual iron. Next, the material trapped in the filter was subjected to washing with deionized water until it reached pH 7 and oven dried at 105 °C for approximately 4 hours. The characterization of fly ash and extracted silica was performed by X-ray diffraction (XRD) on the Enraf-Nonius diffractometer model Cade-4, in the scan intervals of 20 between 15 to 70 °. Figure 1.1 presents the fly ash and silica diffractograms, after extraction process through alkaline fusion and acid leaching.

Figure 1.1 X-ray diffraction - fly ash (a) and silica obtained (b).

A chemical analysis of fly ash revealed the presence of various chemical elements such as: Silicon (Si), Aluminum (Al), Iron (Fe), Potassium (K), Calcium (Ca), Sulfur (S), Thallium and Zinc (Zn). The diffractogram of the purified material showed a diffuse peak in the 20 region between 20 and 40 °, which is related to the predominantly amorphous state of the extracted silica. The absence of crystalline element peaks reaffirms the presence of silica in the amorphous phase (Bhagath Singh; Subramaniam, 2017). The proposed methodology was efficient for the extraction of silica in its amorphous state, which was present in mineral coal ash. It was possible to prove that dry fly ash from the combustion of mineral coal in the Figueira thermoelectric plant has in its composition silica, a noble material of commercial value, with great industrial applicability. The recovery of by-products converted into new value-added products is a good example of sustainable practice.

REFERENCES
NBR 16586 de 02/2017; Carvão Mineral Determinação do Teor de Cinzas, Associação Brasileira de Normas Técnicas - Rio de Janeiro.
Nature-based Solutions for Energy and Resources Recovery from Non-Conventional Water Sources (The HYDROUSA Project)


*National Technical University of Athens, School of Civil Engineering, Department of Water Resources and Environmental Engineering, 5 Iroon Polytechniou St., Zographou Campus, 15780, Athens, Greece, 'email: stavroula_kappa@windowslive.com
**alchemia-nova GmbH, Vienna, 1140, Austria
***Brunel University, Department of Civil and Environmental Engineering, Kingston Lane, Uxbridge Middlesex UB8 3PH Uxbridge, UK
****Department of Science and Engineering of Materials, Environment and City Planning, Faculty of Engineering, Polytechnic University of Marche, Ancona, Italy

Abstract: Water demand in the Mediterranean (MED) Region has increased more than twofold during the second half of the 20th century and is expected to increase further in the near future. In the MED countries, approximately 72% of the total water consumption is used in agricultural activities; especially, in the Southern rim countries, water resources are limited and unevenly distributed leading to serious water scarcity problems with almost 80 million inhabitants with less than 500 m³ of water/capita/year. HYDROUSA project aims to address the above complex problem by applying a series of nature-based innovations for energy and resources recovery from non-conventional water sources.

Keywords: Circular economy; wastewater reuse; decentralized wastewater management; resource recovery; desalination

INTRODUCTION Water resources management has become one of the toughest problems in our era. According to United Nations by 2025 one out of three people all around the world will be living in regions experiencing either absolute water scarcity or being under stress conditions. In the last 50 years water demand in the Mediterranean region has increased by 50%, a trend that is expected to go on. The increase of water demand for agricultural or urban use cannot always be satisfied even in cases with almost adequate water resources. Traditional municipal wastewater management in many European countries is mostly addressing public health and environmental issues related to waste storage and disposal. As a result, in many cases municipal wastewater management has been practiced in a non-sustainable way, employing treatment schemes that exert a high energy demand, have a large carbon footprint and contribute significantly to climate change. In Europe only less than 1% of the wastewater treatment plants is currently utilizing technologies for resource recovery from wastewater. The EU Action Plan encourages the investigation and development of new sustainable water services based on the circular economy; closing the water cycle, while enhancing the recovery and reuse of energy and materials, with significant environmental and economic benefits. Within the
framework of this Action Plan, several projects are being implemented to address water management issues. Among them, the HYDROUSA project provides innovative solutions for MED islands in terms of water/wastewater treatment and management, which will close the water loops and will also boost the agricultural and energy profile.

HYDROUSA PROJECT The HYDROUSA Horizon2020 project aims to setup, demonstrate and optimize on-site, innovative nature based solutions (NBS) for the management of a variety of water streams, including wastewater, rainwater, groundwater, atmospheric vapour water and seawater to produce valuable resources, which can then be treated to enrich the domestic water supply and valorised to increase agricultural production and boost the economic activities of water-scarce Mediterranean areas. HYDROUSA aims at closing all water loops at local level, taking advantage of local resources, promoting the concept of decentralized on-site water, materials and energy conservation, treatment and reuse. The HYDROUSA concept will be materialized by implementing 13 innovations in six demonstration sites:

- Upflow anaerobic sludge blanket (UASB), biodiverse constructed wetland (CW) and biogas upgrade for wastewater reuse and energy recovery
- UASB and bio-electrified wetland for wastewater reuse and energy recovery
- In-vessel composting system with integrated odour abatement to manage sewage sludge
- Tropical greenhouse for seawater desalination and production of edible salt
- Water vapour condensation with passive systems to recover vapour water
- Rainwater harvesting and treatment coupled with aquifer storage

![Figure 1.1 HYDROUSA water loops.](image)

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