DWF Danish Water Forum

WATER VALLEY DENMARK

VIA University College

20th Annual DWF Water Research Conference – 27 January 2026

University of Copenhagen, Thorvaldsensvej 40, 1871 Frederiksberg

Introduction

Welcome to the 20th DWF water research conference in corporation with Water Valley Denmark and Via University College. This year we have +40 presentations, posters and abstracts, providing the latest in water research in groundwater, drinking water, wastewater technology, urban solutions, and recovery of resources in wastewater and other sources.

The key-note focus is on how to design the future cities, taking into account that water is a cruzial factor and should be added to all designs. However, water sometimes becomes an afterthought or technical detail, even a problem, threat, or something we need to get rid of. Headlines such as 'conquering the cloudburst" or 'the fight against climate change' insinuate a battle against nature, and such war rhetoric does not help us address the root causes of our planetary crises.

Many of the presentations will be given by young water professionals and Master students, providing the latest from the universities and industries.

Two of the many presentations will be given an award, sponsored by Grundfos or NIRAS, so stay until the Award- and drinks-session at 17.30.

AWARD SPONSORS

…and one of the poster presenters will be awarded with the DWF award as well.

Best regards

Ida Holm Olesen, President of Danish Water Forum

NEW APPROACH IN 2026: Meet a company during the conference: DHI, NIRAS and Rambøll will both have a small stand/booth during the conference, where you can meet their staff for a chat about the future!!

Overview program

Room	Title	From	To
Auditorium 1	**Opening of the conference**	10.00	10.15
Auditorium 1	**PLENUM:** Design as water, Trine Stausgaard Munk, Rambøll Presentation and plenum discussions.	10.15	11.00
Auditorium 1	**Poster session:** Short presentation of the posters Chair: Jesper Goodley Dannisøe, DWF	11.00	11.20
	TECHNICAL SESSIONS		
Auditorium 1	**SESSION 1: Groundwater and water supply** Chair: Ida Holm Olesen, Novafos and Pia Jacobsen, Water Valley Denmark	11.30	13.00
Auditorium 2	**SESSION 2: Water treatment and drinking water** Chair: Hans-Jørgen Albrechtsen, DTU Sustain and Laila Vinther, Fors.	11.30	13.00
Room 1	**SESSION 3: Surface waters** Chair: Uffe Sognstrup Thomsen, AU WATEC.	11.30	13.00
	LUNCH	13.00	13.45
Auditorium 1	**SESSION 4A: Wastewater and PFAS removal**	13.45	15.00

Room	Title	From	To
	Chair: Søren Hvilshøj, NIRAS, and Lotte Bjerrum Friis-Holm, TI		
Auditorium 2	**SESSION 5A: Resources recovery** Chair: Hans-Martin Friis Møller, HMM Consult and Bo Højris, Grundfos	13.45	15.00
	COFFEE BREAK	15.00	15.30
Auditorium 1	**SESSION 4B: Wastewater and PFAS removal** Chair: Søren Hvilshøj, NIRAS, and Lotte Bjerrum Friis-Holm, TI	15.30	17.00
Auditorium 2	**SESSION 5B: Resources recovery** Chair: Hans-Martin Friis Møller, HMM Consult and Bo Højris, Grundfos	15.30	17.00
	DRINKS AND SNACKS	17.00	17.30
	AWARDS and PRIZES	17.30	18.00
	Official closing of the conference	18.00	
	DINNER (By registration only)	18.15	

Booth companies 2026:

Drinking water sponsor: Kilian Water

Detailed timetable for the sessions:

Plenum, Auditorium 1

Time	Presentation
10:00	Welcome, by **Ida Holm Olesen**, President, Danish Water Forum
10:05	Welcome to the university by **Tinatin Tkesheliadze**, PLEN Logistics, by **Jesper Goodley Dannisøe**, Secretary General, Danish Water Forum
10:15	**Keynote:** Design as water, Trine Stausgaard Munk, Rambøll, Presentation and plenum discussions.
10:45	Plenary discussion
11:00	Poster session
11:20	Short break before start of technical sessions
11:30	**Parallel sessions starts**

Auditorium 1	**POSTER SESSIONS**	From 11.00	To 11.20
Chair:	**Jesper Goodley Dannisøe, Danish Water Forum**		

Speakers	Title of the poster
Andrea Mongelli	From Contaminated Aquifers to Drinking Water: Pilot-Scale Insights from the Stengården UPWATER Case Study
Arya Van Alin	Breaking the Biofilm Cycle: Harnessing Osmotic Stress for Fouling Control
Antonio Vigueras-Rodriguez	Conceptual modelling of the hydraulic influence of planned distribution of bio-retention cells upstream from pedestrian crosses within the city of Murcia (Spain)
Simón Diego Díaz Quezada	Process integration with membrane technologies for lithium enrichment from multicomponent geothermal brines
Julien Fernandez	UV/Carboxylic Acids Photochemistry for PFAS Degradation - A Novel Scalable, Green and Cost-Effective Treatment Process
Zirui Luo	Enhancing Ultrasonic Cavitation for PFAS Elimination by Surfactants: Performance and Mechanisms
Charlotte Skjold Qvist Danielsen	From Waste to Value: Engineered Biochar as a Circular-Economy PFAS Adsorbent
Alba Rodríguez Otero	Introducing the DAWN project: A data-driven framework for optimized quaternary treatment evaluation
Borja Valverde Péres	Sediment microbial fuel cells (SMFCs) to enhance removal of nutrients and pollutants from creek water in a flow-through system
Sithara Dhinethi Weeratunga	Iron-based biochar for phosphorus sorption

Auditorium 1	**SESSION 1: Groundwater**	From 11.30	To 13.00
Chair:	Ida Holm Olesen, Novafos and Pia Jacobsen, Water Valley Denmark		

Speaker	Title of the presentation
Ronja Forchhammer	Balancing Cost and Accuracy: Minimum Sensor Requirements for Groundwater Data Collection
Mathias Busk Nielsen	Probabilistic decision-support for groundwater management made feasible with artificial neural networks
Georgios Ikaros Xenakis	Decadal trends in groundwater quality observed in national groundwater monitoring wells – assessment of climate change effects using machine learning.
Elisa Bjerre	Estimating Groundwater Recharge Variability in a Semi-Arid South African Catchment using Machine Learning
Radoslaw Marcin Guzinski	Mapping actual evapotranspiration with satellite data from field to global scales

Auditorium 2	SESSION 2: Water treatment and drinking water	From 11.30	To 13.00
Chair:	Hans-Jørgen Albrechtsen, DTU Sustain, and Laila Vinther, Fors		

Speakers	Title of the presentation
Kasper Trans Møller	WtX: Water treatment for Power-to-X
Lorenna Alves Xavier	Cleaning during the membrane distillation using geothermal water
Borja Valverde Péres	Bioelectrochemical systems for simulatenous nitrate removal and organic micropollutant degradation at low temperatures
Alen Simonic	Identification of candidate degraders of organic micropollutants in methanotrophic microbiomes
Agata Magdalena Pruss	Day-to-day practical management of UV disinfection at water works – are we doing it right?

Room 1	SESSION 3: Wetlands and surface waters	From 11.30	13.00
Chair:	Uffe Sognstrup Thomsen, AU WATEC		

Speakers	Title of the presentation
Trine Dalkvist	VUDP – RegnKvalitet+: Improving the assessment of hazardous substances in stormwater discharges
Alba Martinez I Quer	Molecular and chemical monitoring of Danish “mini-wetlands” to evaluate long-term water treatment and pollutant retention
Clément Franey	National-scale DEM-derived Stream Geomorphometry for Enhanced Flood Modelling
Lineker Goulart Coelho	Combining Nature-based Solutions and digitalization tools to support climate adaptation and resilience in stormwater infrastructure

Auditorium 1	SESSION 4A: Wastewater and PFAS	From 13.45	To 15.00
Chair:	Søren Hvilshøj, NIRAS and Lotte Bjerrum Friis-Holm, TI		

Speakers	Title of the presentation
Zhiguo Su	Distinct ARG profiles associated with class 1 integrons in municipal and industrial wastewater treatment plants
Xinhui Wang	Searching for N2O respiring bacterial catalysts
Sadiye Kosar	Profiling Microbial Signalling in Wastewater Biofilms: towards a better understanding of bioflocculation and biofilm formation
Fabio Polesel	Model-based identification of suitable quaternary treatment configurations for the removal of micropollutants: The case of Bisphenol A

Auditorium 1	SESSION 4B: Wastewater and PFAS	From 15.50	To 17.00
Chair:	Søren Hvilshøj, NIRAS and Lotte Bjerrum Friis-Holm, TI		

Speakers	Title of the presentation
Sofie Thorgaard	4th Treatment Stage – Treatment of Pharmaceutical Residues at Egå Wastewater Treatment Plant
Vasileia Stoumpou	Mitigations strategies for anaerobic digestion of saline sludge
Kai Bester	The path of benzalkonium compounds (Rodalon) into the environment
Jan-Max Arana Juve	Best Practices for Experimental Design, Testing, and Reporting of Aqueous PFAS-Degrading Technologies
Christian Wieth	Circular Wastewater Filtration with Biosolids Biochar for PFAS and Pharmaceuticals Elimination in the 4th treatment stage

Auditorium 2	SESSION 5A: Resources recovery	From 13.45	To 15.00
Chair:	Hans-Martin Friis Møller, HMM Consult		

Speakers	Title of the presentation
Case van Genuchten	Rethinking arsenic in groundwater treatment by-products: Carcinogen to be disposed or resource recovery opportunity?
Tinatin Tkesheliadze	Phosphate Recovery from Groundwater Treatment Sludge is Governed by Solid-phase Speciation
Thomas William Seviour	Valorizing extracellular polymeric substances: Recovery method confounds characterization and processing
Amir Gholipour	Innovative green solutions: sludge-derived fertilizers free from PFAS and antibiotics

Auditorium 2	SESSION 5B: Resources recovery	From 15.50	To 17.00
Chair:	Hans-Martin Friis Møller, HMM Consult		

Speakers	Title of the presentation
Pietro Postacchini	Advanced treatment of wastewater from fish industry to produce bioenergy and microbial proteins
Imen Bousrih	Membrane Crystallization for Industrial wastewater: Influence of Pre-Concentration Strategies on Crystal Formation
Hussein Fairousha Sulaiman	High-Quality Water Recovery Towards Zero Liquid Discharge from Industrial Wastewater Using Membrane Distillation
Noah Christy	Application of anaerobic membrane bioreactor for water, nutrients and energy recovery in an urban-industrial symbiotic context
Asif Saud	Magnesium sulphate recovery from seawater using photothermal membrane crystallization

Table of Contents

Reserved the date already now:

Danish Water Forum Water Conference 2027:

Date: 2 February 2027

Venue: Via University College, Kolding

POSTER SESSION:

Auditorium 1, Chair Jesper Goodley Dannisøe, Secretary General, Danish Water Forum

Speakers	**Title of the posters**
Andrea Mongelli	From Contaminated Aquifers to Drinking Water: Pilot-Scale Insights from the Stengården UPWATER Case Study
Arya Van Alin	Breaking the Biofilm Cycle: Harnessing Osmotic Stress for Fouling Control
Kasper Trans Møller	Vandternativet: Alternative water sources to produce technical-grade water for industrial use
Antonio Vigueras-Rodriguez	Conceptual modelling of the hydraulic influence of planned distribution of bio-retention cells upstream from pedestrian crosses within the city of Murcia (Spain)
Simón Diego Díaz Quezada	Process integration with membrane technologies for lithium enrichment from multicomponent geothermal brines
Julien Fernandez	UV/Carboxylic Acids Photochemistry for PFAS Degradation - A Novel Scalable, Green and Cost-Effective Treatment Process
Zirui Luo	Enhancing Ultrasonic Cavitation for PFAS Elimination by Surfactants: Performance and Mechanisms
Charlotte Skjold Qvist Danielsen	From Waste to Value: Engineered Biochar as a Circular-Economy PFAS Adsorbent
Alba Rodríguez Otero	Introducing the DAWN project: A data-driven framework for optimized quaternary treatment evaluation
Borja Valverde Péres	Sediment microbial fuel cells (SMFCs) to enhance removal of nutrients and pollutants from creek water in a flow-through system
Sithara Weeratunga	Iron-based biochar for P sorption

From Contaminated Aquifers to Drinking Water: Pilot-Scale Insights from the Stengården UPWATER Case Study

Andrea Mongelli, AU-ENVS, Kai Bester, AU-ENVS***

Abstract

The European project UPWATER (upwater.eu) addresses the challenge of groundwater contamination by pesticides through the development and testing of innovative nature-based solutions to ensure drinking water safety. The Stengården case study (Kirke Hvalsø, Denmark) focused on the implementation of a pilot treatment plant combining Moving Bed Biofilm Reactors (MBBRs) and biofilters, with a technological challenge arising from the naturally high iron concentrations in the groundwater (30 mg/L). The objective was to evaluate the removal efficiency of pesticides such as mecoprop (MCPP), dichlorprop (DCPP) and their metabolites, as well as the influence of environmental factors (iron, oxygen and temperature).

The MBBR + biofilter combination achieved high removal rates (85% for the parent and 60% for the metabolites), reaching concentrations compliant with EU drinking water standards for the parent compounds (0.1 µg/L) but not for the metabolites.

Significant correlations between removal and temperature as well as dissolved oxygen were observed. Elevated iron concentrations (>30ng/L) negatively affected MCPP degradation, while DCPP remained unaffected.

The Stengården case confirms the potential of natural based solutions as a green, effective, and cost-competitive approach to safeguarding drinking water quality in pesticide-impacted aquifers.

*am@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

**kb@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Breaking the Biofilm Cycle: Harnessing Osmotic Stress for Fouling Control

Arya Van Alin[,**], Jan Poulsen[**], Dominique Evans[**], Freja Poulsen[**], Kasper Urup Kjeldsen[**], Klaus Koren[**], Rikke Meyer[*,**]*

Introduction

Biofouling, caused by microbial biofilm formation, is a major operational challenge in reverse osmosis (RO) systems, reducing operational efficiency and increasing maintenance costs. Conventional chemical treatments are often insufficient and environmentally unsustainable. Batch RO introduces fluctuating salinity conditions that may offer a non-chemical alternative to biofouling control.

Methods

This study investigates whether salinity oscillation can suppress microbial growth and delay biofilm development by exploiting microbial stress responses to osmotic fluctuations. We address this question using several experimental model systems that allow us to oscillate salinity and measure the effects on planktonic and biofilm growth, and on pre-formed biofilms. Viable bacteria were quantified by CFU, and biofilms were imaged by laser scanning microscopy (CLSM), scanning electron microscopy (SEM), and optical coherence tomography (OCT), chemically characterised by Fourier-transform infrared spectroscopy (FTIR) and energy-dispersive X-ray spectroscopy (EDX), and metabolic activity was quantified through measurement of oxygen uptake.

Results

Initial characterisation revealed that both RO and tap water microbial consortia could grow across salinities from 0-4%, with only a small fraction (~0.1%) surviving at 5-10% salt concentrations. Adaptation experiments demonstrated that communities grown at low salinity (0-2%) became vulnerable to high salinity exposure, while those adapted to intermediate salinities (4-6%) maintained tolerance across broader ranges. Critically, communities adapted to extreme salinities showed reduced growth rates but retained viability when exposed to contrasting conditions. Hence, salinity oscillation may inhibit growth but does not impact the viability of the microorganisms.

Using an insert-well model to test planktonic populations, we found that three cycles of salinity oscillation between 0-5% significantly inhibited growth, while oscillations between 0-0.5% and 0-2.5% showed minimal effects. We then used flowcells to study biofilm growth after initial seeding of an inoculum and confirmed the inhibition of biofilm growth at 0-5% oscillation. The effect of salinity oscillation on established biofilms was tested using a Membrane Fouling Simulator. Here, oscillation between 0-5% salinity decreased the metabolic activity of biofilms and caused structural changes, including initial swelling followed by shrinkage. After three oscillation cycles, 30-40% of the biofilm detached from the membrane surface.

Conclusion

These findings demonstrate that strategic salinity oscillation, particularly at higher amplitudes (0-5%), delays biofouling without completely eradicating bacterial communities. This approach offers a promising environmentally-friendly alternative or complement to traditional chemical treatments for managing biofilm formation in RO membrane systems

** Interdisciplinary Nanoscience Center (iNANO), Aarhus University, Gustav Wieds Vej 14, 8000 Aarhus, Denmark*

*** Department of Biology, Aarhus University, Ny Munkegade 114, 8000 Aarhus, Denmark*

Authors' email addresses: arya.vanalin@inano.au.dk, jstp@teknologisk.dk, dominique.evans@bio.au.dk, 202205953@post.au.dk, klaus.koren@bio.au.dk, kasperuk@bio.au.dk, rikke.meyer@inano.au.dk

Vandternativet: Alternative water sources to produce technical-grade water for industrial use.

Kasper T. Møller, Teknologisk Institut Project Partners: Lemvig Vand A/S, Fors A/S, Vestforsyning A/S, Montrose Environmental Group Denmark ApS, SUEZ Water A/S, Foreningen Klimatorium, and Teknologisk Institut. The project is funded by MUDP.*

Introduction

Denmark is facing a dual water challenge: the primary source of drinking water, groundwater, is increasingly threatened by contamination (pesticides, PFAS) and strained by rising industrial demand, particularly from the emerging Power-to-X (PtX) sector. Simultaneously, climate change is causing an excess of water in other parts of the water cycle, such as increased rainfall and higher near-surface groundwater levels, which threatens infrastructure and ecosystems. The "Vandternativet" project addresses this paradigm by reframing problematic water sources as valuable resources. The project's core idea is to develop and demonstrate robust, economically viable systems that utilize alternative water sources—specifically near-surface water and treated wastewater—to produce technical-grade water for industrial use.

Methods and Data

The project is structured around three distinct cases, each led by a Danish water utility, to test and validate solutions across different water matrices and industrial needs:

Lemvig Vand: Focuses on treating the challenging, highly concentrated waste stream (retentate) from facilities that produces ultra-pure water for the PtX industry.

FORS: Aims to produce multiple qualities of technical water from surface water (from a local basin, "Ringen") for industries, replacing the current use of drinking water.

Vestforsyning: Investigates the potential of using treated wastewater as a source for producing technical and ultra-pure water on a pilot scale, generating crucial data for future full-scale applications.

The methodology involves developing integrated "technology trains" by combining and optimizing existing technologies from partners Montrose and SUEZ. The project will progress from initial mapping of water sources and industrial quality requirements through pilot-scale testing to the implementation and operation of two full-scale systems, culminating in a comprehensive socio-economic analysis.

Results

By its conclusion in 2028, the project will deliver several concrete, market-ready outcomes. Central to these will be two full-scale systems (TRL 9): one in Lemvig showcasing cost-effective retentate treatment for the PtX industry, and another in Roskilde producing technical water from surface water. Complementing these, the pilot study at Vestforsyning will establish a proven blueprint for safely upgrading treated wastewater for industrial applications. The project's positive environmental impact will be quantified through the measured reduction of hazardous substances and nutrients entering aquatic environments, actively removing pollutants from the water cycle to protect groundwater and improve ecosystem health. Ultimately, these technical and environmental successes will be consolidated into validated business models, creating a clear pathway for water utilities to enter the industrial water market and support both economic growth and sustainability goals.

Market Potential

The market potential for the solutions developed in "Vandternativet" is significant. The European PtX market alone is estimated to require water technology investments of approximately €2.3 billion (DKK 17 billion) by 2030. The project directly positions technology providers to capture a share of this market with proven, full-scale solutions for both water production and retentate handling. The project pioneers a new business area for utilities that enhances local supply security, attracts water-intensive industries, and creates value from what was previously a cost or a problem, e.g., high groundwater levels. The methodologies and technology blueprints can be adapted for a wide range of industries and deployed across Europe and globally, addressing widespread challenges of water scarcity, quality, and resilience.

Discussion and take-home message

The key takeaway is that "problem water" can be transformed into a secure industrial resource, but this requires a full-cycle approach that also manages the resulting waste streams. This strategy enables a new symbiosis where utilities can protect public drinking water reserves while fostering sustainable economic growth by providing industries with high-quality water produced from alternative water sources.

* ktmo@teknologisk.dk: *Kongsvangs Allé 29, DK-8000 Aarhus C, Denmark*

Conceptual modelling of the hydraulic influence of planned distribution of bio-retention cells upstream from pedestrian crosses within the city of Murcia (Spain)

*A. Vigueras-Rodríguez, J. M. García-Guerrero,A. Matos, F.J. Pérez de la Cruz, J. García-Bermejo, Technical University of Cartagena member of European University of Technology EUT+**

Abstract

Introduction: Spanish cities are looking for a reduction in water bodies pollution at the same time than promoting urban biodiversity. In this way, implementation of Sustainable Urban Drainage Systems (SUDS) arises as a suitable tool. The city of Murcia, a Spanish city of about 470 000 inhabitants located in a semiarid region, is elaborating a SUDS city plan for the center of the city (already constructed). The plan is based on the different elements listed in the city utility's design guide [1], although the assessment of only one of the elements is shown in this work. Particularly, bioretention cells which are replacing previous parking slots before pedestrian crosses. Due to street safety concerns in the areas before pedestrian crossing parking is going to be forbidden in Spain once/if approved a new draft. In this way, it is suggested that those areas can be now redesigned as a bioswale with a small storage capacity and connection to the sewer system, due to limitation in the infiltration capacity in most of the city.

Methods and data: In order to evaluate the influence of the proposed bio-retention cells, a distribution of the bio-retension cells is proposed. Particularly, around 2 000 locations are selected. Figure 1a shows the distribution of those points in one of the areas within the considered subcatchments, whereas Figure 1b shows an example actuation. The bioswales are introduced into SWMM in an automated way by using swmmio [2]. In order to evaluate their effects during events a selection of two events which are between the Three Points Approach proposal [3] and thus inspired by that approach. Particularly a 80-percentile year rain event -the event which is greater than the 80% of the year events- is selected as well as a 10 years return period rain event. The first event is greater than usual day-to-day events, in which the whole set of SUDS proposed for the city are designed for, whereas the later event is between the urban storm design periods and the extreme periods.

Moreover, other conceptual simple models to represent the behaviour of the catchments with the bioswales is also assessed.

Results: For both kind of events, the peak flows, volumes, delayed volumes as well as overflows are compared for the base case and considering 50% and 100% of the proposed bioswales. Moreover, the simplified conceptual models are also compared with the detailed ones to show to what extend the can provide some quantification.

Discussion and take-home message:

- Quantifying the influence of SUDS is of major relevance and software libraries make easier to incorporate a large number of them.

-Simplification of models and/or the selection of rain events considered are needed when used to developed a city plan.

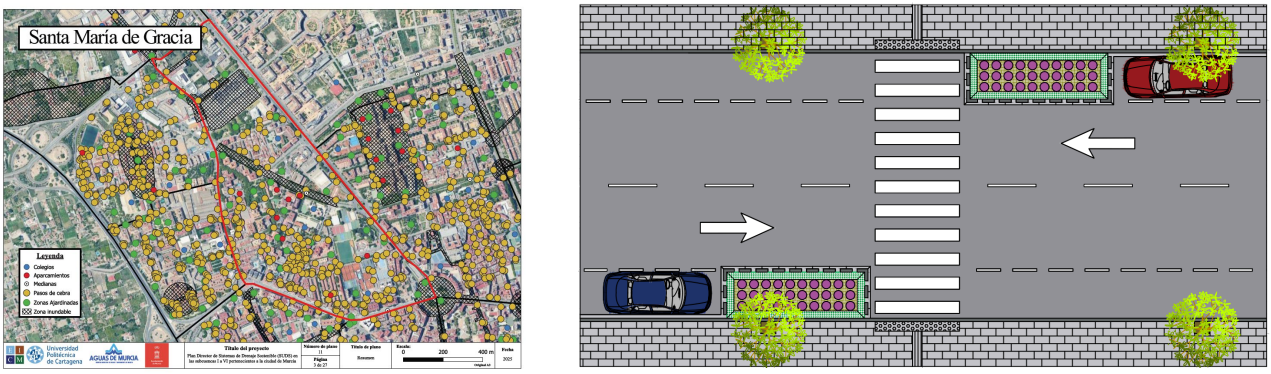


Figure 1: a) On the left a plain of a district of Murcia is shown. There the yellow points represent locations where a bioswale can replace existing parking slots before pedestrian crossings. b) On the right a representation of a type of replacement, which can vary depending on the street layout, is shown.

References:

[1] Perales Momparler, S. et al. (2023). Guía básica de diseño de Sistemas Urbanos de Drenaje Sostenible (SUDS) en el Término Municipal de Murcia. EMUASA.

[2] Erispaha. A. et al. (2025). Swmmio 0.8.2. Available online: https://swmmio.readthedocs.io/en/v0.8.2/.

[3] Sørup, H.J.D. et al. (2016). Efficiency of stormwater control measures for combined sewer retrofitting under varying rain conditions: Quantifying the Three Points Approach (3PA). *Environmental Science & Policy*, 63, 19.

* avigueras.rodriguez@upct.es: *Paseo Alfonso XIII, 52, 30203 Cartagena, Spain*

Process integration with membrane technologies for lithium enrichment from multicomponent geothermal brines

S. Díaz-Quezada[*1], L. Alves X.**[1], A. Ali***[2], C. A. Quist-Jensen****[1]*

[1] *Center for Membrane Technology, Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*

[2] *AAU Energy, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg East, Denmark*

*sddq@bio.aau.dk, **lax@bio.aau.dk , ***aal@energy.aau.dk , ****cejna@bio.aau.dk

Introduction

Geothermal brines represent both a challenge and an opportunity for Europe's green transition. They are characterized by high salinity and the presence of critical raw materials such as lithium. This work explores integrated process configurations combining membrane crystallization (MCr) with complementary pretreatment routes to enable both water recovery and selective enrichment of lithium.

Methods and data

We evaluate alternative process trains by combining mass balances in MATLAB with PHREEQC simulations of thermodynamic equilibria. The selected configurations include: (i) MCr fractionation of salts, (ii) CO_2 reutilization for mineralization to precipitate Ca as $CaCO_3$, (iii) direct chemical softening with $NaHCO_3$, and (iv) nanofiltration (NF) for divalent cation removal. Each route is analyzed in terms of water recovery potential, scaling mitigation, and lithium enrichment.

Results

Preliminary simulations identify the precipitation sequence under each configuration, showing how early Ca and Mg removal can reduce scaling and improve lithium partitioning in the final concentrate. Among the alternatives, CO_2 mineralization offers a dual benefit by coupling brine softening with carbon capture. NF pretreatment achieves effective Ca/Mg separation but requires external infrastructure, while $NaHCO_3$ softening provides a simple chemical route at the expense of reagent consumption.

Market potential

Integrating MCr with upstream Ca-removal processes can create viable pathways for lithium enrichment while valorizing coexisting salts. The resulting concentrates provide a suitable feed for subsequent conversion into LiOH or Li_2CO_3, directly aligned with European strategic interests in critical raw materials.

Discussion and take-home message

1. Mass balance + PHREEQC screening enables early-stage comparison of integrated brine treatment trains.
2. CO_2 mineralization, $NaHCO_3$ softening, and NF offer complementary pathways for Ca/Mg removal prior to MCr.
3. Membrane crystallization provides a selective route for fractionated salt management and lithium enrichment, generating suitable precursors for LiOH or Li_2CO_3 production.

Acknowledgement: The Authors acknowledge financial support from the Danish Eco-Innovation Programme (MUDP) under the Danish Ministry of the Environment.

UV/Carboxylic Acids Photochemistry for PFAS Degradation- A Novel Scalable, Green and Cost-Effective Treatment Process

J. Fernandez, A.L. Damgaard, T. Chen, J. Ferløv, Y. Zhang**, DTU Sustain*

Introduction

Per- and polyfluoroalkyl substances (PFAS) are among the most persistent and hazardous contaminants in the environment, resisting natural degradation and accumulating in water, soil, and living organisms. Their persistence poses long-term risks to human health and ecosystems, while the lack of cost-effective and scalable treatment technologies leaves utilities and industries dependent on adsorption and subsequent incineration. These conventional approaches are not only expensive but also logistically complex, energy-intensive, and generate greenhouse gases. To address this challenge, we develop a novel green photochemical process combining UV irradiation with biodegradable short-chain carboxylic acids. These small carboxylic acids, which can be sourced from biomass and food waste, generate reactive species upon UV excitation that directly mineralize PFAS into harmless fluoride and CO_2.

Methods and Data

Experiments were performed on $PFAS_4$ mixtures (PFOA, PFOS, PFNA, PFHxS), as well as GenX and TFA, which are particularly challenging to degrade. Tests were conducted in both synthetic solutions and real ground and waste-water matrices from Danish utilities, using different setups from few hundreds of mL to a 5L closed-loop system (see picture below), and lamps from 9W to 18W. Short-chain carboxylic acids, namely methanoic (formic, HCOOH) and ethanoic acids (acetic, CH_3COOH), the two simplest carboxylic acids, were used, in combination with UVC (254 and/or 222 nm) lamps (DTU patent). PFAS concentrations were measured by LC-MS, and defluorination was monitored with ion-selective methods. In parallel, ongoing EPR spectroscopy is being conducted to investigate radical formation pathways.

Results

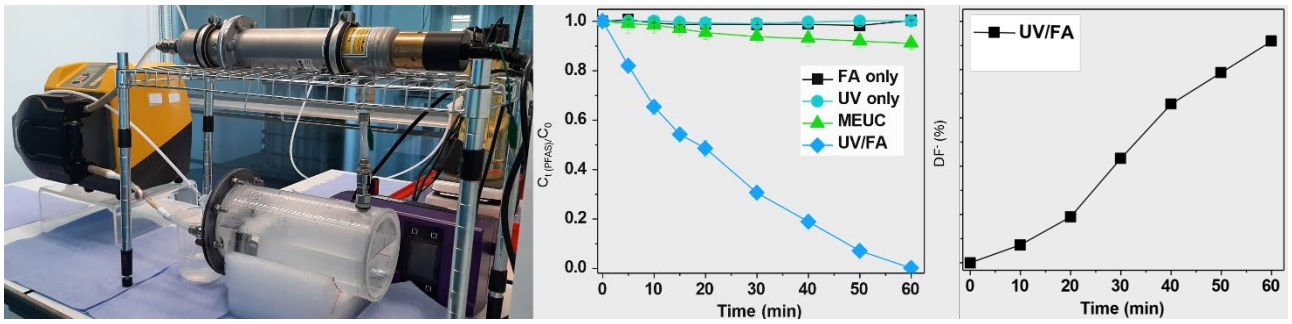
The UV/CA acid process achieved >99% degradation of $PFAS_4$ and >95% defluorination within one hour, with no regulated byproducts detected above ng/L levels. Importantly, early-stage experiments also demonstrate degradation of GenX and TFA, indicating broader applicability to emerging and short-chain PFAS compounds. Early results suggest that under the controlled acidic conditions, •H radicals generated from carboxylic acids play a central role in PFAS breakdown. Compared to UV/sulfate or UV/peroxide approaches, this process is faster, safer, and avoids reliance on toxic or costly reagents.

Market Potential

Utilities currently spend billions of euros on PFAS management, largely due to transport and incineration. A compact, on-site solution that integrates into existing infrastructure could cut treatment costs by up to 90% while eliminating greenhouse gas emissions from incineration. Industries producing PFAS-based materials also represent a significant customer segment for highly concentrated wastewater treatment. Our ongoing and future studies will investigate scalability using a pre-pilot 100W, 254 nm, UV reactor and continuous water flow. This next step will allow to develop and demonstrate the process and make it ready for on-site destruction, through partnerships with Danish and European utilities.

Discussion and Take-Home Message

This work establishes UV/carboxylic acid photochemistry as a promising technology for PFAS remediation. Key benefits include: (1) complete mineralization without toxic byproducts, (2) use of safe and biodegradable reagents, (3) integration with existing UV systems, and (4) effectiveness even against difficult compounds such as GenX and TFA. Mechanistic insights from EPR measurements highlight the role of •H radicals in defluorination, opening new pathways for designing optimized radical-driven PFAS treatment. Together, these findings point to a sustainable, cost-effective alternative for PFAS waste treatment that can be scaled from lab to pilot and to full-scale deployment.



* jufe@dtu.dk: Bygningstorvet, Building 115, R-222, 2800 Kgs. Lyngby, Denmark
** yifz@dtu.dk: Bygningstorvet, Building 115, R-214, 2800 Kgs. Lyngby, Denmark

Enhancing Ultrasonic Cavitation for PFAS Elimination by Surfactants: Performance and Mechanisms

Zirui Luo, Zongsu Wei**, Centre for Water Technology (WATEC), Department of Biological and Chemical Engineering, Aarhus University*

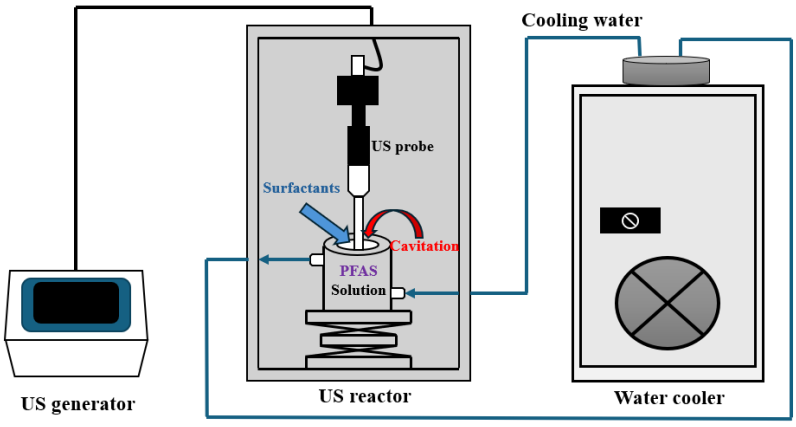
Abstract

Introduction: Sonication treatments are highly effective at defluorinating per- and polyfluoroalkyl substances (PFAS), but the ultrasound generation are usually high-energy cost. Surfactants are widely used in separation technologies for the PFAS contamination for both in situ and ex situ remediation. To improve the feasibility of this defluorination process, we proposed a surfactants-assisted sonication process to further improve the defluorination performance. This study explores the defluorination performance and mechanisms of the US/Surfactants process for five representative PFAS compounds: PFOA, PFOS, PFBA, PFBS and GenX.

Methods and data: Experiments were carried out in a cylindrical, water-jacketed glass reactor equipped with an ultrasonic homogenizer (sonicator)with the probe immersed in solution. The fluoride and PFOA concentrations in samples were measured by IC and UHPLC/MS, respectively. The surfactants properties were analysed by a contact angle instrument using sessile drop contact angle method. The active species were tested by Electron paramagnetic resonance (EPR) spectroscopy. Quenching tests were performed to assess the contribution of these radicals to PFAS degradation. Density functional theory (DFT) calculations were applied to provide theoretically molecular-level insights.

Results: The US/surfactants system achieved up to 11%, 16.25%, 15.23%, 14.15% and 2.53% defluorination enhancement on PFOA, PFOS, GenX, PFBA and PFBS(5μM), respectively. Compared to the defluorination enhancement, the degradation enhancement effects were relatively weaker. The groundwater matrix resulted in obvious effects on the enhancement of surfactants and only achieved3.4% higher defluorination. The dosage experiments and surface tension measurements indicated that even with extremely concentration (1μM of surfactants can still exhibit promising enhancement of PFOA. The quenching experiments indicate that the addition of TBD would conversely increase the PFOA defluorination.

Discussion and take-home message: The addition of surfactants can effectively promote the cleavage of C–F bonds in PFOA, PFOS, GenX, and PFBA, with the extent of promotion primarily determined by the properties of the surfactants, particularly the interaction strength between PFOA and the surfactant molecules. Reduced surface tension was not the key factor driving the enhanced defluorination, nor were free radicals. Instead, improved mass transfer is considered the most significant contributor to the increased defluorination efficiency. In conclusion, the low-dose addition of suitable surfactants can enhance PFAS degradation by sonication, even in groundwater matrix conditions.



** luozirui@bce.au.dk: Ole Worms Allé 3, Building 1171, 8000 Aarhus C, Denmark*

*** zwei@bce.au.dk: Ole Worms Allé 3, Building 1171, 8000 Aarhus C, Denmark*

From Waste to Value: Engineered Biochar as a Circular-Economy PFAS Adsorbent

Charlotte S. Q. Danielsen[1], *Zirui Luo*[1], *Zhiqun Xie*[1], *Zongsu Wei*[1*]

[1]*Department of Biological and Chemical Engineering (BCE), Aarhus University, Denmark*

Introduction: Denmark relies exclusively on groundwater for its drinking water. Rising PFAS levels detected in existing boreholes are increasingly threatening the suitability of several aquifers, which would require active treatment to comply with national drinking water regulations. Commercial treatment technologies, such as granular activated carbon or ion exchange resins, rely on non-renewable and imported resources. Biochar, produced from locally available biomass waste, offers a sustainable alternative with potential for carbon capture and storage (CCS) while enabling waste-to-value solutions. Although pristine biochar typically lacks the adsorption capacity required for PFAS removal, its surface properties can be engineered to enhance performance. In this project, wheat straw-derived biochar was tailored to combine the high surface area and porosity of activated carbon with targeted electrostatic interactions, aiming to develop an efficient, circular-economy-compatible PFAS adsorbent.

Methods and data: Biochar produced by wheat straw pyrolysis was supplied by Stiesdal Skyclean. KOH activation, optimized via DoE, produced the most porous sorbent. Cationic functionalization methods were tested, with H_2SO_4 oxidation followed by Quat188 grafting proving most effective for PFAS capture. Three sorbents were compared: pristine biochar (PBC), KOH-activated biochar (KOH-BC) and quaternary ammonium-grafted KOH-activated biochar (QA-KOH-BC). Batch sorption tests assessed kinetics and adsorption capacities for six perfluorocarboxylates (PFPrA, PFBA, PFPeA, PFHxA, GenX, PFOA) under three conditions: (1) single solute in buffered ultrapure water, (2) stoichiometric mixture in buffered ultrapure water, and (3) stoichiometric mixture in groundwater. Kinetic experiments were conducted at 1 µM PFAS per compound, and isotherms ranged from 0.1 to 1000 µM per compound.

Results: KOH activation increased surface area from 32 to 2145 m²/g, surpassing typical commercial activated carbons (~1000 m²/g). Quaternary ammonium grafting introduced more anion exchange sites and increased surface charge. Structural and surface chemistry modifications were confirmed by BET, XPS, EDS, TGA, Raman, and PZC analysis, among others. PBC showed slow uptake and low adsorption capacity of short-chain PFAS, particularly in groundwater. KOH-BC exhibited high adsorption of short-chain PFAS in mixed solution, though performance decreased in groundwater. QA-KOH-BC displayed the fastest PFAS uptake in all tested solutions. Unlike KOH-BC, QA-KOH-BC capacity decreased in mixed but improved in groundwater, suggesting that complex matrices hinder pore-filling while enhancing adsorption to grafted biochar. The effects of individual competitors (humic acid, $NaNO_3$, Na_2SO_4, NaCl, $MgCl_2$, $CaCl_2$) on PFBA sorption by QA-KOH-BC were tested at elevated concentrations relative to target groundwater. Removal was enhanced by 2 mM Ca^{2+} and reduced by 2 mM NO_3^-, while 3 mg/L humic acid had no observable effect.

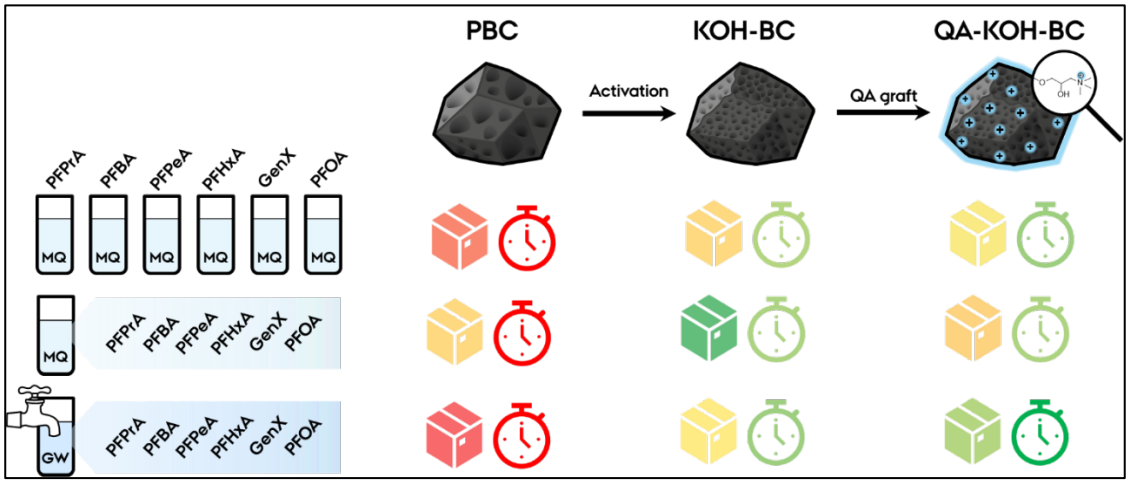


Figure 1. Adsorption capacity (boxes) and uptake rate (timer) of **short-chain PFAS (PFPrA, PFBA, PFPeA)** in different matrixes (MQ: Milli-Q ultrapure water, GW: groundwater) and adsorbents. PFHxA, GenX and PFOA are also included in the project.

Market potential: Waste-derived biochar demonstrates potential for circular-economy PFAS removal (LCA required). Direct application of QA-grafted biochar in drinking water is currently limited due to potential release of quaternary ammonium compounds. Suitable regeneration strategies should be developed.

Take-home message: Low-value biochar can be upgraded to high-performance activated carbons, reducing dependence on imported materials and informing future adsorbent design for efficient groundwater treatment.

Sediment microbial fuel cells (SMFCs) to enhance removal of nutrients and pollutants from creek water in a flow-through system

Anders Nyeggen, DTU, Borja Valverde-Pérez, DTU**, Andreas Libonati Brock, Københavns kommune***, Stefan Trapp, DTU*****

Introduction: The Damhus lake, situated at the border of Copenhagen and Rødovre municipality, is under increasing pressure from nutrient enrichments from combined sewer overflows (CSO) and urban runoff discharges from the inlet river, Harrestrup creek, supplying water to the lake through a pumping station. To mitigate these impacts, sedimentation basins coupled with microbial fuel cells (SMFCs), both with and without biochar, were tested in flow-through conditions to evaluate their potential for pollution removal, representing the first installation worldwide of a flow-through MFC system for water quality improvement.

Methods and data: 15 model reactors on a 1:1000 scale to the final installation were established in parallel in five configurations: controls (regular sedimentation basins), stainless-steel SMFCs, biochar-amended SMFCs, and their open-circuit counterparts, each in triplicate. Inlet water was supplied from Harrestrup creek through a pumping station attached to a tubing system supplying the reactors, each with a working volume of 285 l. The reactors, the system inlet and outlet and the lake were monitored on a weekly basis, following the strategy by Brock et. Al. (2022). Additionally, biochar leaching tests and a sediment gas production experiment were conducted in closed bottle systems.

Results: Monitoring saw values ranging from 50-90 µg/L of total phosphorous, 200-700 µg/L ammonium-N and up to 1400 µg/L of nitrate-N in the creek. Phosphorus measured above the average threshold value of 60 µg/l set by EPA demonstrated a river at risk of algal blooms and with strong need for pollution remediation. In the pilot plant, both biochar-amended and non-amended SMFCs developed stable electrical potentials (up to 750 mV), demonstrating successful inoculation and favorable redox conditions, but limited pollutant removal due to short hydraulic retention times (HRT), preventing sufficient sediment settling times for the systems to remove pollutants. The biochar was found to leach phosphorus up to 676 µg/L under laboratory conditions, but no leaching was seen in the pilot systems. Incubations of sediments saw slightly reduced methane emission with the addition of biochar, with values going from 0.6mL/g in wet sediment incubations down to 0.4mL/g when biochar was added. Additionally, biochar was seen to mitigate the release of sulfide from 0.548mg S/L to values below detection limits.

Market potential: Further research will focus on optimizing HRTs, allowing for solid sedimentation, to properly examine the remediation potential of the SMFCs. Targeted monitoring during CSO events to capture peak pollutant loads will be implemented to optimize the system performance. The findings to date highlight the feasibility of implementing SMFCs in flow-through systems and their promise as a passive, low-energy addition to urban stormwater infrastructure, reducing greenhouse gas emissions and leaching of dissolved nutrients to natural water bodies.

Discussion and take-home message: SMFCs in a flow-through configuration developed stable working potentials and redox conditions, showing promising results for pollution remediation. Further research is expected to optimize performance and clarify the potential for full scale use.

*anyeg@dtu.dk, ** bvape@dtu.dk, ****sttr@dt.dk: Anker Engelunds Vej 1, Bygning 101A, 2800 Kongens Lyngby, ***WD0Y@kk.dk: Hørsholmsgade 20, 2200 København

Iron-based biochar for phosphorus sorption

Sithara Weeratunga, KU-PLEN, Katherine Claire Matthews , Ollie Morgan, Weiyu Wang , Yining Hou, Peter Engelund Holm,' KU-PLEN** and Hans Chr. Bruun Hansen, KU-PLEN****

Abstract

Phosphorus (P) leaching to surface water from agricultural lands, primarily due to the intensive use of fertilisers and manure, deteriorating water quality is a global environmental issue dominant in Asia, Europe, and North America. Hence, there is a need for new materials that can retain phosphorus (P) from agricultural drainage water, urban runoff, and wastewater in the form of filters. Current filter materials – typically based on inorganic host materials such as silica – use adsorption by iron- or aluminium-oxides as the key sorbents, or precipitation as Ca-P by calcite or lime. The use of adsorption is desired as it is more environmentally and economically friendly and allows for the regeneration of the filter material (Akintola et al., 2020).

Biochar is one such possible new material. It is a carbon-rich adsorbent, and as it is derived from organic waste sources such as agricultural soil waste and municipal sludge, it is produced cheaply and sustainably from renewable sources (Qin et al., 2022). Biochars are highly porous, have a high surface area, and can be used as an effective CO_2 adsorbent (Akintola et al., 2020). However, pristine biochar has shown poor performance as a P sorbent (Jung et al., 2015; Pathy et al., 2021; Qin et al., 2022; Zhu et al., 2020). Therefore, the addition of strong P sorbents such as iron or aluminium oxides to the biochar is needed. Using a substrate naturally rich in iron often also contains high amounts of phosphorus, e.g. wastewater sludge, and hence would result in risks of P leaching from the resulting biochar. Alternatively, biochars may be coated with iron oxide films, but the film typically has poor anchoring to the biochars, resulting in loss of iron and sorption capacity, including adsorbed phosphorus.

Therefore, the aim of this study is to fabricate and compare the sorption capacity of iron-rich biochar using a new strategy, with wood chips (2 – 4 mm) being impregnated by iron(III)- chloride or iron(III) -sulphate salt solutions, dried, and followed by carbothermal reduction (900 °C) using the methodology described by (Zhao et al., 2025). This method produces different types of iron-containing biochars: biochar with Fe^0 (ZVI) and iron oxide-biochar. The synthesised materials were characterised by X-ray diffraction, total iron and ZVI. Phosphate sorption affinity and capacity of the resulting biochars were examined via sorption isotherm experiments.

The results support the hypothesis that ZVI-biochar has better phosphate sorption than iron oxide-biochar, which in turn has much better sorption than non-iron amended biochar, which shows negligible phosphate sorption. In addition, the iron (ZVI or iron oxide) embedded in the biochar matrix is physically stable, and hence the iron-modified biochar materials are useful as column packing materials for filters to treat phosphorus-loaded waters in both rural and urban areas. The filter material will be interesting for the retention of many other both organic and inorganic contaminants, due to both the biochar (activated carbon-like material) and the iron oxide components that retain both hydrophobic and polar contaminants. For these filter materials, a large particle size is beneficial as powdered particles would get washed away. Thus, filling key gaps such as the performance of the material in column test, in the field and long-term is required.

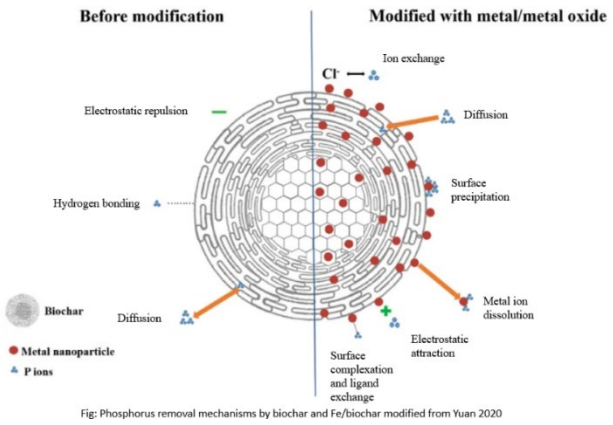
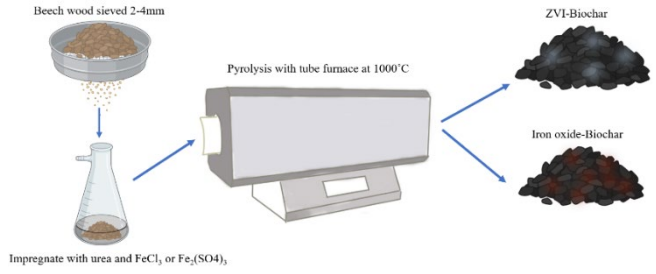


Fig: Phosphorus removal mechanisms by biochar and Fe/biochar modified from Yuan 2020

Created with



*sdw@plen.ku.dk: Thorvaldsensvej 40, 1871 Frederiksberg C
** peho@plen.ku.dk: Thorvaldsensvej 40, 1871 Frederiksberg C
*** haha@plen.ku.dk: Thorvaldsensvej 40, 1871 Frederiksberg C

SESSION 1: Groundwater, Auditorium 1

Chair: Ida Holm Olesen, Novafos and Pia Jacobsen, Water Valley Denmark

Speaker	**Title of the presentation**
Ronja Forchhammer	Balancing Cost and Accuracy: Minimum Sensor Requirements for Groundwater Data Collection
Mathias Busk Nielsen	Probabilistic decision-support for groundwater management made feasible with artificial neural networks
Georgios Ikaros Xenakis	Decadal trends in groundwater quality observed in national groundwater monitoring wells – assessment of climate change effects using machine learning.
Elisa Bjerre	Estimating Groundwater Recharge Variability in a Semi-Arid South African Catchment using Machine Learning
Radoslaw Marcin Guzinski	Mapping actual evapotranspiration with satellite data from field to global scales

Balancing Cost and Accuracy: Minimum Sensor Requirements for Groundwater Data Collection

Ronja Forchhammer, VIA University College and Aalborg University, T. R. Andersen, VIA University College, M. R. Rasmussen, Aalborg Universitet****

Introduction

Rising shallow groundwater levels are increasingly challenging urban infrastructure and agricultural land use, particularly under conditions of heavy precipitation and climate change. In Denmark, more than 450,000 residences are affected by high groundwater tables. National models provide a valuable tool for large-scale screening, but they fail to capture the fine-scale local variations that are critical for municipal climate adaptation. Optimizing groundwater monitoring networks requires balancing data collection costs and predictive accuracy. This study investigates the minimum number of groundwater sensors needed to reliably reconstruct groundwater levels and key hydrological parameters.

Methods and data

A total of 82 wells were established in two study areas: a village (0.31 km², 40 wells) and a rural field site (0.63 km², 42 wells). Vented sensors and IoT loggers provided 15-minute groundwater time series over multiple years. Data were quality-controlled, outliers removed and interpolated using ordinary kriging. Iteration analyses with >3500 random well combinations is used to assess how well groundwater fluctuations can be estimated using reduced sensor networks. The Nash-Sutcliffe Efficiency (NSE) metric is used to evaluate the predictive accuracy of models based on sparse sensor data compared to a dense observation network. The findings provide guidelines for designing cost-effective yet reliable monitoring networks, which are essential for sustainable groundwater management and climate adaptation.

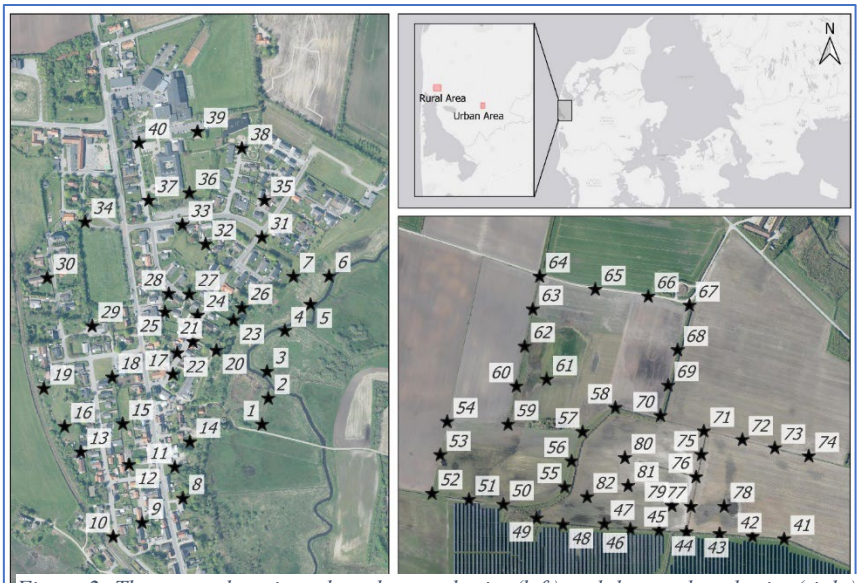


Figure 2: The sensor locations the urban study site (left) and the rural study site (right).

Results

Analyses showed that configurations with only 5 or 10 wells produced highly unstable reconstructions at both study sites but still succeeded to generate configurations with very good NSE-values (NSE > 0.75). The accuracy increased rapidly with additional sensors and with 15 strategically placed wells. From 20–25 wells, performance stabilized with diminishing returns. Analysing the best result showed recurrent patterns in placement of the sensors. The results underline the importance of sensor density and placement, demonstrating that robust groundwater surfaces can be reconstructed with far fewer sensors if located optimally.

Market potential

The findings provide direct value for municipalities, utilities, and consultants facing costly groundwater management. Optimized sensor configurations can reduce monitoring costs while safeguarding accuracy, supporting better investment decisions in climate adaptation. The approach is transferable to other municipalities and can be integrated with satellite-based monitoring or machine learning models for predictive applications.

Discussion and take-home message

1. National models underestimate shallow groundwater variability; local high-resolution monitoring is crucial.
2. Effective monitoring networks can be downsized to 5 strategically placed wells without losing reliability.
3. The methodology provides a cost-efficient, evidence-based tool for municipalities to manage groundwater risks and plan targeted climate adaptation.

* rocf@via.dk: Banegårdsgade 2, 8700 Horsens
** thra@via.dk, Banegårdsgade 2, 8700 Horsens
*** mrr@build.aau.dk, Thomas Manns Vej 23, 9220 Aalborg

Probabilistic decision-support for groundwater management made feasible with artificial neural networks

M.B. Nielsen, T.N. Vilhelmsen, NIRAS, R.B. Madsen, GEUS**, T.M. Hansen, Aarhus University****

Abstract

The everyday operations of administrative decision-making in the Danish municipalities heavily rely on numerical model-based flow simulations. The increasing demand for drinking water and its potential effect on natural habitats and interference with polluted sites are simulated and outcomes are evaluated according to local policies and government laws. However, most of these numerical models are based on a single geological representation of the subsurface with a fixed set of layer specific hydrological properties. Simulations from such a deterministic model present a single outcome and can not account for the uncertainty related to the geological model and hydrological parameters it is based on. Decision-makers are not fully informed about potential adverse effects and have to be either highly conservative in there management style or risk environmental damages. Including the uncertainty from the geological model and hydrological properties in the simulations is required to resolve the full space of outcome, but this is time consuming and often infeasible to perform in a decision-support framework.

To overcome this, we suggest utilizing artificial neural networks trained on pre-simulated results from a stochastic groundwater model to emulate the computationally heavy numerical models. We present a method for building an ensemble of groundwater models of the same location with stochastic geology and hydrological layer properties. Simulations run in the model ensemble present the full outcome space as a distribution instead of a single value. We prove the value of the method on a well catchment zone test case, where particle tracking simulations are performed using a MODFLOW groundwater model and a trained neural network of a Danish catchment site. Results (Figure 1) show that the trained neural network predicts with high accuracy and decreases the computation time from hours to seconds.

The rapid computational capabilities of the neural network makes it suitable as a computational engine within a decision-support tool that can help greatly improve the decision-making process of administrative groundwater management personnel. Furthermore, the method allows for exhaustive scenario simulations earlier deemed infeasible to perform that are highly valuable when assessing the environmental impact of groundwater abstraction.

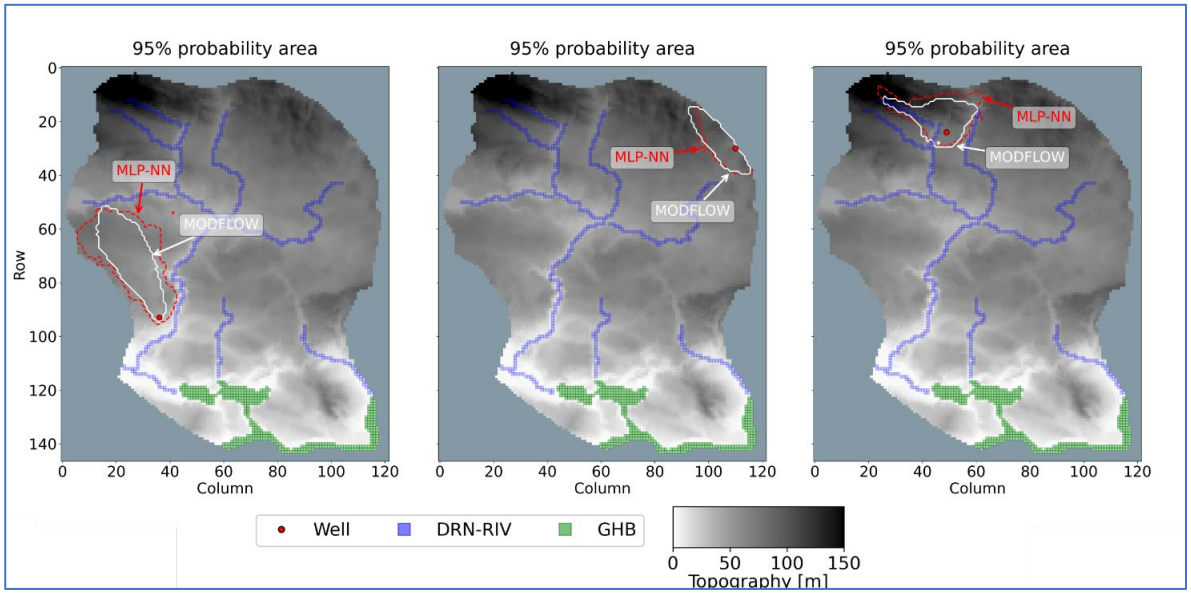


Figure 3: Well catchment zones with 95 % confidence of capture for three different well locations derived from a groundwater model with stochastic geology and hydraulic layer conductivity. Catchments are simulated with both MODFLOW and a trained Multilayer Perceptron Neural Network (MLP-NN).

* dahl@niras.dk: Kalkværksvej 16, 3. sal, 8000 Aarhus C, Denmark
** rbm@geus.dk: Universitetsbyen 81, Bygning 1872, 8000 Aarhus C, Denmark
*** tmeha@geo.au.dk: Høegh-Guldbergs Gade 2, Bygning 1671, 8000 Aarhus C, Denmark

Decadal trends in groundwater quality observed in national groundwater monitoring wells – assessment of climate change effects using machine learning.

Authors: *Georgios Ikaros Xenakis[1,2], Søren Jessen[1], Julian Koch[2], and Jolanta Kazmierczak[2].*
Affiliations: *[1]Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark. [2]Geological Survey of Denmark and Greenland, Øster Voldgade 10, 1350 Copenhagen, Denmark*

Introduction:
Ensuring sufficient quantity and quality of drinking water is a global challenge due to increasing pressures on water resources from climate change, pollution, and population growth. Groundwater is a major source of drinking water worldwide, and likely vulnerable to climate-induced changes in temperature, precipitation, and evapotranspiration, which can alter chemical equilibria, reaction kinetics, and soil processes, including pollutant leaching. Despite its potential importance, the impact of climate change on groundwater quality remains underexplored, representing an important gap in scientific knowledge.

Methods and data:
This study utilizes high-quality, long-term datasets from 1988 to 2024, covering environmental and hydroclimatic variables, groundwater quality, and quantity from over 200 groundwater monitoring wells across Denmark. Machine learning techniques are applied 1) to identify the main drivers of changes in geogenic constituent concentrations, and 2) to predict maps of the slope of the concentration changes, linking geo-spatial big data with groundwater quality trends.

Results:
Preliminary analysis indicates a general decrease in pH and oxygen content, and a temperature increase over the 1988-2024 period. Greater changes in pH and temperature were identified in shallow wells (0-15 m), while a greater decrease in oxygen was found in middle-depth wells (15-25 m). Ongoing work aims to quantify temporal trends in selected geogenic contaminants and other key chemical and physical parameters during this climatic period. National-scale prediction maps and identification of governing factors will be the main upcoming results.

Market potential:
The machine learning framework developed in this study has the potential for global upscaling and application in sustainable groundwater management. Our results can support water utilities and environmental agencies in identifying vulnerable areas, optimizing monitoring strategies, and reducing purification costs.

Discussion and take-home message:
The study aims to identify significant shifts in groundwater geochemistry under climate change. Machine learning is a powerful tool that can help reveal the drivers of concentration changes in important groundwater quality parameters. Additionally, developing prediction maps provides a valuable foundation for modeling future scenarios. These insights can contribute to groundwater management strategies under climate change and to long-term sustainable planning, ensuring drinking water quality and ecosystem health in Denmark.

Estimating Groundwater Recharge Variability in a Semi-Arid South African Catchment using Machine Learning

E. Bjerre, University of Copenhagen; J. Koch, GEUS; W.K. Dalum, University of Copenhagen now Fredensborg Municipality; N. Smith, University of Pretoria SA; K.G. Villholth, Water Cycle Innovation; S. Jessen, University of Copenhagen, K.H. Jensen, University of Copenhagen*

Introduction:
In semi-arid regions characterized by little and erratic precipitation and ephemeral river flow, groundwater is commonly the only perennial source of freshwater sustaining ecosystems and freshwater withdrawals for agricultural, domestic and industrial uses. Groundwater replenishment may occur either as (1) diffuse recharge, which refers to the recharge occurring across the landscape as precipitation infiltration or as (2) focused recharge, which represents groundwater replenishment via seepage from river channels during high flow occurrences. The latter component has been shown to contribute substantially to groundwater recharge locally. Estimation of both recharge components is highly uncertain and is constrained by the limited observational data both in time and space often prevailing in semi-arid regions. Moreover, their relative contributions at catchment scale remain underexplored.

Methods and data:
This study employs a data-driven machine learning approach to estimate annual groundwater recharge for the period 1970-2021 in the semi-arid Hout/Sand catchment (7,722 km2), Limpopo, South Africa. The Water Table Fluctuation (WTF) method is used to derive annual recharge estimates from 97 individual groundwater hydrographs spanning different time periods. Following, the recharge estimates are used to train a Light Gradient-Boosting Machine (LightGBM) model, generating fully distributed annual recharge maps at a 100 m resolution over the study period.

Results:
Results demonstrate considerable spatial variability in recharge, with high recharge values concentrated along river networks. Accordingly, proximity to rivers emerged as the most important co-variate in the LightGBM model.
Both focused and diffuse recharge are decreasing over the period 1970-2021, although focused recharge at a lower rate, ultimately causing a decline in the overall catchment-scale recharge. The relative contribution of focused recharge is increasing over time, due to stronger decline in diffuse recharge.

Discussion and take-home message:
- The machine learning approach is computationally efficient and robust, overcoming some limitations of conventional models caused by sparse data for calibration, uncertain parameters, and conceptual uncertainties in semi-arid catchments.
- The recharge training dataset based on the WFT method is subject to uncertainty due to the limited knowledge of specific yield used as input in the WTF calculations.
- The results suggest that although the relative importance of focused recharge increases over the 52-year period with rainfall intensification, is does not buffer the overall decrease in diffuse recharge, putting in question the hypothesis that focused recharge will act as a climate change buffer.

* elbj@ign.ku.dk: *University of Copenhagen, Department of Geosciences and Natural Resource Management, Øster Voldgade 10, 1350 København K, Denmark*

Mapping actual evapotranspiration with satellite data from field to global scales

*R. Guzinski, DHI**

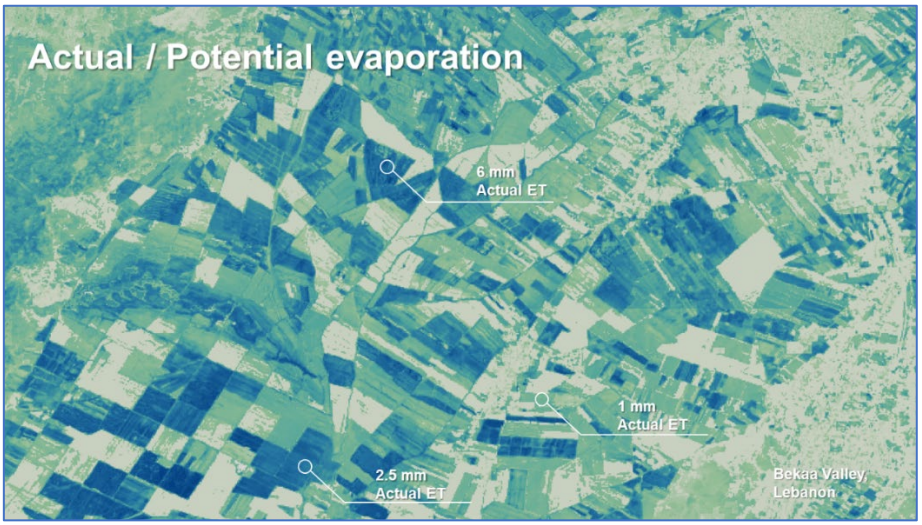
Introduction: Sustainable management of fresh-water resources is of growing importance due to stresses triggered by climate change and increased demand caused by growing population and economy. Water use in agriculture is responsible for consumption of large majority of fresh-water resources. The spatial and temporal patterns of this consumption can be quantified with the use of actual evapotranspiration (ET) maps derived with Earth observation data. Those impartial and consistent datasets can aid in transparent monitoring of Sustainable Development Goals, enhancing water-use efficiency and sustainable management of fresh-water consumption.

Methods and data: High quality data from European Union's Copernicus Earth observation programme provides all the necessary inputs for modelling ET. Copernicus provides free and open access to satellite data with up-to 10 m spatial resolution and up-to daily temporal resolution as well as higher-level products such as landcover maps and meteorological forecasts. With the use of this data and machine learning and physical models it is possible to obtain accurate maps of ET with spatial resolution ranging from 20 m for field-scale water management through to 300 m for global-scale monitoring.

Results: DHI has been at the forefront of research into the modelling of ET with satellite data through projects involving the European Space Agency, Food and Agriculture Organization, European Union's Joint Research Center and Danish Environment Agency. This resulted in the development of state-of-the-art ET products with wide ranging applicability. Those products can be obtained in almost all agricultural and natural areas globally and can be fine-tuned for specific local applications. As an example, a global actual evapotranspiration product with 300 m spatial resolution and dekadal temporal resolution, which was co-designed by DHI, will join the portfolio of the Copernicus Land Monitoring Service and enter operational production by the end of 2025. The product achieves a root-mean square difference of around 0.8 mm/day and bias of around 0.1 mm/day when compared against globally distributed set of ground measurements. Like other Copernicus products, ET maps will have a free and open license and guaranteed long-term continuity.

Market potential: Maps of actual evapotranspiration have many uses in the policy and commercial space. This ranges from mapping and quantifying local irrigation and providing sub-field irrigation advice, through combining ET maps with hydrological models for water resources allocation planning and management, to national, continental and global applications in the field of food security or monitoring the progress of Sustainable Development Goals.

Discussion and take-home message: Satellite imagery can be used to produce precise maps of actual evapotranspiration from field to global scales. The Copernicus ET product, which is operationally produced from the end of 2025, should significantly contributed to global availability of accurate ET datasets. This information can be very useful for multitude of applications ranging for more efficient irrigation water management to monitoring of global food security.



* rmgu@dhigroup.com: *Agern Allé 5, DK-2970 Hørsholm, Denmark*

SESSION 2: Water treatment and drinking water, Auditorium 2

Chair: Hans-Jørgen Albrecthsen, DTU Sustain, and Laila Vinther, Fors

Speakers	**Title of the presentation**
Kasper Trans Møller	WtX: Water treatment for Power-to-X
Lorenna Alves Xavier	Cleaning during the membrane distillation using geothermal water
Borja Valverde Péres	Bioelectrochemical systems for simulatenous nitrate removal and organic micropollutant degradation at low temperatures
Alen Simonic	Identification of candidate degraders of organic micropollutants in methanotrophic microbiomes
Agata Magdalena Pruss	Day-to-day practical management of UV disinfection at water works – are we doing it right?

WtX: Water treatment for Power-to-X

Rune Harpøth Kjær, **Kasper Trans Møller,** Danish Technological Institute, Centre for Water Technology*
Project partners: ECT2 and MUTAG. The project was funded by Energy Cluster Denmark

Introduction: In Denmark there are plans for several large Power-to-X (PtX) plants, which require both a continuous water supply and the production of ultrapure water for electrolysis. Various activities are underway to identify which water types are suitable, and there is a broad consensus among decisionmakers that groundwater, which could otherwise be utilized as drinking water, should not be used as a basis for hydrogen production. Therefore, it is necessary to identify non-potable water sources to use as an alternative by applying advanced purification technology to obtain ultrapure water (<1 µS/cm). This project explores the possibility of purifying two different types of non-potable water, provided by Lemvig Vand (aka. Klimatorium) and Vestforsyningen.

Methods and data: Two different water sources were used in the project: surface water from Høvsøre pumping station in Lemvig, and effluent from Holstebro wastewater treatment plant (WWTP). The water samples were subjected to ultrafiltration followed by reverse osmosis (RO), which is a widely used method for water purification. Biological treatment of the reject water from RO-filtration was performed using moving bed biofilm reactors (MBBR's), under anaerobic conditions to allow for removal of both nitrate and COD through denitrification.

Results: The UF/RO filtration was successfully completed for both surface water and WWTP effluent, lowering the conductivity from 480 µS/cm and 1236 µS/cm to 38 µS/cm and 24 µS/cm, respectively. The results show elevated levels of pollutants in the reject water, as the conductivity was increased by a factor of 3-4, while the extended analysis indicated concentration factors as high as 10-15 for specific pollutants such as PFAS and diclofenac.

With addition of acetate as external carbon source in the MBBR reactor, the nitrate concentration of the reject water was reduced by 77-97 %, while it was not possible to reduce the COD concentration of the reject water.

Market potential: The results supports further research into the operational costs of processing non-potable water to produce ultrapure water for electrolysis purposes, depending on the concentration factor applied in the RO filtration and the polishing technologies required to further improve the quality of the RO permeate.

Discussion and take-home message: The results demonstrated the processing of two types of non-potable water to conductivity levels close to ultrapure water quality, through membrane filtration, suggesting that this may be a viable alternative to drinking water. However, it was observed how membrane filtration generates reject water with an elevated level of pollutants, which may require specific advanced treatment. The need for treatment of the reject water will depend on the operational parameters of the filtration process (concentration factor) and the environmental regulations that apply to the water recipients available in each case. The project highlights the need to draw attention to the handling of the reject water to ensure environmental sustainability of PtX-plants using a non-potable water source.

* rdh@teknologisk.dk*: Kongsvang Allé 29, 8000 Aarhus C*

Cleaning during the membrane distillation using geothermal water.

L. Alves X.[1], A. Ali**[2],Mads K. Jørgensen***[1], C. A. Quist-Jensen****[1]*

Introduction

Nowadays, geothermal water is gaining increasing attention due to its valuable mineral resources. The use of membrane distillation (MD) offers an efficient method for separating these resources and water reuse. However, this process poses challenges, particularly from high salinity brines and the potential for scaling. These issues can reduce the flux, shorten membrane lifetime, and limit large-scale applications. Hence, it is necessary to evaluate the cleaning process during the MD treatment.

Methods and data:

The study was conducted using a lab-scale Direct Contact Membrane Distillation (DCMD) system, operated in co-current mode. Geothermal water at a temperature of 50 °C and a flow rate of 75 L h^{-1} was used on the feed side, while deionized water was utilized on the permeate side. After recovering the crystals, the system was cleaned with deionized water (DI). This process was repeated in cycles until all the feed was consumed. Throughout the experiments, flux, pH, and conductivity were monitored. The crystals of the precipitates were analyzed using X-ray diffraction (XRD).

Results:

The results indicated that an 80% water recovery rate was achieved when processing geothermal brine by DCMD. However, membrane scaling occurred during the DCMD process, which manifested as a decrease in permeate flux. Cleaning during the process was effective in restoring membrane functionality, as shown in Figure 1. Additionally, XRD analysis revealed the presence of NaCl in all recovered crystals.

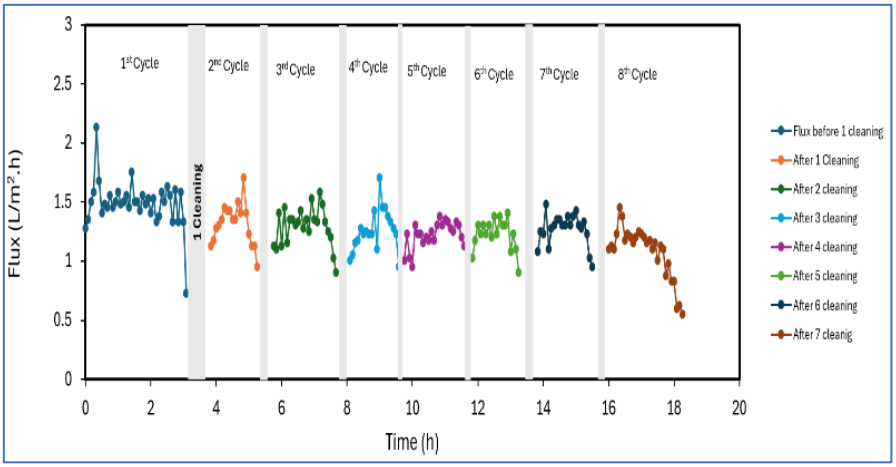


Figure 4. Comparison of the initial flux recovery rates achieved by the seven cleaning cycles.

Market potential:

Membrane distillation could provide a sustainable solution for geothermal water treatment and resource recovery. However, effective scaling control and optimized cleaning protocols are crucial to ensure stable and cost-effective operation. These findings highlight the potential for MD to support resource recovery in geothermal applications.

Discussion and take-home message:

NaCl scaling is a critical challenge in geothermal water treatment by MD.
Cleaning with DI water offers to restore membrane performance.
Developing cleaning methods is needed to support a long period of operation and to increase the market potential of MD for geothermal water treatment and mineral recovery.

Acknowledgement: The Authors acknowledge financial support from the Danish Eco-Innovation Programme (MUDP) under the Danish Ministry of the Environment.

* lax@bio.aau.dk: *Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*
** aal@energy.aau.dk: *Pontoppidanstræde 111, 9220 Aalborg East, Denmark*
*** mkj@bio.aau.dk : *Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*
**** cejna@bio.aau.dk : *Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*

Bioelectrochemical systems for simulatenous nitrate removal and organic micropollutant degradation at low temperatures

*Francesco Savio (frasa@dtu.dk), Martin Hansen (marhan@dtu.dk), **Borja Valverde-Pérez** (bvape@dtu.dk)*
DTU Sustain (Bygningstorvet, Bygning 115, 2800 Lyngby)

Introduction: Despite its importance for drinking water supply, groundwater quality faces growing challenges from pollutants. Nitrate from intensive agriculture is a major concern due to harmful health effects such as methemoglobinemia and colorectal cancer [1]. Bioelectrochemical systems (BES) are promising technologies removing nitrate from groundwater. Hydrogen (H_2) produced in-situ by water electrolysis is consumed by cathodic biofilm communities as electron donor to reduce nitrate (NO_3) to nitrogen gas (N_2). Promising performance has been achieved even at 4°C, supporting potential for in-situ remediation Nordic conditions [2]. Groundwater quality is also threatened by organic micropollutants (OMPs) and their transformation products, which pose risks to human health even at low concentrations [3].

Methods and data: Three bioelectrochemical reactors (BERs) were operated in continuous mode at 10°C with synthetic groundwater (10 mg N-$NO_3 \cdot L^{-1}$) and tested for nitrogen removal. After acclimation reactors were furthermore tested in batch mode (30 hours, 70 mL) for their biodegradation potential of a mixture of ten OMPs commonly found in groundwater, each spiked at a target concentration of 4 $\mu g \cdot L^{-1}$. Degradation and quantification of mother compounds was monitored over time through targeted HPLC–MS/MS, while degradation products were analysed through non-targeted high-resolution mass spectrometry.

Results: Reactors operated in continuous mode for a total of approximately 400 days. High total nitrogen (TN) removal rates compared to existing literature at same temperatures. Maximum cathode volumetric removal rates of 11.5 kg-$N \cdot m^{-3} \cdot d^{-1}$ were achieved at low hydraulic retention time (HRT). Nitrite was detected as main denitrification intermediate, while N_2O concentration remained below 1.3 mg-$N \cdot L^{-1}$ for all reactors. The normalized average concentrations of the mother compounds are shown in Fig. 1. At the end of the experiment, best removal (78±6%) was achieved for all reactors for the sulfonamide antibiotic sulfamethoxazole. Removal above 50% was also achieved for other compounds, such as atrazine and 1H-benzotriazole (61±2% and 52±6% respectively).

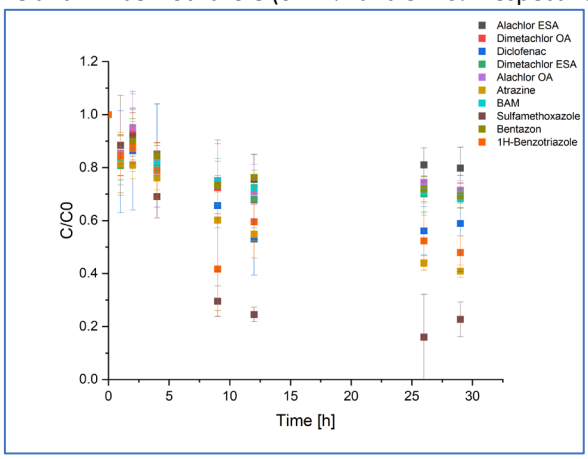


Figure 5: Average normalized concentrations of OMPs from three BERs operating at 10°C

Market potential: Standard treatment technologies at Danish drinking water treatment plants (DWTPs) traditionally do not target removal of nitrate and organic micropollutants. Physico-chemical processes are usually expensive, energy intensive and generate nitrate rich by-products which require further treatment. Here we propose a biotechnology able to efficiently operate at low winter temperatures. If implemented at DWTPs, health net savings of minimum $179 million/year could be nationally achieved [1], without considering OMPs removal benefits.

Discussion and take-home message:
BES achieved high nitrogen removal (11.5 kg-$N \cdot m^{-3} \cdot d^{-1}$) at 10 °C with low N_2O emissions. This shows their potential for sustainable nitrate remediation even in cold aquifers. Reactors effectively removed OMPs, with up to 78% removal of sulfamethoxazole. This highlights BES as a multi-contaminant treatment option for safer drinking water.

[1] B. H. Jacobsen, B. Hansen, and J. Schullehner, "Health-economic valuation of lowering nitrate standards in drinking water related to colorectal cancer in Denmark," *Science of the Total Environment*, vol. 906, Jan. 2024, doi: 10.1016/j.scitotenv.2023.167368.

[2] M. Xu *et al.*, "Inorganic bioelectric system for nitrate removal with low N2O production at cold temperatures of 4 and 10 °C," *Water Res*, vol. 274, p. 123061, Apr. 2025, doi: 10.1016/j.watres.2024.123061.

[3] M. Y. Nanusha *et al.*, "Nontarget Analysis of Drinking Water from Danish Waterworks: Profiling of Organic Micropollutants and Health Risk Screening," *ACS ES and T Water*, vol. 5, no. 7, pp. 4054–4066, Jul. 2025, doi: 10.1021/acsestwater.5c00280.

Identification of candidate degraders of organic micropollutants in methanotrophic microbiomes

A. Simonic, N. De Bernardini***, G. Zampieri***, F. Savio*, N. Andersen*, S. Campanaro***, A. Dechesne**, L. Treu***, B. Valverde-Pérez**

Introduction: The transition to green alternatives in water treatment aims to reduce environmentally hazardous waste and enhance sustainability. Danish national groundwater monitoring (GRUMO) shows increasing occurrence of organic micropollutants (OMPs) in waterworks wells over the past decade. Current technologies for OMP removal are either inefficient or costly, highlighting the need for sustainable, bio-based solutions. Methane oxidizing bacteria (MOB) can co-metabolize OMPs, while aerobic heterotrophs within MOB communities further contribute to biodegradation (Mortensen et. al. 2023). However, the effects of operating conditions on OMP removal in complex microbiomes remain poorly understood.

Methods and Data: Methanotrophic microbial consortia were enriched from hospital wastewater and cultivated in 2L batch reactors under controlled conditions (25°C). Adapted cultures were pre-exposed to OMPs over multiple transfers, while non-adapted cultures were grown without prior exposure. Multi-omics datasets were generated, including 91 metagenomes and 60 metatranscriptomes. State-of-the-art bioinformatic pipelines were used for genome-centric metagenomic analysis and metatranscriptomics. Metatranscriptomic reads were mapped to MAGs to assess condition-dependent gene expression.

Results: Our analysis revealed distinct gene expression profiles between adapted and non-adapted communities, as well as in response to micropollutant exposure, highlighting condition-dependent transcriptional shifts relevant for biodegradation potential. Integration of metagenomic and metatranscriptomic data allowed us to link these transcriptional changes to specific taxa within the methanotrophic consortia. Differential expression patterns pointed to candidate degraders, including *Cupriavidus basilensis* and other heterotrophic taxa, which exhibited strong upregulation of enzymes such as cytochrome P450s. Measured sulfamethoxazole degradation supported these findings, with biomass-normalized rate constants ranging between 1.44 and 2.54 $L \cdot g^{-1}$ VSS$\cdot d^{-1}$. Principal component analysis (Figure 1) of differentially expressed genes showed a clear separation between non-adapted and pre-adapted cultures, with additional effects of environmental conditions, indicating distinct transcriptional profiles linked to adaptation.

Market potential: By identifying keystone species and condition-dependent degradation pathways, the study supports the design of optimized bioreactors that could complement energy-intensive treatment technologies, reducing operational costs.

Discussion and take-home message:

- Adaptation to OMPs drives clear transcriptional and functional shifts in methanotrophic communities.
- Multi-omics integration offers a predictive framework for optimizing microbial communities in engineered systems, advancing the potential for green and cost-effective OMP remediation.

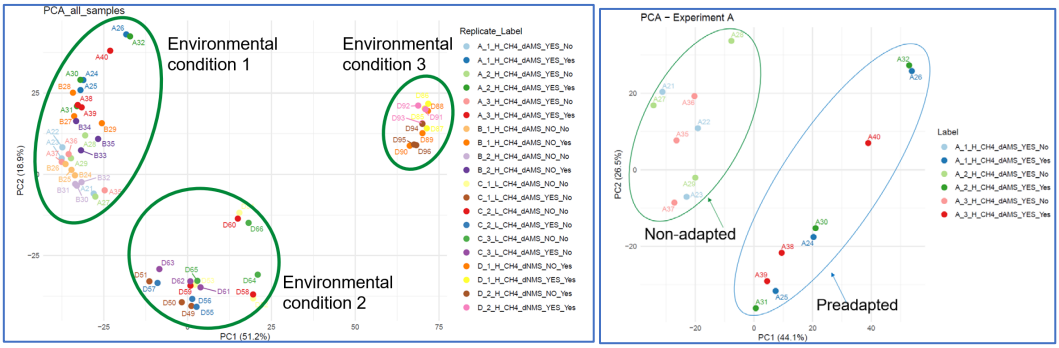


Figure 1 Differential gene expression analysis (PCA) revealed clear transcriptional differences between OMP-adapted and non-adapted cultures, as well as condition-dependent shifts. Specifically, condition 1 combined high methane concentrations with ammonium-based medium, condition 2 applied low methane with the same medium, and condition 3 combined high methane with nitrate-based medium.

Mortensen, A. T. et al. (2023). Methanotrophic oxidation of organic micropollutants and nitrogen upcycling in a hybrid membrane biofilm reactor (hMBfR) for simultaneous O_2 and CH_4 supply. Water Research, 227, 120104. https://doi.org/10.1016/j.watres.2023.120104

Technical University of Denmark, Department of Environmental and Resource Engineering, Kgs. Lyngby, Denmark. Email: alsim@dtu.dk. Technical University of Denmark, Department of Biotechnology and Biomedicine, Kgs. Lyngby, Denmark. Email: arde@dtu.dk,***University of Padova, Department of Biology, Padova, Italy. Email: laura.treu@unipd.it*

Day-to-day practical management of UV disinfection at water works – are we doing it right?

***A.M. Pruss**, DTU Sustain[1], A.N. Vernon, DTU Sustain[2], M. Hansen, DTU Sustain[3], S.C.B Christensen, HOFOR[4], P. L. Tüchsen, Novafos[5], J.E. Christoffersen, Novafos[6], C.S. Vesterlund, TREFOR[7], N.F. Petersen, TREFOR[8], L. Clausen, HOFOR[9], S. Tygesen, DIN Forsyning[10], H-J. Albrechtsen, DTU Sustain[11]*

Abstract

UV-plants are established in increasing numbers for permanent disinfection of drinking water e.g. at the effluent of drinking water treatment plants, water works or clean water tanks. Authorities may require UV-plants to be implemented together with e.g. advanced water treatment or with recovery of water from backwash of sand filters.

The purpose of UV-disinfection is to increase safety as an extra hygienic barrier against microbial contaminations. In this way UV-treatment should reduce the risk of downtime due to microbial contamination. UV-treatment should also prevent disturbances of the production and thus increase the stability of the supply.

During UV-disinfection nitrite may be formed, or natural organic compounds may be oxidized to form available organic carbon (AOC) which may be an easily available substrate for microorganisms. Subsequently this may increase the risk for microbial after growth in distribution networks.

We conducted a literature study which revealed little information on formation of unwanted by-products by UV-disinfection with low pressure lamps, which are the most used form in Denmark. Generally, only few examples of problems were reported, mainly in the form of risk of formation of nitrite. However, the reported investigations were conducted with specific chemical analysis for the organic by-products. At this background seven UV-plants were sampled for Non-Target Analysis, a new technology which would detect a much wider field of compounds with a very high sensitivity.

Furthermore, the day-to-day practical management differs substantially between different plants. In some instances, the plants are running continuously, while other plants are seen as a back-up to be utilized in case of incidents in the water. Different practices may result in unwanted effects of the UV-treatment, e.g. warming up a lamp may take a while and during this warming-up period, the disinfection is not optimal, and contaminants may pass. On the other hand, stopping the flow, leaving water resting in the UV reactor during the whole warming-up period may lead to too high exposure, which may increase the risk for nitrite formation. Practice may also differ regarding the maintenance, e.g. swapping the UV-lamp to remove fouling and precipitates, in some cases even cleaning-in-place (CIP) of the UV-reactor may be necessary. The need for such cleaning may depend on e.g. the hardness of the water.

To map the day-to-day practice, and to investigate if non-optimal management and maintenance procedures can result in formation of unwanted compounds, we wanted to collect procedures and experiences from UV-plants at water works which have been running for a longer period. This included both questionnaires and on-site interviews of the personnel at these utilities. Data and experiences will also be collected from service technicians from major suppliers.

The aim was to establish best practice descriptions to provide a better platform for the implementation of UV-treatment at water works.

The project was supported by VUDP and will end primo 2026.

[1] aqapr@dtu.dk : Bygningstorvet, Bygning 115, 2800 Lyngby, [2] anave@dtu.dk : Bygningstorvet, Bygning 115, 2800 Lyngby, [3] marthan@dtu.dk : Bygningstorvet, Bygning 115, 2800 Lyngby, [4] sach@hofor.dk : Ørestads Boulevard 35, 2300 , København S, [5] plt@novafos.dk : Blokken 9, 3460 Birkerød, [6] jhc@novafos.dk : Blokken 9, 3460 Birkerød, [7] , cs@trefor.dk : Kokbjerg 30, 6000 Kolding, [8] npet@trefor.dk : Kokbjerg 30, 6000 Kolding, [9] licl@hofor.dk : Ørestads Boulevard 35, 2300 København S, [10] sty@dinforsyning.dk : Ulvsundvej 1, 6715 Esbjerg N, [11] hana@dtu.dk : Bygningstorvet, Bygning 115, 2800 Lyngby

SESSION 3: Wetlands and surface waters

Chair: Uffe Sognstrup Thomsen, AU, WATEC.

Speakers	**Title of the presentation**
Trine Dalkvist	VUDP – RegnKvalitet+: Improving the assessment of hazardous substances in stormwater discharges
Alba Martinez I Quer	Molecular and chemical monitoring of Danish “mini-wetlands” to evaluate long-term water treatment and pollutant retention
Clément Franey	National-scale DEM-derived Stream Geomorphometry for Enhanced Flood Modelling
Lineker Goulart Coelho	Combining Nature-based Solutions and digitalization tools to support climate adaptation and resilience in stormwater infrastructure

VUDP – RegnKvalitet+: Improving the assessment of hazardous substances in stormwater discharges

T. Dalkvist, DHI A/S, F. V. Frandsen, DHI A/S**, D. Rasmussen, DHI A/S***, J. Clauson-Kaas, HOFOR*****

Introduction

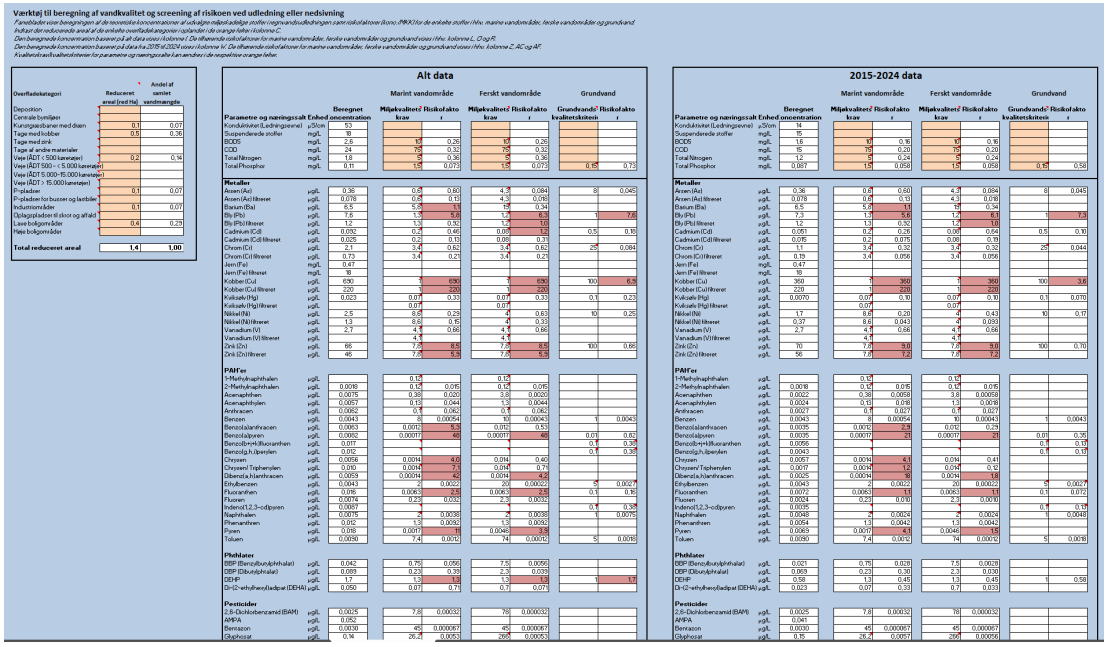
The RegnKvalitet+ project aimed to improve the understanding and assessment of hazardous substances (MFS) in stormwater discharges from separately sewered catchments. As climate adaptation and separate sewer systems expand across Denmark, utilities and municipalities face increasing demands for documentation and evaluation of stormwater quality when applying for discharge permits. The project responded to these needs by updating the existing RegnKvalitet tool, enabling a more robust, transparent, and data-driven basis for evaluating environmental risks associated with stormwater discharges.

Methods and data: The project compiled and quality-assured analytical data on MFS concentrations in stormwater discharges from across Denmark. Statistical methods were revised to ensure consistent handling of data below detection limits, more robust calculation of typical concentration values, and improved representation of pollution levels across different surface types. Coordination with the Danish Environmental Protection Agency ensured methodological alignment and regulatory relevance.

Results: The updated tool, RegnKvalitet 2.0, provides an accessible web-based application (www.regnvandskvalitet.dk) with new datasets and improved analytical functionality. Results show that many hazardous substances, including metals (Cu, Zn, Pb) and organic pollutants (PAHs, DEHP, Bisphenol A), frequently exceed environmental quality standards (EQS). The analysis highlights significant variability between surface types and points to construction materials and traffic as key sources.

Market potential: RegnKvalitet 2.0 has strong potential for widespread use by municipalities, utilities, and consultants. It supports evidence-based decision-making in connection with planning, discharge permits, and compliance with the EU Urban Wastewater Directive.

Discussion and take-home message: RegnKvalitet+ provides a harmonized and transparent foundation for stormwater quality assessment in Denmark. The tool strengthens decision-making processes related to separate sewer systems, facilitates risk-based regulation, and helps identify needs for both source control and treatment. The project demonstrates how data-driven approaches can bridge regulatory requirements, practical planning, and sustainable urban water management.



* tda@dhigroup.com: ** frvi@dhigroup.com: Wastewater Treatment, DHI A/S, Åbogade 15, 8200 Aarhus N, Denmark, *** dor@dhigroup.com: Environment & Toxicology, DHI A/S, Agern Allé 5, DK-2970 Hørsholm, Denmark, ****jecl@hofor.dk: Spildevand Plan Øst, HOFOR, Ørestads Boulevard 35, 2300 København S, Denmark

Molecular and chemical monitoring of Danish "mini-wetlands" to evaluate long-term water treatment and pollutant retention

A.Martínez i Quer, AU-ENVS, L. Ellegaard-Jensen, AU-ENVS and AU-WATEC**, E. A. Jespersen AU-Bio and AU-WATEC, ***, M. B. Vejlgaard AU-Bio and AU-WATEC, ***, C.A. Arias AU-Bio and AU-WATEC, **,***, P.N. Carvalho, AU-ENVS*

Introduction:
Constructed wetlands, including Danish "mini-wetlands," are widely implemented to intercept agricultural runoff and improve water quality. While nutrient removal has been the primary focus, emerging challenges such as micropollutant accumulation, metals, and antibiotic resistance require an updated assessment of system performance. Within the EU Path4Med project, we are using molecular and chemical analyses to further evaluate a Danish "mini-wetland" in operation for more than 10 years.

Methods and Data:
Two campaigns were planned: 1) Sediment Transect Campaign (August 2025) to evaluate long-term accumulation of micropollutants, metals, and microbial communities along the wetland flow path, and 2) Fertilization Campaign (Spring 2026) to test system resilience under high nutrient and micropollutant loads from surrounding fields. Sampling includes sediment cores (top and bottom layers) and water collected after rain events via autosamplers. Analyses comprise total RNA sequencing (metatranscriptomics) for microbial community structure and function, and LC-HRMS for suspect screening of a 500+ micropollutant library. Preliminary micropollutant screening has been completed; sequencing data is forthcoming.

Results:
Ongoing micropollutant and RNA analyses aim to identify key taxa and functional genes linked to nutrient cycling, pollutant degradation, and antibiotic resistance, providing insights into system performance and potential vulnerabilities. Preliminary data will be shown at the conference.

Market Potential:
Understanding microbial and chemical dynamics in mini-wetlands can optimize future designs, monitoring, and management of treatment wetlands and other nature-based solutions for agricultural runoff. The data can support regulatory guidance for pollutant mitigation and identify potential for bioremediation technologies targeting micropollutants and resistance genes.

Discussion and Take-Home Message:

1. Ten-year-old mini-wetlands provide a unique opportunity to study long-term pollutant retention and microbial ecosystem functions.
2. Molecular tools, combined with chemical monitoring, allow evaluation of both performance and resilience under environmental stressors.
3. Insights from these systems can guide practical management strategies, optimize pollutant removal, and inform stakeholders about sustainable treatment wetland deployment.

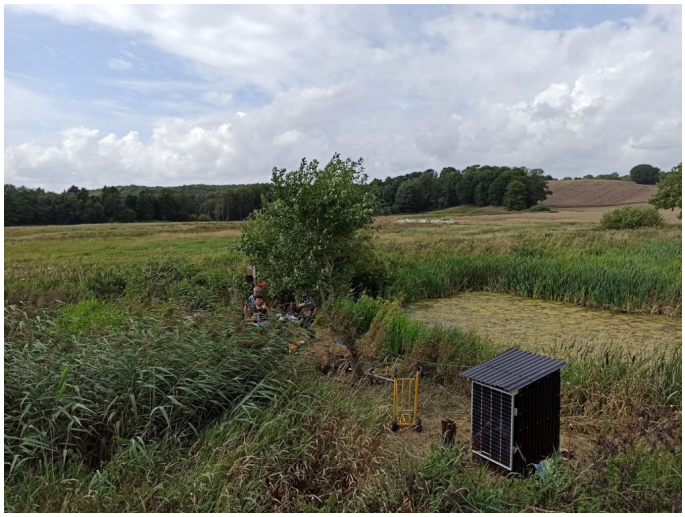


Figure 6: photo of the first free floating basin and the sub-surface flow woodchip reactor. The autosampling device is stored in the shed. Ondrup, Denmark. August 2025.

**alma@envs.au.dk, leael@envs.au.dk,*
pedro.carvalho@envs.au.dk: Frederiksborgvej 399, Roskilde 4000, Denmark

***WATEC– _Centre for Water Technology, Aarhus University,* Ole Worms Allé 3, Bldg 1171, *Aarhus 8000, Denmark*
*****au636430@uni.au.dk*, *emil@bio.au.dk*, *carlos.arias@bio.au.dk: Department of Biology, Aarhus University, Ole Worms Alle 1, Aarhus C 8000, Denmark*

National-scale DEM-derived Stream Geomorphometry for Enhanced Flood Modelling

Clément Franey, GEUS, Søren J Kragh, Vordingborg Municipality, Lars Troldborg, GEUS & Julian Koch, GEUS*

Introduction: Accurate water level prediction is crucial for effective flood risk mitigation, which is increasingly relevant in the context of climate change adaptation planning. Hydrological and hydrodynamic models are key tools, but their reliability depends on the availability of detailed information about stream cross-sections and floodplain topography, which is difficult to obtain at large scale. While local-scale assessments using drone-based green LiDAR or GPS surveys provide high-quality data, such approaches are not feasible for national-scale applications. This study aims to address this gap by deriving stream geomorphometric parameters for all stream calculation points in the Danish National Water Resources Model (DK-model), enabling better flood modelling at the national scale. Our approach is consistent and fully automated and once implemented in the DK-model, it is expected to improve water level forecasts.

Methods and data: We present a methodology for extracting stream geomorphometry from Denmark's high-resolution (40 cm) digital elevation model (DEM), provided by the Danish Agency for Climate Data (KDS). The approach involves analysing elevation profiles across approximately 62,000 stream locations throughout the Danish river network. Stream widths are estimated by identifying the most probable position of the riverbanks using a probabilistic analysis of all possible bank locations on 100-meter-long watercourse reaches. Additional parameters, including water surface slope, water surface elevation, dry-channel area, and riverbank to water surface height, are also derived from the DEM for each reach. The DEM-derived stream width estimates are compared with 2,251 measured cross-sections available from the DK-model database for data validation.

Results: Our results reveal meaningful and consistent spatial patterns of the derived stream geomorphometric parameters across the Danish stream network. Validation of the stream width estimates shows a bias of approximately 2 meters on average and a correlation coefficient of 0.9. Figure 1 illustrates the spatial distribution of stream widths. Detailed evaluations along Ribe Å and Skjern Å from upstream to downstream confirm realistic patterns when compared to measured widths, supporting the robustness of the method. We find that the method is generally more reliable for larger streams than for small ones.

Market potential: The presented national-scale approach is fully automated and offers a valuable complement to local-scale cross-section assessments. While local surveys naturally yield higher-quality data, our large-scale method provides a consistent overview that can support modelling or serve as a cost-effective starting point for local-scale modelling in the absence of field data.

Discussion and take-home message: Stream geomorphometry can be derived from high-resolution DEMs with reasonable accuracy at large scale, offering key parameters for improving flood modelling, especially for larger rivers where the method provides best results. As municipalities increasingly conduct local river assessments as part of climate adaptation planning, the proposed method can serve as a practical foundation for this work.

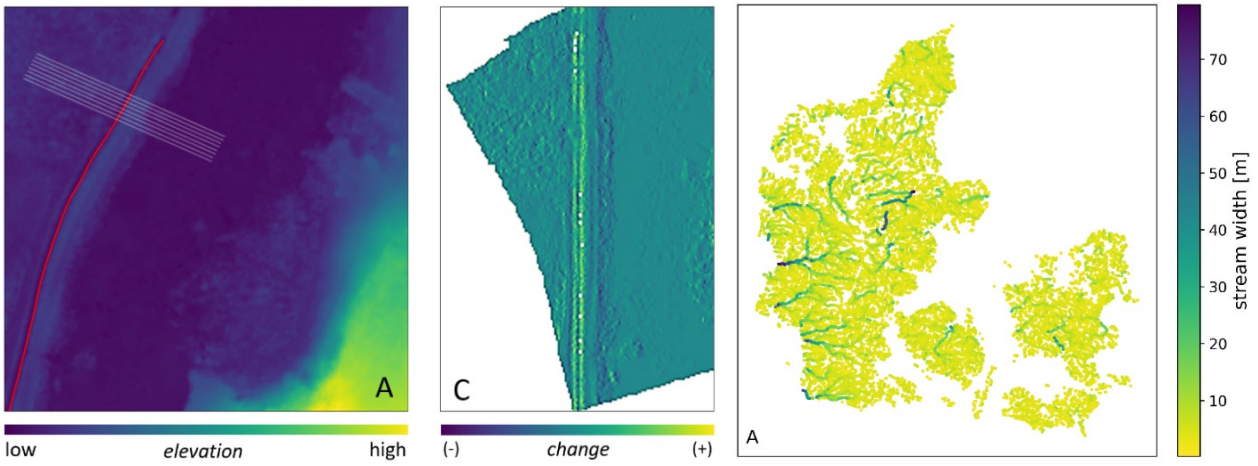


Figure 1. *Left panel: example of a stream reach topography with stream centreline in red and 50 m transects in white. Centre panel: Relative elevation change extracted at all 50 m transects along the stream centreline, revealing the most probable position for the riverbanks in yellow, where the elevation change is the highest. Right panel: Resulting stream width for the entire Danish stream network.*

**clefr@geus.dk: Øster Voldgade 10, 1350 Copenhagen, Denmark*

Combining Nature-based Solutions and digitalization tools to support climate adaptation and resilience in stormwater infrastructure

L. M. G. Coelho, O. Schultz**, S. Christiansen***, J. Molin****, DTU Eng. Technology*

Introduction:
Nature-based solutions (NBS), particularly, are considered an interesting approach in the context of climate adaptation and resilience, as they can at the same time help mitigate several climate-related issues, enabling flood control, heat island reduction, while promoting biodiversity and creating recreational urban spaces. On the other hand, digitalization associated with such solutions is essential to support real-time monitoring aiming at active control systems in order to optimize the operation of multiple decentralized NBS to support a more effective and integrated stormwater water management. So, the main purpose of this paper is to investigate different applications addressing the combination of NBS with digitalization tools to support climate adaptation and resilience in urban stormwater management.

Methods and data:
The experimental apparatus consisted in 3 different NBS: green roofs and green downspouts and infiltration basins. Green roofs and green downspouts were tested at pilot consisting in 2 pilot systems installed in the Technical University of Denmark located in Ballerup: a climbed green roof system with a total area of 25 m^2 and a green downspout with 1,5 m high, 0,6 m large and 0,2 m thick. Moreover, the third system is a full-scale stormwater basin located in the municipality of Frederiksberg in a public playground. The green roof was monitored based on the rain directly received by it (25 m^2), whereas the green downspout was supplied by the rain collected in a 16 m^2 roof. The infiltration basin, in turn, receives stormwater from Frederiksberg urban drainage network. The green roof and green downspout were monitored using load cells, flow meters and moisture sensors to monitor peak flow reduction and delay, whereas the infiltration basin was used for testing water quality parameters (conductivity, turbidity) using IoT sensors. All the data were monitored in real-time and made available on digital platforms.

Results:
The results of the hydraulic measurements for both greenroof and green downspout show a high variability in terms of peak flow reduction, depending on the lag between successive rains as well as the rain intensity. In both cases, the retention capacity was shown to be very low, while a detention effect was clearly noted, leading to peak flow reduction and delay. As for climate adaptation, peak flow reduction and delay are interesting features for decentralized solutions, because it enables to create a cascading effect in the overall peak flow of the watershed, the use of such NBS was proven to be a interesting approach if appropriately distributed over the catchment area and the use of IoT hydraulic systems can be helpful in order to predict the performance of overall system based on the local real-time data gathered. On the other hand, for the infiltration basin, the IoT sensors also provided insightful information of the temporal variation of the water quality in a real-time basis enabling decision making in terms of potential reuse of the stored water depending on the water quality requirements of the intended use, such as irrigation, washing or aquifer recharge, which also support climate resilience in terms of water scarcity.

Discussion and take-home message:
The experimental results shows that the combination of NBS and IoT monitoring was able to provide an more natural approach to support stormwater management together with a smarter way to obtain insightful information on a real-time basis to the system performance, which can support operation optimisation as well as identify patterns that can help in the design of new systems and enhancements of existing infrastructure in order to face the challenges related of climate change.

Figure 1 – Green roof pilot and infiltration basin used as case studies for the IoT experimental data

**linco@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark, ***osch@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark

**** solb@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark, *****jemol@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark*

SESSION 4A: Wastewater and PFAS

Chair: Søren Hvilshøj, NIRAS, and Lotte Bjerrum Friis-Holm, TI

Speakers	**Title of the presentations**
Zhiguo Su	Distinct ARG profiles associated with class 1 integrons in municipal and industrial wastewater treatment plants
Xinhui Wang	Searching for N2O respiring bacterial catalysts
Sadiye Kosar	Profiling Microbial Signalling in Wastewater Biofilms: towards a better understanding of bioflocculation and biofilm formation
Fabio Polesel	Model-based identification of suitable quaternary treatment configurations for the removal of micropollutants: The case of Bisphenol A

Distinct ARG profiles associated with class 1 integrons in municipal and industrial wastewater treatment plants

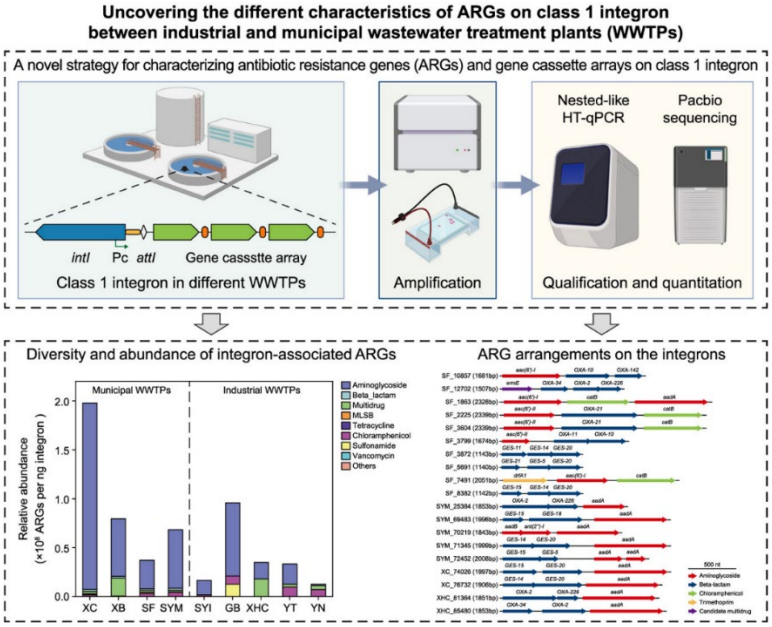
Zhiguo Su, Aarhus University, Yan Zhang, Jiangnan University**, He Liu, Jiangnan University#, Donghui Wen, Peking University##*

Introduction: Class 1 integrons facilitate horizontal gene transfer, significantly influencing antibiotic resistance gene (ARG) dissemination within microbial communities. Wastewater treatment plants (WWTPs) are critical reservoirs of ARGs and integrons, yet the integron-mediated dynamics of ARG transfer across different WWTP types remain poorly understood. Here we show distinct ARG profiles associated with class 1 integrons in municipal and industrial WWTPs using a novel approach combining nested-like highthroughput qPCR and PacBio sequencing.

Methods and data: This study proposes a novel methodology that combines nested-like qPCR and PacBio sequencing to analyze ARGs and gene cassette arrays associated with class 1 integrons. Initially, conventional PCR was employed to amplify class 1 integrons, followed by a quantitative analysis of ARGs on the integrons using high-throughput qPCR with the amplicons as the deoxyribonucleic acid (DNA) template. This approach enabled an evaluation of the relative abundance of ARGs on class 1 integrons. The main amplification bands of class 1 integrons, retrieved from electrophoresis gel, were then subjected to PacBio sequencing. The long-read length and high throughput of PacBio sequencing allow for accurate analysis of the gene cassette arrays on class 1 integrons.

Results: Although industrial WWTPs contained higher absolute integron abundances, their relative ARG content was lower (1.27×10^7–9.59×10^7 copies/ng integron) compared to municipal WWTPs (3.72×10^7–1.98×10^8 copies/ng integron). Of the 132,084 coding sequences detected from integrons, 56.8% encoded antibiotic resistance, with industrial plants showing lower ARG proportions, reduced ARG array diversity, and greater incorporation of non-ARG sequences. These findings suggest industrial WWTP integrons integrate a broader array of exogenous genes, reflecting adaptation to complex wastewater compositions.

Discussion and take-home message: (1) A novel strategy combining nested-like qPCR and PacBio sequencing was developed for analyzing class 1 integrons. (2) Distinct ARG patterns on class 1 integrons were identified in municipal and industrial WWTPs. (3) Industrial WWTPs exhibited fewer ARGs associated with class 1 integrons compared to municipal WWTPs. (3) More than 56% of coding sequences integrated by class 1 integrons in industrial WWTPs were not ARGs. (4) More diverse genes on class 1 integrons in industrial WWTPs indicated adaptation to complex wastewater environments.



* suzhiquo@bce.au.dk: Ole Worms Allé 3, 8000 Aarhus C, Denmark
** yanzhang@jiangnan.edu.cn: Jiangnan University, Wuxi, 214122, China
# liuhe@jiangnan.edu.cn: Jiangnan University, Wuxi, 214122, China
dhwen@pku.edu.cn: Peking University, Beijing, 100871, China

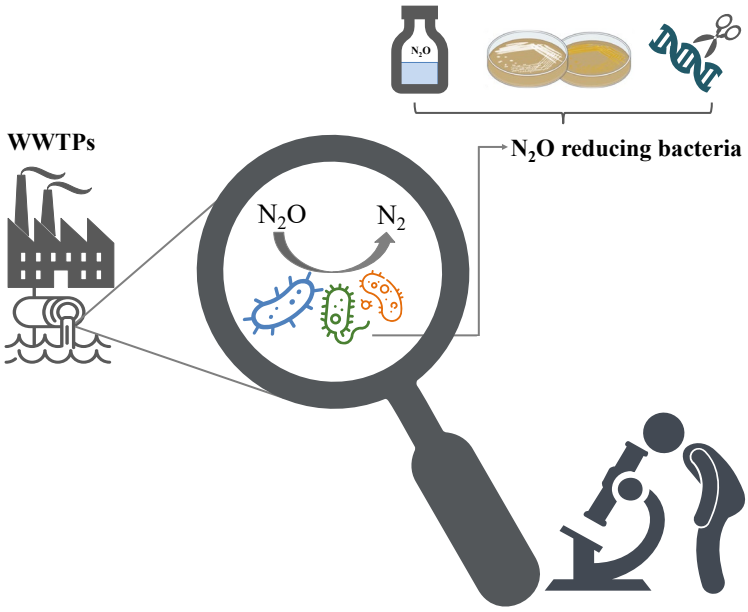
Searching for N_2O respiring bacterial catalysts

Xinhui Wang, Ines Oliveira**, Barth F Smets***, WATEC- University of Aarhus*

Introduction: Nitrous oxide (N_2O) is one of the most powerful greenhouse gases (GHGs) and an important ozone-depleting substance in the atmosphere. The major N_2O emissions are anthropogenic and associated with agronomic N fertilizer use and the waste sector. In wastewater treatment, N_2O is produced during oxic and anoxic conditions, but emitted mainly during aeration due to stripping. To address this challenge, we are investigating the use of oxygen-tolerant N_2O-reducing bacteria to mitigate N_2O emissions from wastewater off-gas.

Methods and Results: Samples were collected from diverse natural environments, and enrichment cultures under N_2O supplementation have yielded microbial communities with high N_2O reduction capacity. Metagenomic sequencing and analysis has identified potential key N_2O reducers, which are currently subjected to isolation and functional assays. Several isolates are likely to serve strong N_2O sink activity.

Discussion and take-home message: Our ultimate goal is to immobilize selected strains in beads for application in off-gas treatment from wastewater processes. Our work will provide the foundations for developing a novel N_2O mitigation strategy in wastewater treatment, contributing to mitigating of greenhouse gas emissions and climate change forcing.



** wxh@bce.au.dk: Ole Worms Allé 3, 8000 Aarhus C, Denmar*

*** 202403341@post.au.dk: Ole Worms Allé 3, 8000 Aarhus C, Denmark*

**** bfsm@bce.au.dk: Ole Worms Allé 3, 8000 Aarhus C, Denmark*

Profiling Microbial Signalling in Wastewater Biofilms: towards a better understanding of bioflocculation and biofilm formation

*Sadiye Kosar, T. Seviour, L. Vergeynst, Aarhus University**

Abstract

Quorum sensing (QS) plays a crucial role in microbial communication within wastewater treatment plants (WWTPs), influencing biofilm formation, flocculation, sludge stability and settleability, and resource recovery efficiency. Among quorum sensing signals, N-acyl homoserine lactones (AHLs) are key regulators, yet their presence in WWTPs remains underexplored due to analytical limitations. We present a robust analytical method for the detection and quantification of AHLs across diverse wastewater matrices—including effluent and biofilms such as suspended sludge, granular sludge, and carrier-attached biofilms. Understanding AHL profiles across these systems offers new insight into how microbial interactions impact treatment performance, with implications for downstream resource recovery, such as methane generation via anaerobic digestion (AD), biopolymer extraction from extracellular polymeric substances (EPS), or hydrothermal liquefaction (HTL) for biocrude oil production.

Introduction: Quorum sensing governs microbial cooperation in WWTPs and is essential for processes such as production of extracellular polymers, floc formation and biofilm maturation. AHLs, the main QS signals in Gram-negative bacteria, play critical roles in shaping microbial community behaviour. However, their actual occurrence, diversity, and concentrations in full-scale wastewater matrices remain poorly characterized. A better understanding of microbial signalling networks may lead to improved biological treatment performance and support the transition of WWTPs into circular resource recovery facilities.

Methods and data: An analytical method based on liquid chromatography – high resolution mass spectrometry (LC-HRMS) was developed to detect AHLs and screen for unknown QS-related compounds. Recovery during sample preparation was optimized to matrix type: liquid samples (effluent, water phase) were extracted via solid-phase extraction (SPE, Oasis HLB), while biofilm samples were extracted using solvent extraction involving freeze-drying, sonication and SPE. LC and MS parameters were optimized for optimal sensitivity and selectivity in complex wastewater matrices. A standard mixture of 11 AHLs was used to construct calibration curves, verify retention times, and validate compound identities in environmental samples.

Results: High detection sensitivity (down to ~10 pM in water and ~0.9 pmol/g in sludge) and consistent recoveries (>70%) were achieved. Short-chain AHLs, especially C6-HSL, dominated across matrices, reaching 53.9 ± 17.9 pmol/g biomass in carrier biofilms and 70.8 ± 35.5 pmol/g biomass in granular sludge. C8-HSL was broadly detected in both effluent and sludge, though generally at lower concentrations of 10.5 ± 1.2 pM and 0.90 ± 0.14 pmol/g biomass. Long-chain and modified AHLs, including C12-HSL, C12-3oxo-HSL, and C12-3OH-HSL, were mainly associated with sludge samples, indicating stronger interactions with biological materials. Effluent samples consistently contained short-chain AHLs, with occasional detection of long-chain analogues. Full-scan HRMS also revealed untargeted peaks, suggesting the presence of additional, yet uncharacterized quorum sensing signals.

Market potential: This analytical method enables researchers to investigate unexplored aspects of probably the most important biological process in WWTPs, namely bioflocculation and biofilm formation. By investigating the presence and role of quorum sensing, we aim to enhance our understanding of bioflocculation and biofilm formation in WWTPs, which directly impact wastewater treatment efficacy and resource recovery potential.

Discussion and take-home message: This study delivers:(1) A validated and matrix-specific LC-HRMS method for AHL detection across complex WWTP matrices, (2) Direct quantification of short- and long-chain AHLs across effluent, carrier biofilms, and sludge., and (3) Evidence that microbial signalling networks vary by sludge type, with implications for biofilm stability and circular wastewater management.

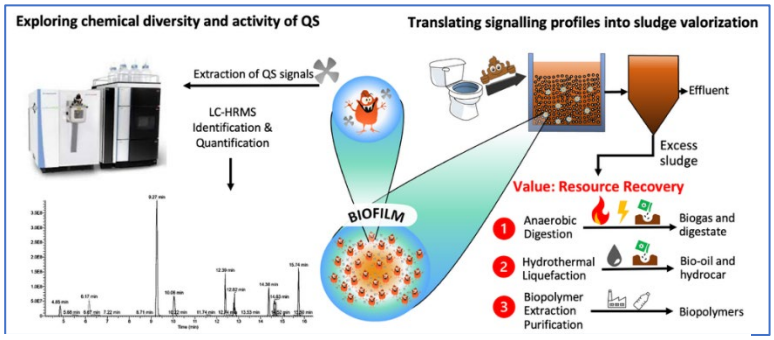


Figure 7 Conceptual overview - microbial signaling and resource recovery potential

*twseviour@bce.au.dk: Department of Biological and Chemical Engineering, Ole Worms Allé, 8000 Aarhus
*leendert.vergeynst@bce.au.dk: Department of Biological and Chemical Engineering, Ole Worms Allé, 8000 Aarhus

Model-based identification of suitable quaternary treatment configurations for the removal of micropollutants: The case of Bisphenol A

Martina Di Luca, Politenico di Milano Enrico Remigi, DHI A/S**, Thor Danielsen, DHI A/S**, Dines E. Thornberg, BIOFOS***, Artur T. Mielczarek, BIOFOS***, Fabio Polesel, DHI A/S**, Manuela Antonelli, Politecnico di Milano**

Introduction: Bisphenol A (BPA) is a widely used product in plastic manufacturing. Its ubiquitous presence in the environment is a matter of concern due to its negative effects on the health of living organisms (including humans). Wastewater treatment plants (WWTPs) are a primary source for the discharge of BPA in the environment. The recently approved revision of the EU Urban Wastewater Treatment Directive (EU UWWTD) has introduced specific requirements for the removal of organic micropollutants (80% removal for a set of 12 substances), resulting in the potential need of upgrading WWTPs with quaternary treatment steps. These requirements should align with other regulatory specifications at national level. In Denmark, a limit of 10–100 ng/L exists for BPA as quality requirement in water recipients.

The objective of the present study was to address knowledge gaps in relation to BPA removal in WWTPs and identify the needs for upgrading a Danish WWTP (Lynetten, 750,000 PE) to comply with Danish requirements set for BPA in water recipients. A model-based approach was adopted to fulfil this objective, predicting BPA removal under existing WWTP operations and for alternative upgrade scenarios. The approach included: (i) critical review of existing data on BPA occurrence and removal in WWTPs; (ii) set up and calibration of a process model for Lynetten WWTP to predict BPA removal in conventional treatment steps; and (iii) extension of the WWTP model with quaternary treatment steps (ozonation, granular activated carbon–GAC) to achieve the recipient's quality requirements.

The initial review highlighted that BPA removal has been widely investigated in conventional (activated sludge) and quaternary treatment, however under conditions that do not reflect full-scale WWTP operation. Modelling results showed that Lynetten WWTP can remove BPA with an average efficiency of 95%, in line with existing literature data and highlighting that considerable removal can be obtained already through conventional treatment. This was not sufficient to achieve effluent BPA concentrations below the quality requirement (Figure 1, a-b). Three alternative scenarios were investigated for WWTP upgrade with quaternary treatment, i.e.: (i) GAC only (Scenario 1); (ii) ozonation only (Scenario 2); (iii) ozonation combined with GAC (Scenario 3). Findings from this evaluation were that:

(i) Upgrade with GAC alone can achieve the requirement for BPA, however requiring frequent active carbon regeneration (every 3,600 bed volumes, corresponding to 86 days);

(ii) Upgrade with ozonation alone can also remove BPA down to the required discharge limits, however requiring a rather higher ozone dose (0.6 gO_3/gDOC). A lower, more realistic ozone dose (0.2 gO_3/gDOC) can support the removal of BPA to levels close to, but still higher than the discharge limit (Figure 1a)

(iii) Upgrade with ozonation and GAC combined can support the fulfilment of BPA quality requirement (Figure 1b), while operating at more realistic and cost-effective ozone dose (0.2 gO_3/gDOC) and activated carbon regeneration frequency (7,500 bed volumes, corresponding to approximately 172 days)

While Scenario 3 would require high initial investment due to the construction of two additional process units, it will also benefit from reduced operational costs due to lower chemical and energy use for ozone generation and activated carbon regeneration. Although this deserves further investigation, it is also expected that GAC would represent an additional barrier for the removal of byproducts formed in the ozonation step.

The findings from this study highlight the value of using modelling approaches in decision-making for WWTP upgrades, supporting water utilities in cost-benefit analysis while considering compliance to multiple regulatory requirements.

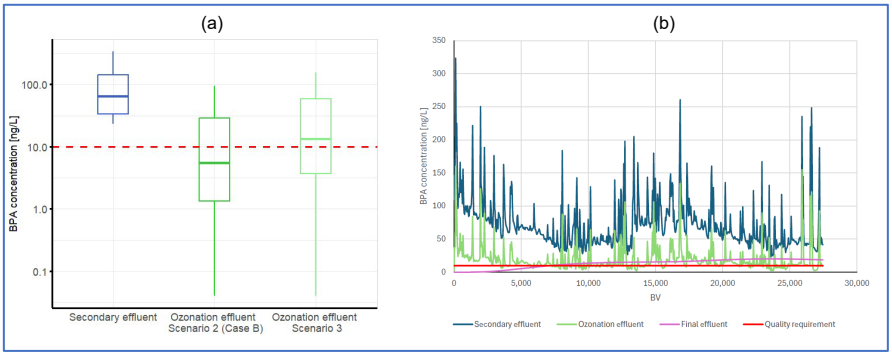


Figure 1. Average (a) and dynamic (b) effluent concentrations of BPA from secondary effluent, ozonation (Scenario 2: 0.6 gO_3/gDOC dose; Scenario 3: 0.2 gO_3/gDOC dose) and GAC.

* martina.diluca@mail.polimi.it ; manuela.antonelli@polimi.it: Piazza Leonardo da Vinci 32, 20133 Milano, Italy, ** eure@dhigroup.com; fapo@dhigroup.com: Agern Allé 5, DK-2970 Hørsholm, Denmark, *** dt@biofos.dk; atm@biofos.dk: Kanalholmen 28, 2650 Hvidovre, Denmark

SESSION 4B: Wastewater and PFAS

Chair: Søren Hvilshøj, NIRAS, and Lotte Bjerrum Friis-Holm, TI

Speakers	**Title of the presentations**
Sofie Thorgaard	4th Treatment Stage – Treatment of Pharmaceutical Residues at Egå Wastewater Treatment Plant
Vasileia Stoumpou	Mitigations strategies for anaerobic digestion of saline sludge
Kai Bester	The path of benzalkonium compounds (Rodalon) into the environment
Jan-Max Arana Juve	Best Practices for Experimental Design, Testing, and Reporting of Aqueous PFAS-Degrading Technologies
Christian Wieth	Circular Wastewater Filtration with Biosolids Biochar for PFAS and Pharmaceuticals Elimination in the 4th treatment stage

4th Treatment Stage – Treatment of Pharmaceutical Residues at Egå Wastewater Treatment Plant

Author(s): Sofie Thorgaard, Aarhus Vand

Introduction:

Egå Wastewater Treatment Plant (WWTP) receives untreated wastewater from Aarhus University Hospital, one of Denmark's largest hospitals. The plant operates with a conventional activated sludge process without specific treatment for pharmaceutical residues. A joint project (2019–2020) by Aarhus Municipality, Aarhus Vand, and Aarhus University Hospital assessed sources and impacts of pharmaceutical residues within the Egå WWTP catchment.

Methods and data:

The study mapped wastewater loads and analyzed concentrations of 10 pharmaceuticals identified as environmental risk substances. Their levels were compared against Predicted No-Effect Concentrations (PNEC). Technology options for central versus decentral treatment were evaluated, focusing on effectiveness, cost, and climate impact.

Results:

The mapping showed that 87% of pharmaceutical residues originate from households, while 13% stem from the hospital. The existing activated sludge process already removes a significant portion of the load. Nevertheless, concentrations of several substances exceeded or potentially exceeded PNEC thresholds in effluent. Ozonation combined with sand filtration was selected as the optimal technology, offering effective removal, lower carbon footprint, and broad applicability compared to activated carbon.

Market potential:

The project responds directly to upcoming EU requirements for a 4th treatment stage and provides Aarhus Vand with practical experience in implementing advanced treatment technologies. This positions the utility to meet regulatory demands cost-effectively and with lower environmental impact, with clear transferability to other European WWTPs.

Discussion and take-home message:

Centrally located ozonation at Egå WWTP was chosen over decentralized hospital treatment to maximize environmental protection of Egå River and Aarhus Bay. The ongoing design and tender process (2023–2025) provides valuable lessons for utilities considering pharmaceutical treatment. Key takeaways are:

1. Centralized treatment can address diffuse household contributions more effectively.
2. Ozonation with sand filtration balances performance, cost, and climate concerns.
3. Early technology assessment and regulatory alignment are crucial to ensure successful implementation.

Mitigations strategies for anaerobic digestion of saline sludge

V. Stoumpou, G. Burchietti*, P. Postacchini*, K. Tsigkou**, I., Angelidaki**, B. Valverde-Pérez**

Introduction: Wastewaters with high salinity from industrial, food processing and membrane treatment sources pose significant challenges to anaerobic digestion (AD) due to salt concentrations often exceeding 10 g/L. Such elevated salinity can inhibit microbial activity, reduce methane yields and challenge process stability. Although osmotic stress effects are known, the specific impacts of different salt types are not fully understood, and there is limited guidance on operational strategies for mitigating salinity effects in full-scale AD systems. This study investigated the inhibitory effects of salinity on AD of mixed sewage sludge and evaluated mitigation strategies to enable safe digestion of mixed sewage sludge to improve process resilience.

Methods and data: Standard biomethane potential (BMP) assays tested mixed sewage sludge (50:50 ratio of primary and secondary sludge) with 1.6% VS under four osmotic pressure levels 3,7,11,15 bar for both NaCl and $MgCl_2$ at mesophilic conditions (37°C, ISR=3.33, OLR=2 g-VS/L/d). The biomethane yield (ml-CH_4/g-VS), biogas composition %CH4, %CO2 and achieved solids degradation were monitored over 60 days. Three parallel continuous stirred-tank reactors (CSTRs) with 15 days solids retention time (SRT) and a loading rate of 1.06 g-VS/L/d, were operated to evaluate three different strategies to mitigate salinity in digesters: (1) gradual stepwise salt addition (0 to 15 bar), (2) shock exposure (15 bar), and (3) shock exposure with adaptive OLR control (20 bar). In the latter the loading rate was daily changed according to performance parameters including volatile fatty acids (VFAs), pH, biogas production and composition [1].

Results: BMP assays revealed progressive inhibition with increasing salinity, exhibiting linear correlations between osmotic pressure and methane yield reduction ($R^2 \geq 0.96$ for both salts). $MgCl_2$ demonstrated stronger toxicity than NaCl at equivalent osmotic pressures: at 15 bar, inhibition reached 51.9% ($MgCl_2$) vs 29.8% (NaCl), with $MgCl_2$ additionally causing prolonged lag phases (13.7 vs 9.0 days). The CSTR experiments demonstrated strategy-dependent tolerance to salinity. Gradual addition showed initial inhibition at 3 bar (71.6 ml-CH_4/g-VS) but recovered and then stabilized at 12 bar at around 130.4 ml-CH4/g-VS indicating microbial adaptation. Sharp exposure caused immediate 21% inhibition at 15 bar but methane yield recovered to 59% above baseline within 2 SRTs (135.7 ml-CH_4/g-VS). Adaptive control operated for 1.7 SRT under extreme salinity (20 bar) and led to a rapid drop in yield from 170 ml-CH_4/g-VS to 30 ml-CH with partial recovery thereafter. A final decline was observed due to VFA overload (>2 g/L) though extended monitoring is needed.

Market potential: This study supports further research on how to integrate wastewater streams with high salinity into bioenergy production though anaerobic digestion. Effective operational strategies to mitigate salinity inhibition can enhance biogas yields and process stability making saline streams more viable at centralized plants.

Discussion and take-home message: These findings demonstrate that saline sludge can be handled in centralized AD infrastructure though appropriate operational strategies. Gradual adaptation protocols could enable salt tolerance and potential enhancement of performance while shock exposure could prove viable for intermittent saline loads. Further optimization of these approaches is essential for the practical integration of saline streams into bioenergy systems while maintaining robust centralized biogas production.

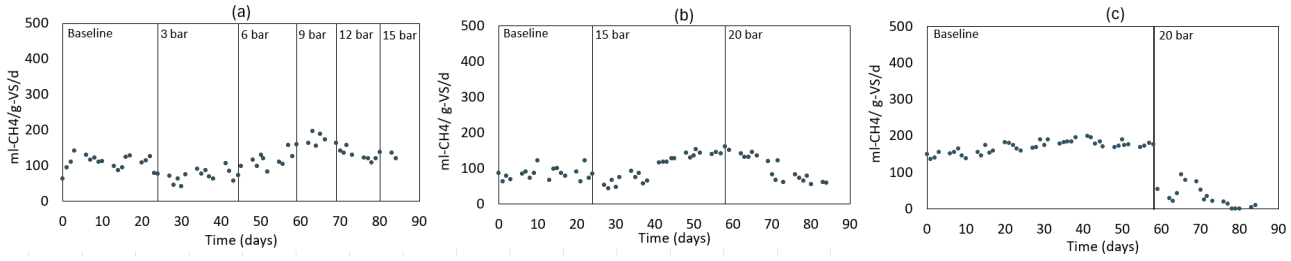


Figure: Daily methane yield (mL CH_4/gVS·d) during CSTR operation under different salinity management strategies, (a) gradual addition, (b) sharp addition, (c) control.

References

[1] Ghofrani-Isfahani, P., Valverde-Pérez, B., Alvarado-Morales, M., Shahrokhi, M., Vossoughi, M., & Angelidaki, I. (2019). Supervisory control of an anaerobic digester subject to drastic substrate changes. *Chemical Engineering Journal*, *391*, 123502. https://doi.org/10.1016/j.cej.2019.123502

* vasto@dtu.dk ; bvape@dtu.dk *Department of Environmental and Resource Engineering, Technical University of Denmark, Bygningstorvet, Bygning 115, 2800 Lyngby, ** Department of Chemical Engineering, Technical University of Denmark, Bygningstorvet, Bygning 227, 2800 Lyngby*

The path of benzalkonium compounds (Rodalon) into the environment

Kai Bester, AU-ENVS Andrea Mongelli, AU-ENVS**, Yrsa Larsson, AU-ENVS****

Abstract

Benzalkonium compounds are among the most used biocides in Denmark. They are used in human-, in food-, and animal hygiene according to rules and on building protection (roofs and terrasses not according to regulations) and are thus quite abundant.

Concentrations in raw wastewater are around 1.5 µg/L in the dissolved phase and around 40 µg/Kg in the particulate phase. In wastewater treatment the transfer from dissolved to particulate is quantitative.

This leads to emissions of about 16t Benzalkonium to the Danish environment via wastewater.

Concentrations in manure are about 800 µg/L with 40 Mio t manure production in Denmark this is giving an emission of 32 t BAC/ a via manure.

On the other hand BAC degrades relatively easily thus metabolites are maybe of larger importance than parent compounds in risk assessments. However, in the overall picture, it seems like BAC is relatively easily removed by most biofilms reactors, however the assessment of the persistent or semi persistent metabolites is an open issue.

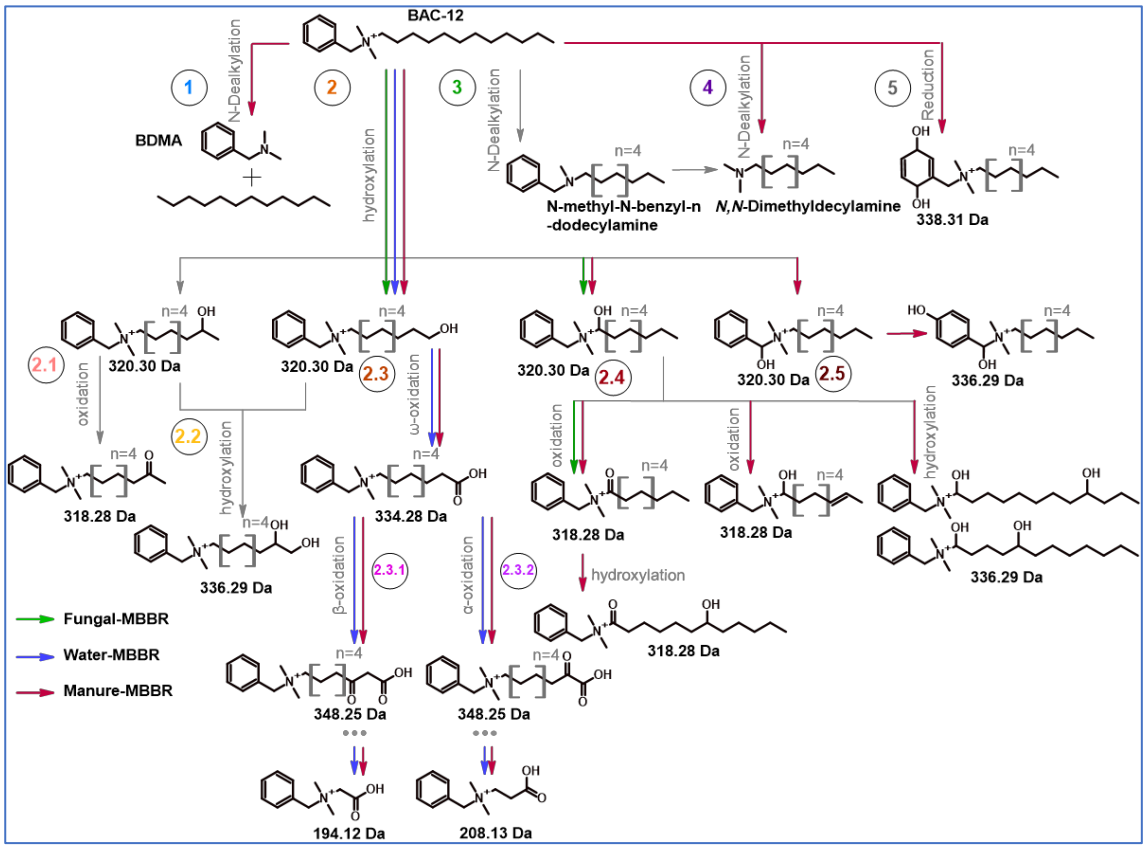


Fig. 1. Overview on known and newly identified metabolic pathways in the different systems. 1: N-Dealkylation, 2: hydroxylation followed by 2.1: oxidation, 2.2 hydroxylation, 2.3 omega-oxidation followed by 2.3.2 beta-oxidation or 2.3.2 alpha-oxidation. 3: N-dealkylation and 4: N-dealkylation in environmental biofilm technology

*kb@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

**am@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

***yrsa@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Best Practices for Experimental Design, Testing, and Reporting of Aqueous PFAS-Degrading Technologies

Allyson Leigh Junker[1], Jan-Max Arana Juve[1,2], Lu Bai[1], Charlotte Skjold Qvist Christensen[1], Lutz Ahrens[3], Ian T. Cousins[4], Mohamed Ateia[5,6], Zongsu Wei[1]

Introduction: Increased awareness of pervasive per- and polyfluoroalkyl substances (PFAS) contamination and the need for zero-pollution treatment solutions necessitate that the scientific and engineering community respond urgently and systematically.

Existing approaches lack standardized methods. Consequently, it is difficult to compare innovations and assess potential.

This perspective sheds light on hurdles encountered in the lab-scale research of aqueous PFAS destruction technologies and offers recommendations. This work aims to foster progress in the development of effective treatment solutions.

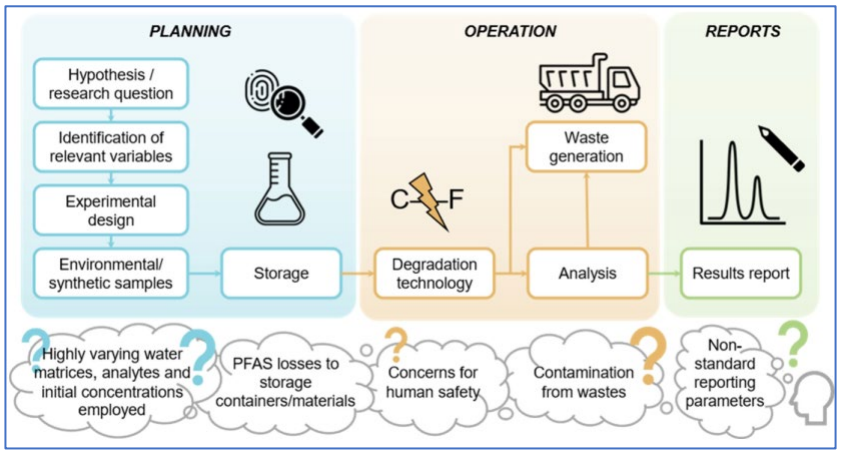


***Figure 1**: Sequence of steps when conducting PFAS lab-scale degradation research.*

Methods and data: Insights were derived from a comprehensive literature review, direct experimental experience, and expert judgment. These inputs were synthesized to critically evaluate current practices and to propose actionable guidelines for ensuring consistency and rigor in PFAS laboratory research. The aim is to establish a foundation for best practices that can support both academic inquiry and industrial innovation.

Results: This work introduces best practices for developing robust PFAS experimental protocols, addressing essential aspects such as study design, sample handling and storage, analytical methods, waste management, and data reporting (**Figure 1**). Furthermore, five key criteria are proposed to standardize the evaluation and communication of PFAS destruction technologies: (1) treatment scope, (2) defluorination efficiency, (3) relative energy demand, (4) material stability, and (5) unit process considerations.

Discussion and take-home message:

Conducting PFAS research requires robust experimental planning, informed selection of analytes, and appropriate storage and operating conditions. Once the effects of these variables are well-known, experiments can follow realistic conditions such as:

1) Multi-component water matrices
2) Environmentally relevant concentrations
3) Effective reporting based on 5 criteria (**Figure 2**)

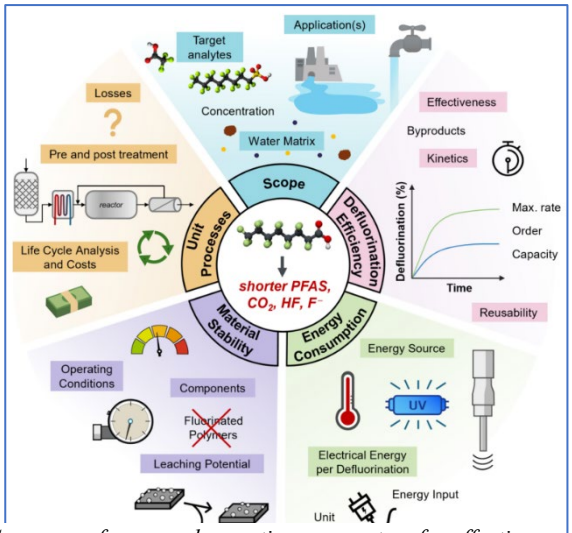


***Figure 2**: Summary of proposed reporting parameters for effective PFAS-degrading technology assessment.*

Collectively, these parameters can serve as the foundation to provide a transparent framework for benchmarking progress and assessing the potential market value of emerging treatment solutions.

[1] Centre for Water Technology (WATEC) & Department of Chemical Engineering, Aarhus University, 8000 Denmark, [2] Process Design Department, NIRAS, Sortemosevej 19-21, 3450 Denmark, [3]Department of Aquatic Sciences and Assessment, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden, [4]Department for Environmental Science, Stockholm University, 106 91 Stockholm, Sweden, [5]Center for Environmental Solutions & Emergency Response, U.S. Environmental Protection Agency, Ohio 45268, USA, [6]Department of Chemical and Biomolecular Engineering, Rice University, Houston, Texas 77005-1827, United States

Circular Wastewater Filtration with Biosolids Biochar for PFAS and Pharmaceuticals Elimination in the 4th treatment stage

Bester K.[1], Zhong J.[1], Skaarup S.[2], Wieth C.[3],*

*[1]Aarhus University, [2]Hillerød Utility Company, [3]AquaGreen ApS, Denmark, *chwi@aquagreen.dk*

Introduction:

Municipal wastewater treatment faces increasing challenges due to regulatory requirements for pharmaceutical removal and PFAS monitoring. Conventional solutions, such as activated carbon, incur significant costs of 5-7 €/person equivalent/year. This study investigates the feasibility of biosolids or sewage sludge (SS) biochar as an alternative to activated carbon for wastewater filtration, combining cost-effectiveness with circular economy principles.

Methods and data:

The research included a one-year column filtration study on wastewater from Hillerød Utility in Denmark, encompassing 2000 bed volumes (BV) with detection of 31 pharmaceuticals, six of which exceeded predicted no-effect concentrations (PNEC). PFAS sorption capacity was assessed through equilibrium studies using samples spiked with six PFAS compounds. The experimental work was carried out by Aarhus University.

Results:

Results demonstrate that Biosolids/Sewage Sludge (SS) biochar effectively removes all pharmaceuticals to below PNEC levels at 0,5-2 g/L dosage (500-2000 BV) and reduces PFOS and PFOA concentrations by 50% at 1 g/L dosage (1000 BV). SS biochar therefore looks promising as a sorbent, applied as powdered activated carbon (PAC) in a municipal wastewater treatment plant.

Market potential:

This study highlights the potential of biosolids biochar as a sustainable circular alternative to activated carbon, addressing micropollutant challenges while promoting resource efficiency and economic feasibility in wastewater treatment systems. More than 1000 Wastewater treatment plants > 100.000 PE in EU have to establish 4.th treatment level, and use of activated carbon is today an accepted practice. If they can save 3 €/PE/year this is equivalent to a potential saving of ca. 1 bn €/year across all wastewater treatment plants > 100.000 PE in EU (based on 2020 data for number and size of wastewater treatment plants in EU).

Discussion and take-home message:

By integrating on-site sludge pyrolysis, biochar can be recycled with the SS and regenerated, thereby reducing costs, capturing carbon, and effectively eliminating organic pollutants from both the wastewater and the biosolids. Potential phosphate leaching from the biosolids biochar is an area to be investigated further. AquaGreen is interested in finding utility companies that can test this application further.

SESSION 5A: Resources recovery, Auditorium 2

Chair: Hans-Martin Friis Møller, HMM Consult, Bo Højris, Grundfos

Speakers	**Title of the presentations**
Case van Genuchten	Rethinking arsenic in groundwater treatment by-products: Carcinogen to be disposed or resource recovery opportunity?
Tinatin Tkesheliadze	Phosphate Recovery from Groundwater Treatment Sludge is Governed by Solid-phase Speciation
Thomas William Seviour	Valorizing extracellular polymeric substances: Recovery method confounds characterization and processing
Amir Gholipour	Innovative green solutions: sludge-derived fertilizers free from PFAS and antibiotics

Rethinking arsenic in groundwater treatment by-products: Carcinogen to be disposed or resource recovery opportunity?

Case M. van Genuchten, Geological Survey of Denmark and Greenland (GEUS), Kaifeng Wang. GEUS ***

Abstract: Arsenic (As) is a potent carcinogen whose presence in groundwater poses a persistent global public health threat. While groundwater treatment mitigates As exposure, it generates concentrated As-rich sludge that is viewed as a disposal problem rather than a resource recovery opportunity. Here, we document, for the first time, the conversion of As-laden sludge into pure As(0), a valuable Critical Raw Material needed for the transition to clean energy systems.

Introduction: Naturally-occurring arsenic (As) in groundwater has been a global public health concern for decades. Iron-based groundwater treatment is an established approach to safeguard human health from carcinogenic As, but generates concentrated As-rich waste as a by-product that is universally viewed as an environmental and economic burden. However, As is experiencing a renaissance. Multiple regions, including the European Union (EU) and United States (US), have now classified metallic As(0) as a Critical Raw Material (CRM) due to the indispensable use of As(0) in materials needed to transition from fossil fuels to clean energy, such as batteries and high-speed electronics (e.g., semiconductors). Taken together, the requirements to improve As-rich sludge management and create local sources of CRMs reveal a compelling opportunity to redefine carcinogenic As as a commodity. In this work, we present a new chemical method to form valuable metallic As(0) from As-rich groundwater treatment sludge.

Methods and data: Groundwater treatment sludge samples were obtained directly from the sludge storage areas of a variety of treatment plants selected strategically to encompass a wide range of geographic location, groundwater composition and plant properties. Sludge upcycling was performed using a two-stage chemical process consisting of *extraction* and *refinement*. The *extraction* step involved mixing dried sludge with 1 M NaOH to mobilize surface-bound As from the solids. The As-rich extraction solution was then separated from the residual solid sludge by centrifugation and reserved for the subsequent *refinement* step. Refinement of the As-rich extraction solution was performed by adding a selective chemical reductant, thiourea dioxide (TDO), to reductively precipitate As(0). The upcycled As(0) solids were characterized by a set of advanced molecular- and nano-scale characterization techniques.

Results: In optimal conditions, alkali As extraction using 1 M NaOH released up to >99% As contained in the initial sludge, leaving an As-depleted Fe(III) (oxyhydr)oxide solid residual that can be reused as adsorbent media in treatment. The extracted aqueous As concentration was found to routinely exceed 100 mg/L for most sludges, but reached the highest concentration (>200 mg/L) for sludges with initial As mass fractions >2.0 g/kg. The addition of TDO to the extraction solution of all sludges selectively reduced aqueous As to form As(0), with >99% conversion efficiency for extraction solutions with aqueous As concentrations >200 mg/L. Structural characterization of the upcycled solids revealed a pure As(0) product (>99% As) with an amorphous structure. This unique structure of upcycled As(0) contrasts with the high crystallinity of commercially available As(0), which is a potentially critical finding that can be exploited to facilitate further processing of the upcycled As(0) to form high-value semiconductors, such as 2-dimensional arsenene.

Market potential: The economic potential of forming As(0) from waste lies in offsetting the expenses already associated with disposing As-laden waste, which is one of the major costs associated with groundwater treatment, as well as the income generated from selling upcycled As(0). Additional research is needed to develop a reliable estimate of the income potential from the sale of As(0) because the price of As(0) spans orders of magnitude (e.g., 100 to 10.000 DKK/kg) depending on its chemical form and industrial application.

Discussion and take-home message: The conversion of As contained in groundwater treatment sludge to form valuable As(0) has the profound 2-for-1 benefit of eliminating unsustainable and hazardous sludge disposal methods while reducing the reliance on imports of CRMs derived from extractive mining practices. The upcycling approach presented here can disrupt current water sector practices globally, but can be most societally transformative in rural, resource-scarce areas where geogenic As has for decades decimated the health and livelihood of millions.

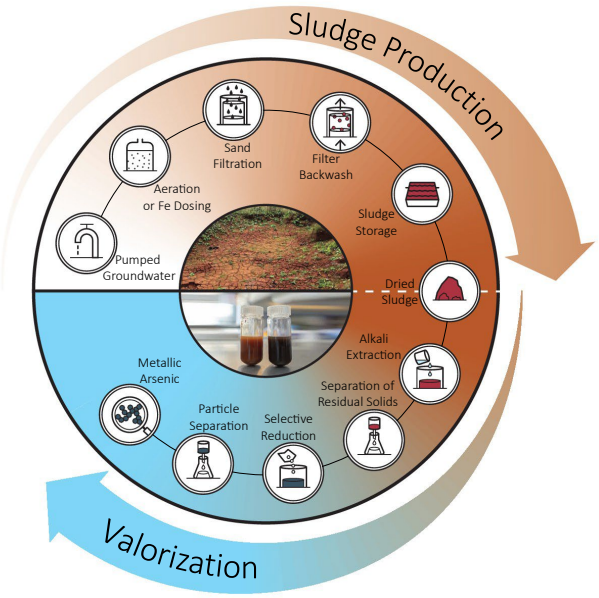


Figure 1: Conceptual diagram of upcycling As-laden groundwater treatment sludge to form valuable As(0) metal.

** cvg@geus.dk, ** kawan@geus.dk: Oester Voldgade 10, DK-1350 Copenhagen, Denmark*

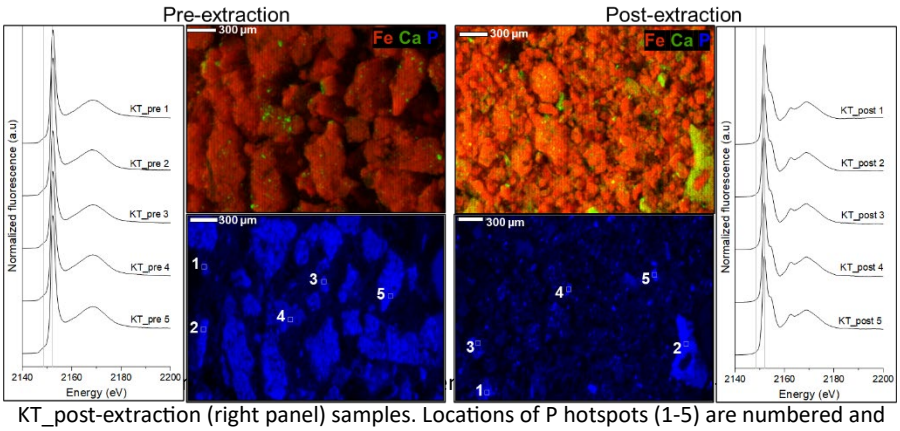
Phosphate Recovery from Groundwater Treatment Sludge is Governed by Solid-phase Speciation

*Tinatin Tkesheliadze, * [1,2] Eleanor Spielman-Sun, [3] Peter E. Holm, [2] Case van Genuchten [1]*

Introduction: Recovering phosphorus (P) from P-rich wastes offers a sustainable alternative to mining-derived P. Iron (Fe) oxide sludge from groundwater treatment contains high levels of P (>2 mass%) originating from geogenic sources, along with calcium (Ca), aluminum (Al) and organic matter. Alkali extraction using NaOH is commonly used to release Fe-bound P. However, our previous work using alkali extraction to recover P revealed that extracted aqueous P concentrations peak initially but decrease subsequently over several days. This behavior is different from alkali extraction of arsenic from the sludge and implies a change in solid-phase P speciation during extraction. In this study we applied microscale X-ray fluorescence (µ-XRF) imaging and micro-X-ray absorption near edge structure (µ-XANES) spectroscopy to track P speciation during the upcycling of groundwater treatment sludge.

Methods and data: The sludge samples were collected from three separate Fe-based groundwater treatment plants: Holmehave (HH), DK; Kerte (KT), DK and West Bengal (WB), IN. In this presentation, we focus primarily on the KT sample due to its high P content (> 1.7±0.5 g/kg) and variable P extraction behavior. Dried, homogenized and sieved samples were exposed to 1 M NaOH (200 g/L) for 1 week and dissolved P was quantified by ICP-OES. The spatial distribution of P and colocation with other elements in the pre- and post-extraction sludges were investigated using µ-XRF imaging. P speciation in hotspots identified from µ-XRF maps was determined by µ-XANES spectroscopy. µ-XRF maps (beamlines 2-3, 14-3) and P K-edge µ-XANES spectra (beamline 14-3) were collected at the Stanford Synchrotron Radiation Lightsource (SSRL). To determine P speciation, characteristic features in P K-edge XANES spectra from the sludge samples were compared to spectra of known P-bearing standards.

Results: µ-XRF maps of selected regions (Fig. 1) of the KT sample revealed predominance of Fe-rich particles in both pre- and post-extraction solids, consistent with the composition of the sludges identified previously. In the pre-extraction sample, colocation of P and Fe is apparent by visual comparison. Colocation of P and Ca is also evident in the maps, though to a lesser extent. µ-XANES spectra of each P hotspot (1-5) identified from µ-XRF maps of the pre-extraction solids displayed characteristic features of P sorbed to poorly crystalline Fe oxides, including a pre-edge peak at 2148.5 eV and a broad secondary peak at 2168.5 eV. For the post-extraction solids, the distribution of P and the solid-phase P speciation varied substantially from the pre-extraction sludges. The distribution of P in the µ-XRF maps largely matched that of Ca. Indeed, Ca-P bonding was confirmed by µ-XANES analysis of P hotspots, which revealed characteristic features of Ca-P solids, such as the prominent post-edge shoulder at 2154.4 eV and secondary peaks at 2162.5 and 2168.5 eV. These characteristic features in the XANES spectra of the post-extraction solids resemble that of the crystalline Ca-P mineral, hydroxyapatite.



KT_post-extraction (right panel) samples. Locations of P hotspots (1-5) are numbered and the corresponding µ-XANES spectra are presented in the side panels.

Market potential: Our results provide key insights into P speciation during extraction from groundwater treatment sludge, which is an essential first step to recovering P and valorizing this waste stream. Although P recovered from waste has direct market value, our recovery approach is at an early stage. Therefore, this work primarily supports further research and process optimization.

Discussion and take-home message: The change from primarily P-Fe bonding in the pre-extraction solids to P-Ca bonding in the post-extraction solids suggests P recovery methods can be optimized by preventing the formation of secondary P-Ca solids during extraction through precise control of extraction time and pH. Moreover, the characterization techniques (µ-XRF, µ-XANES) employed in this study, which target dilute, adsorbed and poorly ordered species, effectively distinguished different P host-phases, implying their applicability to characterize other heterogeneous solid waste streams for the purpose of designing resource recovery systems.

**tintk@geus.dk* [1]*Department of Geochemistry, Geological Survey of Denmark and Greenland, Copenhagen, DK.* [2]*Department of Plant and Environmental Sciences, University of Copenhagen, Frederiksberg C, DK.*

[3]*Stanford Synchrotron Radiation Lightsource, Menlo Park, California, USA.*

Valorizing extracellular polymeric substances: Recovery method confounds characterization and processing

S. A. Zahra, WATEC, A. Bhattacharya, WATEC**, A. Rosenvinge, WATEC***, T.W. Seviour, WATEC*

Introduction: Activated sludge is one of societies biggest biosolid wastes. Sludge disposal also represents one of the largest operating costs associated with wastewater treatment. Sludge is the waste product of a waste product, and the only opportunity of valorization was long believed to be energy, through either incineration or fermentation to biogas (i.e. a low value product). Nonetheless, activated sludge contains biopolymers, as extracellular polymeric substances (EPS) like proteins and polysaccharides. Alternative biopolymer sources are increasingly in demand as society weens itself of fossil fuels, and now sludge EPS is being considered as a source of biopolymers. Several EPS recovery processes already exist at pilot stage, specifically for recovering EPS from granular sludge. The sludge is alkalinized and heated, the EPS is released into solution and is then recovered from the supernatant by acidification. Various applications for the EPS are currently sought, including flame retardant, soil conditioner, leaf foliar, flocculant, and cement binder. Upon recovery, however, this EPS is difficult to characterize and purify further. We sought to assess whether the extraction method induces chemical reactions that confound characterization and isolation.

Methods and data:

- Assess pH and temperature dependence of advanced glycation reactions
- Assess effect of reaction conditions on protein structure by SDS-page gel
- Assess affinity of proteins to cationic exchange resin (for protein recovery) upon exposure to extraction conditions
- Chemical fingerprinting of EPS and standards by NMR upon exposure to extraction conditions

Results:

SDS-page gels showing 1) that proteins and sugars undergo Maillard reaction under extraction conditions (as indicated by smearing) and 2) that extracellular proteins have undergone Maillard reaction in activated sludge EPS.

FPLC chromatograms showing that proteins bind to protein purifying weak cationic exchange resin, but not following the exposure of proteins to sludge extraction conditions, which is also what happens to EPS proteins.

NMR fingerprinting of the EPS indicating likely composition.

Market potential:

Understanding that the extraction conditions for EPS recovery induce Maillard reaction informs the composition of the EPS (i.e. identity), with implications for branding, and prospects for further purification into an even more valuable product.

Discussion and take-home message:

1) Current EPS extraction method likely changes the composition, structure and properties of the EPS.
2) These changes make it hard to recover the individual and original EPS from the sludge (also required for valorization)
3) These changes also likely largely determine the composition of EPS (currently a mystery and scientific/technical frontier)
4) EPS extraction under hot alkaline conditions is widely practiced, so these are likely issues faced widely in biofilm characterization studies.

* *sasmitha@bce.au.dk: Ole Worms Allé 3, DK-8000 Aarhus, Denmark*

** *Amrita.bhattacharya@bce.au.dk: Ole Worms Allé 3, DK-8000 Aarhus, Denmark*

*** *axelro@bce.au.dk : Ole Worms Allé 3, DK-8000 Aarhus, Denmark*

**** *twseviour@bce.au.dk : Ole Worms Allé 3, DK-8000 Aarhus, Denmark*

Innovative green solutions: sludge-derived fertilizers free from PFAS and antibiotics

Amir Gholipour*, Steen Nielsen**, Nicolas Forquet***, Pedro N. Carvalho*,****

Introduction: Sewage sludge from wastewater treatment plants is increasingly restricted for agricultural use due to contamination with per- and polyfluoroalkyl substances (PFAS) and pharmaceuticals. In Denmark, Sludge Treatment Reed Beds (STRBs) are widely applied as a nature-based solution for long-term sludge management. As the first step of the FERTIPAS project, we are characterizing the extent of PFAS and pharmaceutical contamination in full-scale Danish STRB systems to establish a baseline for assessing risks and evaluating future treatment and reuse options.

Methods and data:

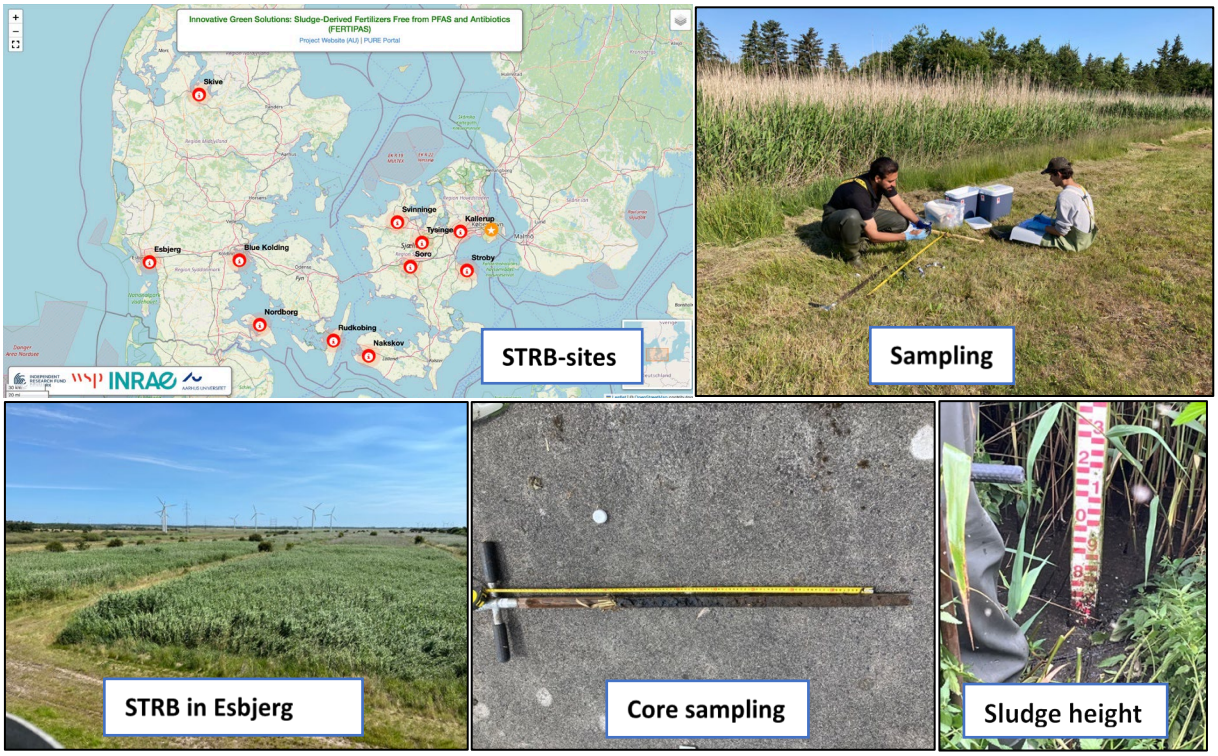
A total of 11 full-scale STRB systems were selected, including some that have been in operation since the 1990s with initially reported concentrations of PFAS and pharmaceuticals. Sampling was conducted in June and July 2025 across all beds at each site, with two beds per site subjected to high-resolution depth coring. In total, more than 1,400 sludge samples were collected. These samples are currently being extracted and analyzed using LC-MS/MS to quantify pharmaceuticals and PFAS.

Results:

We have initiated the analysis of pharmaceuticals, with PFAS analysis scheduled to begin in autumn. Concentrations will be compared both within and across sites, and efforts will be made to relate observed levels to historical usage patterns, regulatory bans, plant design, and operational practices. In addition, a preliminary risk assessment will be conducted to evaluate scenarios for the application of treated sludge to soil. Preliminary findings will be presented at the conference.

Keywords:

Nature-based solutions; PFAS; Pharmaceuticals, Sludge Treatment Reed Beds; Circular economy



* amir@envs.au.dk: Department of Environmental Science, Aarhus University, Frederiksborgvej 399, Roskilde 4000, Denmark

** Steen.Nielsen@wsp.com: WSP Denmark, Linnes Alle 2, 2630 Taastrup, Denmark

*** nicolas.forquet@inrae.fr: INRAE, UR REVERSAAL Centre de Lyon-Grenoble Auvergne-Rhône-Alpes, Lyon, France

**** pedro.carvalho@envs.au.dk : WATEC – Centre for Water Technology, Aarhus University, Ny Munkegade 120, Aarhus 8000, Denmark

SESSION 5B: Resources recovery, Auditorium 2

Chair: Hans-Martin Friis Møller, HMM Consult, Bo Højris, Grundfos

Speakers	**Title of the presentations**
Pietro Postacchini	Advanced treatment of wastewater from fish industry to produce bioenergy and microbial proteins
Imen Bousrih	Membrane Crystallization for Industrial wastewater: Influence of Pre-Concentration Strategies on Crystal Formation
Hussein Fairousha Sulaiman	High-Quality Water Recovery Towards Zero Liquid Discharge from Industrial Wastewater Using Membrane Distillation
Noah Christy	Application of anaerobic membrane bioreactor for water, nutrients and energy recovery in an urban-industrial symbiotic context
Asif Saud	Magnesium sulphate recovery from seawater using photothermal membrane crystallization

Advanced treatment of wastewater from fish industry to produce bioenergy and microbial proteins

Pietro Postacchini, Borja Valverde-Pérez**

*Department of Environmental and Resource Engineering, Technical University of Denmark, Bygningstorvet, Bygning 115, 2800 Kgs. Lyngby, Denmark **

Introduction: Addressing the risks related of natural ecosystems imbalances involves upcycling wastewater streams by reshaping industrial systems. Fishmeal production by extrusion and extraction processes typically produces high volumes of COD- and nutrient-rich wastewaters. A novel, potentially low-carbon and low-cost upcycling streamline for wish processing wastewater entails (1) anaerobic digestion (AD) for biogas production and ammonification; (2) electrochemical ammonia extraction either *in situ* or *ex situ*; (3) microbial protein production by hydrogen oxidizing bacteria (HOB) fed with the extracted ammonia as the nitrogen source, CO_2 from flue gases and renewable H_2 as energy source. Major challenges for process upscaling are (a) assessing the stability and biomethane yield of AD; (b) optimize the AD biomethane and ammonia recovery by increasing the organic loading rate while controlling ammonia liquid concentration by adjustment of voltage and electrodialysis cell configuration; (c) assess and optimize microbial protein production by HOB . Our aim was to partially address these challenges by assessing the bench scale performance of fish wastewater AD and ammonia extraction by electrodialysis.

Methods and data: Fish processing wastewater was collected from a fishmeal production facility located in Jutland, Denmark. The biomethane potential (BMP) of fish processing wastewater was determined in mesophilic batch assays setting the inoculum-to-substrate ratio (on VS basis) equal to 3. Furthermore, mesophilic AD of fish wastewater has been carried out in a continuous CSTR reactor (active volume 1.9 L). The biomethane yield and productivity, as well as the reactor performance stability, were assessed at hydraulic retention time (HRT) down to 15 d and at organic loading rates (OLR) between 0.62 and 1.2 $g \cdot L^{-1} \cdot d^{-1}$. Ammonia was extracted from the produced digestate in an electrodialysis cell designed with three separate chambers (each with a volume of 300 mL), respectively for anode, cathode, and the digestate feedstock. The cell chambers were separated by a cation exchange membrane. Anode (IrO_2) and cathode (stainless steel) had a projected area 8 cm^2. A voltage of 5 V was applied. Sodium carbonate was chosen as catholyte, and 48 h was set as the catholyte retention time.

Results: Fish processing wastewater yielded significant amounts of biomethane (557 $mL \cdot g_{VS}^{-1}$) with respect to cellulose (441.3 $mL \cdot g_{VS}^{-1}$) in batch tests. This result may be consequence of the high VFA concentration (17 $g \cdot L^{-1}$) and other soluble organic compounds in the feedstock. The averaged biomethane productivity of the continuous AD reactor, which was operate for 65 days, increased with increasing OLR: 223 $mL_{CH4} \cdot L^{-1} \cdot d^{-1}$ at OLR 0.62 $g_{VS} \cdot L^{-1} \cdot d^{-1}$; 389 $mL_{CH4} \cdot L^{-1} \cdot d^{-1}$ at OLR 0.93 $g_{VS} \cdot L^{-1} \cdot d^{-1}$; 509 $mL_{CH4} \cdot L^{-1} \cdot d^{-1}$ at OLR 1.2 $g_{VS} \cdot L^{-1} \cdot d^{-1}$. On the other hand, the biomethane yield remained stable over the whole reactor operating period at a value of 385 ± 30 $mL_{CH4} \cdot g_{VS}^{-1}$. The pH remained on average equal to 7.75 over the full operational period. Offline ammonia extraction yielded 0.3 $g \cdot L^{-1}$ total-N over 48 h in the catholyte solution having an Initial Total-N concentration of 1.5 $g \cdot L^{-1}$ in the digestate produced by continuous processing wastewater AD.

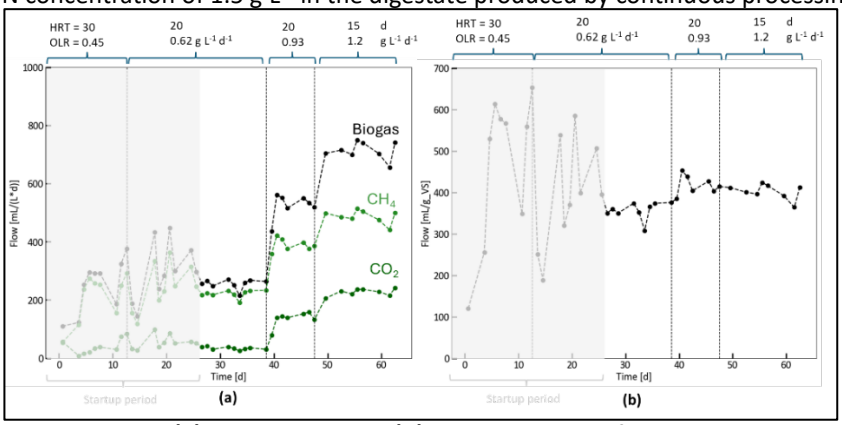


Figure 1: **(a)** gas productivity; **(b)** CH_4 yield over different operational stages.

Marketpotential: This study provided a first assessment of the biomethane yield and performance of continuous fish wastewater AD at bench scale showing high potential for energy and nitrogen recovery. Future work will focus on optimizing continuous microbial protein productivity and quality as a function of the gas-liquid mass transfer rate and gas impurities concentrations.

Discussion and take-home message: Fish processing wastewater was shown to be a high biomethane yielding substrate both in batch and continuous enabling stable AD operation. The resulting digestated was proven to be a valuable N source within an electrodialysis extraction setup. Ongoing work aims to maximize biomethane and ammonia productivity by tailoring the OLR and the operational variables affecting online nitrogen extraction.

Membrane Crystallization for Industrial wastewater: Influence of Pre-Concentration Strategies on Crystal Formation

I. Bousrih[1], S. Diaz-Quezada**[1], C. A. Quist-Jensen***[1], A. Ali****[2]*

Introduction: Membrane crystallization (MCr) is a thermally driven separation process that couples high water recovery with solute crystallization by exploiting vapor pressure gradients and supersaturation. In this work, we present our study, carried out under the framework of the European Horizon project CORNERSTONE, focusing on the potential of MCr to treat and valorize steel industry wastewater.

Methods and data: Experiments were conducted using a membrane crystallization (MCr) process employing a polypropylene (PP) hollow fiber membrane with a nominal pore size of 0.2 µm and a porosity of 73% (figure 1a). Industrial wastewater was first pre-concentrated to target levels of 50% (solution 1), 75% (solution 2), and 90% (solution 3) water recovery using membrane distillation (MD). These pre-concentrated feeds were then processed in the MCr system at a constant feed inlet temperature of 60 °C, with all other operating parameters held constant. Process performance was monitored by measuring permeate flux, water recovery percentage, and the conductivity of both the feed and permeate streams.

Results: Solution 1 and 2 demonstrated stable permeate flux at a feed temperature of 60 °C and a permeate temperature of 20 °C. The water conductivity at the permeate side was less than 12 µS/cm, indicating the recovery of a good water quality. On the other side, solution 3 which was the most concentrated, showed stable permeate flux even under continuous crystallization of $CaSO4.2H_2O$ (figure 1b), achieving a recovery factor of 97.8 %. This demonstrates the stability of MCr under high solute concentrations.

Discussion and take-home message: Our findings highlight three key points: (i) MCr modules can operate stably at high recoveries without fouling or wetting; (ii) effective crystallization requires feed pre-concentration beyond 97.8%; and (iii) applying MCr in industrial contexts could couple water reuse with resource recovery. These insights provide a pathway for scaling MCr as both a water treatment and valorization technology.

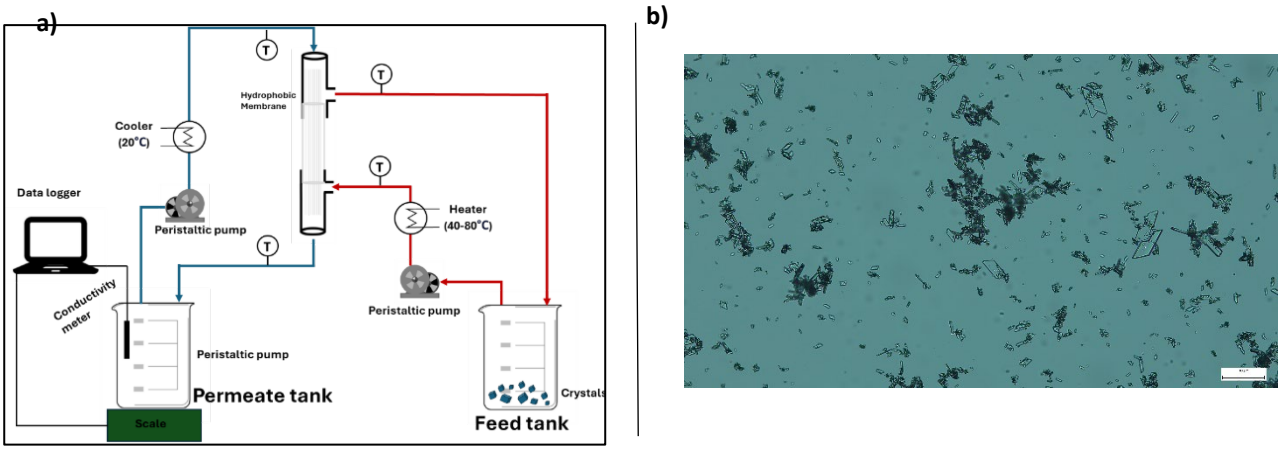


Figure 1. a) MCr experimental set-up, b) Microscope picture of $CaSO_4.2H_2O$ crystal formed through solution 3.

Acknowledgement: The Authors acknowledge the financial support of the EU Horizon under the projects CORNERSTONE "Combined technologies for water, energy, and solute recovery from industrial process streams" (HORIZON-CL4-2023-TWIN-TRANSITION-01-40, Grant Agreement No. 101072449).

[1] Center for Membrane Technology, Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark, [2] AAU Energy, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg East, Denmark

**imenb@bio.aau.dk* , ***sddq@bio.aau.dk* , ****cejna@bio.aau.dk*, *****aal@energy.aau.dk*

High-Quality Water Recovery Towards Zero Liquid Discharge from Industrial Wastewater Using Membrane Distillation

Hussein Fairousha Sulaiman[1], Imen Bousrih**[1], Simon Díaz-Quezada***[1], Aamer Ali****[2], Cejna Anna Quist-Jensen*****[1]*

Abstract

The steel industry generates large volumes of saline wastewater, and current treatment options often fail to reach high water recovery or reuse targets. Direct Contact Membrane Distillation (DCMD) offers a thermally driven solution that can exploit low-grade waste heat, enabling both high water quality and near zero-liquid-discharge operation.

We combined (i) thermodynamic simulations (PHREEQC) to predict solution properties and scaling risk, (ii) laboratory-scale experiments using a hollow fiber polypropylene DCMD module, and (iii) a validated predictive model for process performance. Wastewater composition was representative of steel industry effluents, and operating conditions included feed temperatures of 40–60 °C and velocities of 0.05–0.5 m/s.

Results:

Experiments showed stable fluxes (1.4–4.8 $kg \cdot m^{-2} \cdot h^{-1}$), >99.9% salt rejection, and no fouling/wetting up to 93% recovery **(Figure 1a)**. The model reproduced flux and outlet temperatures with low error (MAPE < 5%, $R^2 > 0.96$). Simulations demonstrated that higher feed temperature and velocity improve flux, productivity, and reduce membrane area required for 1 $m^3 \cdot day^{-1}$ of water **(Figure 1c)**.

DCMD, when integrated with waste heat from steel processes, can reduce freshwater intake and wastewater discharge. This aligns with industry sustainability goals and provides a pathway toward circular water management with potential scalability to other energy- and water-intensive sectors.

Discussion and take-home message:

DCMD can achieve very high recovery (>90%) and excellent water quality (conductivity < 5 µS/cm) from real steel wastewater. Validated modelling tools support design optimization and scale-up, reducing trial-and-error in implementation. Waste heat integration offers a cost-efficient and sustainable route for industrial water reuse and near zero-liquid-discharge operation.

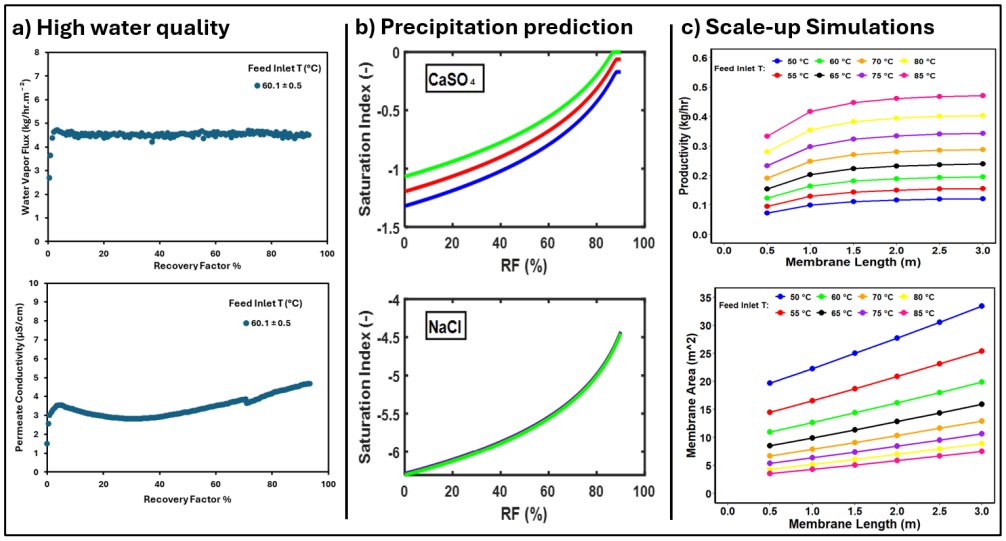


Figure 8: a) Experimental results, b) Thermodynamic simulations predicting solution properties and scaling risk, and c) Validated predictive model for process performance and scale-up.

Acknowledgements: *The Authors acknowledges the financial support of the EU Horizon under the projects CORNERSTONE "Combined technologies for water, energy, and solute recovery from industrial process streams" (HORIZON-CL4-2023-TWIN-TRANSITION-01-40, Grant Agreement No. 101072449) and the MELODIZER "Sustainable membrane distillation for industrial water reuse and decentralised desalination approaching zero waste" (HORIZON-CL4-2022-RESILIENCE-01-14, Grant Agreement No. 101091915).*

[1] *Center for Membrane Technology, Department of Chemistry and Bioscience, Aalborg University, Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark,* [2] *AAU Energy, Aalborg University, Pontoppidanstræde 111, 9220 Aalborg East, Denmark*

*hfsu@bio.aau.dk, **imenb@bio.aau.dk , ***sddq@bio.aau.dk , ****aal@energy.aau.dk , *****cejna@bio.aau.dk

Application of anaerobic membrane bioreactor for water, nutrients and energy recovery in an urban-industrial symbiotic context

Noah M. Christy*, Anders Nyeggen, Vasileia Stoumpou, Sara Björkqvist, Paulo Martins Silva, Henrik R. Andersen, Daniel Seth Larson**, Borja Valverde-Pérez*

Introduction: anaerobic membrane bioreactors (AnMBR) present an opportunity for water, energy, and nutrients to be recycled. Through co-digestion from urban and industrial waste streams, a more cost-efficient process and enhancing energy recovery is possible. However, integrating those streams can lead to cross contamination (e.g., organic micropollutants from municipal wastewater) which can prevent the acceptance of recovered nutrients or water. Thus, this project explores co-digestion scenarios to enhance safe resource recovery by employing an AnMBR.

Methods: Co-digestion scenarios were assessed on a 2500L pilot sale AnMBR at the Svaneke wastewater treatment plant in Bornholm DK. Microfiltration membranes were polymeric (Alfa Laval). The waste streams included municipal wastewater (MWW), brewery wastewater (BWW) and food waste (FW), all fed after filtration through a drum filter with pore size 500µm. Feeding was separated into different periods to explore the effects of different co-digestion and organic loading rates, as well as mesophilic vs operation without temperature control. pH, biogas production, total volatile fatty acids (VFA), total and volatile solids, chemical oxygen demand, heavy metals, and organic micropollutants were monitored. Fertigation tests were conducted to assess the reuse potential of the permeate. This was done through hydroponic transpiration tests with willow trees (energy crop) and pot tests with Padrón peppers (edible crop).

Results and discussion: The system revealed stable digestion and adaptability throughout the different feeding periods, with a relative methane yield of 0.2-0.3 m^3/kg of COD inputted. Average biogas composition was 64.3% CH_4, 24.4% CO_2, 0.13% O_2 and 3837.8 ppm H_2S. Mixtures of FW and MWW saw higher CO_2 levels in the biogas, due to the FW lowering the buffer capacity of the system, thereby reducing pH due to VFA build up. Digestion led to a 98.5% COD removal, and 95.8% BOD removal. 99.99% of E.coli was removed, and the permeate reached water quality class B as defined in EU regulation 741/2020.

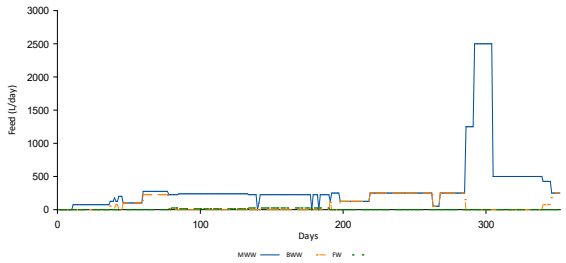


Fig. 1 daily feeding and co-digestion rates

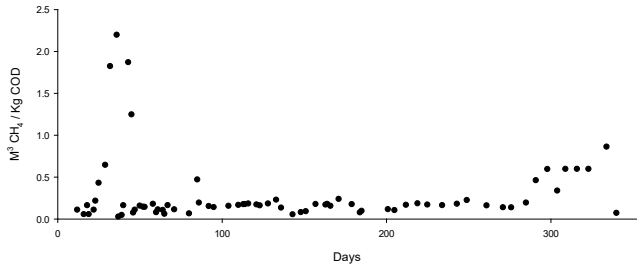


Fig. 2 Relative methane yield as a function of m3/CH4 per Kg of COD inputted

50/50 mix of standard chemical nutrient fertilizer and digestate (BWW and MWW) was the most effective method for fertigation, due to the different forms of nitrogen present in each. The combination of NH_4^+ from the digestate and NO_3^- from the chemical fertilizer allowed for the highest transpiration rates during the willow tree experiment. A 50/50 mix of FW and MWW was used for the Padrón pepper experiment with similar effects. Plants fertigated with the digestate/nutrient fertilizer combination yielded the highest fruit mass as a function of water use during the experiment.

Market potential: The use of an AnMBR system present an opportunity to generate circular loops of water, energy and nutrient streams. It has potential for reducing GHG emissions, producing energy and reusable water, as well as new high-value resources. This would lead to decreased reliance on imported resources and save participants in the urban industrial symbiosis on costs of raw materials, water and/or energy. Furthermore, will support local farmers suffering from water scarcity during summer periods.

Take-home message: The use of an AnMBR on co-digestion MWW, BWW, and FW was found to a stable and effect method of treatment. The use of brewery and food waste promoted higher biogas generation, while still removing contaminants from wastewater. The effluent from the processed proved to have potential for fertigation application, reducing the use of chemical fertilizers and drinking water for irrigation.

* noach@dtu.dk; ***bvape@dtu.dk Department of Environmental and Resource Engineering, Technical University of Denmark, Bygningstorvet, Bygning 115, 2800 Kgs. Lyngby, Denmark, ** dsl@beof.dk BEOF, Skansevej 2, 3700 Rønne, Denmark

Magnesium sulphate recovery from seawater using photothermal membrane crystallization

Asif Saud[1,2*], Bruno Marco Inzillo[2], Sergio Santoro[2], Aamer Ali[1], Efrem Curcio[2], Cejna Anna Quist[1]

Introduction: Magnesium plays a vital role in various industries, including aerospace, electronics, agriculture, and pharmaceuticals [1]. Seawater, with its vast and renewable supply, offers a promising source for Mg recovery. However, conventional extraction methods are often energy-intensive and environmentally not suitable [2]. To address these challenges, this study explores photothermal membrane crystallization (PhMCr) as a sustainable and efficient approach for Mg recovery. By utilizing solar energy to drive localized heating at the membrane surface, PhMCr enables controlled crystallization of magnesium sulfate ($MgSO_4$)—while simultaneously producing high-purity water. This dual-function process not only reduces energy consumption but also mitigates scaling and energy loss, positioning PhMCr as a green and scalable solution for mineral extraction from seawater.

Methods: A lab-scale PhMCr setup with graphene oxide (GO) coated polyvinylidene fluoride (PVDF) membrane has been utilised for the photothermal experiments. Synthetic nanofiltration (NF) brine was prepared and used as feed solution for PhMCr test (Table 1). Two different feed temperature (50 °C and 60 °C) verses permeate temperature of 20 °C has been tested.

Results: The membrane shows surface temperature of 66.3 °C under 1 sun condition in <5 mins which demonstrates a strong photothermal effect that boosts water evaporation as well as avoid crystal deposition on the membrane surface. PhMCr test with pure water, demonstrated increase in water flux from 5.7 to 8.1 $kg \cdot m^{-2} \cdot h^{-1}$ at feed temperature (T_f) of 50 °C and 60 °C respectively (Figure 1a). While using concentrated NF brine (Table 1) at the same conditions, flux slightly decreased to 2.8 and 3.2 $kg \cdot m^{-2} \cdot h^{-1}$. The crystallization data showed that recovered MgSO4 crystals (Figure 1b) demonstrated high rate of nucleation at high temperature. On the other side, the growth rate of crystals decreased with increase in temperature. Border crystal size distribution (CSD%) and high coefficient of variation (CV%) was observed at lower temperature with mean crystal size in the range of 196-300 µm. It is important to mention that the permeate water conductivity was less than 20 µS/cm under the tested condition. At the end, XRD analysis confirmed the high purity of the recovered crystals, with all diffraction peaks exclusively matched with commercial $MgSO_4 \cdot 7H_2O$ and none corresponding to NaCl.

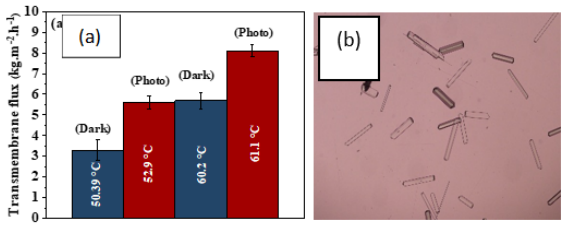


Figure1. (a) Transmembrane flux at two different temperature conditions (b) Recovered $MgSO_4$ crystals.

Salt	Concentration (g/L)
NaCl	2.85
Na_2SO_4	78
$NaHCO_3$	0.9
$MgCl_2 \cdot 6H_2O$	135
$CaCl_2$	1.1
KCl	3
NaBr	0.255
$MgSO_4 \cdot 7H_2O$	600

Table 1. Composition of salts used in the current study.

Discussion and take-home message: PhMCr offers a sustainable and energy-efficient approach for Mg recovery from highly concentrated brine. The integration of carbon-based photothermal materials, such as GO in this work, enhances the environmental friendliness and cost-effectiveness of the method. A key advantage of PhMCr lies in its ability to control crystallization, enabling the production of crystals with tailored shape, size, and purity—factors that significantly influence the market value of the final product. Moreover, the simultaneous recovery of high-purity water alongside salt crystals under extreme salinity conditions positions PhMCr as a promising technology for zero-liquid discharge strategies.

Acknowledgments: *The Authors acknowledges the financial support of the European Union's Horizon Europe Research and Innovation Programme under the project EXBRINER "Next-generation membrane technologies for sustainable exploitation of seawater brine resources: transition towards a circular blue industry" (HORIZON-MSCA-DN-2021, Grant Agreement No. 101072449)."*

Reference: [1] W. N. A. Wan Osman *et al.*, «A Review on Recent Progress in Membrane Distillation Crystallization», *ChemBioEng Reviews*, vol. 9, n.º 1, pp. 93-109, feb. 2022, doi: 10.1002/cben.202100034.

[2] M.-C. Sparenberg, S. Chergaoui, V. Sang Sefidi, y P. Luis, «Crystallization control via membrane distillation-crystallization: A review», *Desalination*, vol. 519, p. 115315, dic. 2021, doi: 10.1016/j.desal.2021.115315.

[1]*Department of chemistry and biosciences, Aalborg University, Denmark*
[2]*Department of Environmental Engineering (DIAm), University of Calabria, Via Pietro Bucci CUBO 44A, 87036 Rende, CS, Italy*
[*]*Corresponding Author's E-mail address: asifsaud@bio.aau.dk*

Introducing the DAWN project: A data-driven framework for optimized quaternary treatment evaluation

Alba Rodríguez Otero[a,b], Dines Thornberg[b], Per Henrik Nielsen[c] and Jan H. Christensen[a]

[a]Analytical Chemistry Group, Department of Plant and Environmental Sciences, University of Copenhagen, Thorvaldsensvej 40, DK-1871 Frederiksberg C, Denmark, [b]BIOFOS A/S, Refshalevej 250, DK-1432 , Copenhagen, Denmark, [c]VCS, Vandværksvej 7, 5000 Odense, Denmark

Wastewater Treatment Plants (WWTPs) face the critical challenge of implementing advanced quaternary treatment to effectively remove persistent micropollutants (MPs) and their transformation products. While there are already established technologies, such as granular activated carbon (GAC), powdered AC, or ozonation, WWTPs must deal with the technical complexity arising from the diversity of material types (e.g., GAC, powdered AC, and their variants), the varying configurations of the treatment setups, as well as the surge of new technologies that promise even better performance. Before investing in a large or even pilot scale, lab-scale tests provide a preliminary assessment of a technology's suitability. However, current R&D laboratory-scale tests often rely on a limited number of target compounds, failing to leverage the full optimization potential of available analytical data.

The DAWN project addresses this gap by developing a novel methodology for the data-driven optimization of quaternary treatment selection. We integrate advanced analytical techniques, specifically Non-Target Screening (NTS) coupled with liquid chromatography and high-resolution mass spectrometry (LC/SFC-HRMS), and Quantitative Structure-Property Relationship (QSPR) models. This approach allows for the comprehensive evaluation and optimization of treatment technologies based on their broad removal performance for MPs and other relevant parameters.

The project is structured across laboratory assessment, predictive removal, and pilot-scale validation, facilitated through close collaboration between the University of Copenhagen, BIOFOS, and VandCenter Syd (VCS). DAWN will bridge the divide between complex chemical data and practical applications, aiming to be a practical decision-making tool for WWTPs. This outcome is crucial for de-risking significant industrial investment, improving compliance with EU directives, and delivering substantial public health and environmental benefits.