DWF
Danish Water Forum

WATER VALLEY
DENMARK

Venue:
Copenhagen University
Thorvaldsensvej 40
1871 Frederiksberg

18th DWF Water Research Conference – 30th January 2024

Program and abstract catalogue

Introduction

Welcome to the 18th DWF water research conference in corporation with Water Valley Denmark. We are thrilled to present a conference with +60 presentations and abstracts, providing the latest in water research in groundwater, drinking water, wastewater technology, urban solutions, and development withing sensors and new methods.

This year DWF is very proud to present you speakers from the World Bank, EU Parliament, and Mykolayiv Water Supply in Ukraine during our opening session on groundwater under climate change.

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.

SPONSORS

Best regards

Hans-Martin Friis Møller, Chairman of Danish Water Forum

Timetable

Room	Title	From	To
AUD 1	**Rethink Groundwater management under climate change**, Chair: Hans-Martin Friis Møller, Chairman of DWF	10.00	12.00
	LUNCH	12.00	12.45
AUD 1	**Wastewater and treatment technologies**. Chair Søren Hvilshøj, NIRAS	13.00	15.00
AUD 2	**Groundwater Parks: Strategic Water Supply Security -Concept and Cases** Chair: Tommy Mostrup, former Director, Hjørring Water and Lars Skov Andersen, ex. EU Adviser	13.00	15.00
ROOM 1	**India-Denmark Water Innovation Technology Network,** Chair Bjørn K. Jensen	13.00	15.00
ROOM 2	**Danish Water Research: International strengths and improvement opportunities**; Chair: Jesper B. Christensen, Water Valley Denmark	13.00	15.00
	BREAK	15.00	15.30
AUD 1	**Drinking water** Chair Hans-Jørgen Albrechtsen, DTU	15.30	17.30
AUD 2	**Urban water and wetlands,** Chair Ole Mark, Krüger	15.30	17.30
ROOM 1	**Sensors, Energy and Mine discharge**, Chair Uffe Thomsen, WATEC, Aarhus University	15.30	17.30
ROOM 2	**Groundwater**, Chair Ida Holm Olesen, Novafos Utility.	15.30	17.00
	Snacks, awards	17.30	18.00
	Dinner **(By registration only)**	18.15	

Detailed timetable for the sessions:

Plenum, Auditorium 1

Time	Presentation
10:00	Welcome, by **Hans-Martin Friis Møller**, Chairman, Danish Water Forum
10:10	Logistics, by **Jesper Goodley Dannisøe**, Director, Danish Water Forum
10:15	Setting the groundwater scene: Rethink groundwater management to secure safe drinking water in the future. **Katerina Tsitonaki**, WSP Denmark and Chair of the ATV Foundation for Soil and Groundwater.
10:30	Water reuse strategies in Portugal. **Nuno Brôco**, CEO, Aguas do Tejo Atlântico, part of Grupo Aguas de Portugal
10:50	High groundwater levels: A Danish problem caused by substantial changes in rain patterns. **Pernille Weiland**, Klimatorium, **Uffe L. Gangelhof**, Vandcenter Syd
11:05	Building robustness in management of groundwater under pressure, **Viktor Pisotskiy**, CSP, Mykolayiv Vodokanal, Ukraine.
11:20	The Hidden wealth of nations; **Francois Bertone**, World Bank (Link to report)
11:35	The Blue Deal: EU policy. **Pernille Weiss**, Member of the EU parliament
11:55	Q&A
12:00	**Lunch break**
13:00	**Parallel sessions from 13.00 – 17.00 followed by Snacks and AWARD session**

Groundwater Parks: Strategic Water Supply Security -Concept and Cases

Room	**Title**	**From**	**To**
AUD 2	Groundwater Parks: Strategic Water Supply Security -Concept and Cases	13.00	15.00
	Chair: Tommy Mostrup, former Director, Hjørring Water and Lars Skov Andersen, ex. EU Adviser		

Speaker	**Topic**
Lars Skov Andersen	Groundwater Parks: A Window of Opportunity
Lærke Thorling	Status of Groundwater - Now and in the future
Tommy Mostrup	Cost-Benefit analysis of Groundwater Parks
Loren Ramsay	Groundwater Quality and Treatment Operation Influence Drinking Water CCPP
Brian H Jacobsen	Socio-economic impact of nitrate in drinking water
Pernille Weiss	Integration of Groundwater Parks in EU Blue Deal
Lars Skov Andersen	Closing Remarks

Water and climate resilience in India – research and innovation needs

Room	**Title**	**From**	**To**
ROOM 1	India-Denmark Water Innovation Technology Network	13.00	15.00
	Chair: Bjørn K. Jensen, GEUS, Former Chairman of Danish Water Forum		

Danish Water Research: International strengths and improvement opportunities

Room	**Title**	**From**	**To**
Room 2	Danish Water Research: International strengths and improvement opportunities	13.00	15.00
	Chair: Jesper Borg Christensen, Water Valley Denmark		

Wastewater

Room	Title	From	To
AUD 1	Wastewater	13.00	15.00
	Chair: Søren Hvilshøj, Senior Market Director, NIRAS		

Speaker	Title of presentation
Sofie Zacho Vestergaard	Microflora Danica: Investigation of the microbiome of Denmark with focus on wastewater and wastewater treatment plants
Sabine Lindholst	Washing and recycling of PFAS-contaminated soil
Charlotte Skjold Qvist Christensen	Waste Derived Biochar Sorbents for Water Treatment of Long- and Short-Chain PFAS
Rune Dall Harpøth	Utilizing treatment train concepts to remove PFAS compounds from wastewater from sludge treatment reed beds
Yu Yang	National landscape of environmental resistome in Denmark
Leendert Vergeynst	High-rate Biological Phosphorus Removal using a Moving Bed Biofilm Reactor: Effect of Biofilm Thickness and Hydraulic Retention Time
Kai Bester	Single compound risk, cumulative risk or removal-based design of advanced wastewater treatment for micropollutants
Sara Brorson Jensen	A new tool for effect-directed analysis of drivers of endocrine disruption in wastewater: coupling state-of-the-art chemical analysis with in vitro bioassays
Francesco Savio	Enhancing sustainable biodegradation of organic micropollutants by methanotrophic microbiomes: insights into the interaction between heterotrophic and methane oxidizing bacteria

Drinking water

Room	Title	From	To
AUD 1	Drinking water	15.30	17.30
	Chair: Hans-Jørgen Albrechtsen, DTU		

Speaker	Title of the presentation
Tabea Mumberg	Understanding the effects of artificial infiltration on DOC and PFAS in the Uppsala Esker using stable water isotopes (d18O and d2H)
Denitza Voutchkova	Mapping drinking water hardness in Denmark
Nicolaj Schmidt Damgaard	Rotor induced sand filtration – a novel sustainable technology for effective drinking water production
Sanin Musovic	ReGEN: On-site regeneration of pesticide-saturated activated carbon filters at Danish waterworks
Jan Benecke	Pilot-scale performance and benchmarking study of Aquaporin Inside® CLEAR series low energy BWRO membranes
Loreen Ople Villacorte	Boosting water efficiency of reverse osmosis (RO) for low brackish groundwater desalination
Wei Han	Non-revenue water (NWR) management in an innovative and digitalized way in water stressed Indian city, Pune

Sensors, energy and mine discharge

Room	Title	From	To
ROOM 1	Sensors, Energy and Mine discharge	15.30	17.30

	Chair: Uffe F. Thomsen, WATEC, Aarhus University		

Speakers	Title of the presentation
Wenyu Zhao	Membrane distillation for the production of ultrapure water for power to X
Qipeng (Helen) Liu	Analysis of green oxygen from PtX for wastewater treatment applications
Williane Vieira Macêdo	The Sludge2Fuel project: Integrating hydrothermal liquefaction in wastewater treatment plants for biofuel production from sewage sludge
Tanzila Sharker	MgAl-LDH doped porous carbon material as CDI electrode for selective recovery of phosphorus from eutrophic lake water
Quynh Nguyen	Gas phase N2O sensor development and process control for WWTPs
Adrian-Florin Florea	Phosphorus release from rewetted organic soils varies strongly in dependence of the phosphorus sorption capacity
Tamlyn Sasha Naidu	Valorising Wastewater: A Novel Approach for Critical Raw Materials Recovery from Acid Mine Drainage
Jayaluxmi Indu	Tracking Surface water from Space using SWOT mission: Impacts on Indian Hydrology

Groundwater

Room	Title	From	To
ROOM 2	Groundwater	15.30	17.00
	Chair: Ida Holm Olesen, Chief specialist, Novafos Utility		

Speakers	Title of the presentation
Enrico Pizzi	Building a Synergistic Vision for Multi-Objective control of WRRFs through Stakeholder Engagement
Case van Genuchten	Life cycle assessment of disposal strategies for arsenic-rich groundwater treatment sludge
Ka Wang	Molecular-scale characterization of groundwater treatment sludge from around the world: Implications for potential arsenic recovery
Caroline Kragelund Rickers	Treatment of water from two generational pollution sites utilizing the treatment train concept
Jinxin Zhao	Efficient trichloroethylene elimination by granular nitrogen-doped biochar supported zero-valent iron
Andreas K.-Rasmussen	Screening IoT sensing approaches to support real-time groundwater quality monitoring

Urban water and wetlands

Room	Title	From	To
AUD 2	Urban water and wetlands	15.30	17.30
	Chair: Ole Mark, Senior project manager, Krüger		

Speakers	Title of the presentation
Marie Riisgaard-Jensen	The sewer microbiome: Source of the process-critical bacteria in wastewater treatment plants
Antonio Vigueras-Rodriguez	Assessment of the overflow reduction potential of a plan to install extensive rooftop SUDS on Cartagena's buildings
Niels Eisum	Water retension and peak flow reduction measured during 5 years from full scale green roofs
Lineker Goulart Coelho	Assessing the performance of a green downspout solution to handle rainwater by using IoT based monitoring system
Mark Frenstrup Tørner Hansen	Satellite-based Mapping of Flood Extent and Depth in Denmark

Speakers	Title of the presentation
Vasileios Chrysochoidis	Assessment of current practice model structures for predicting TSS load from Combined Sewer Overflow (CSO) discharge point
Alba Martinez I Quer	Constructed wetlands to remediate cyanotoxins - a story of microbes, design, and transformation products.
Pedro Carvalho	Treatment wetlands for wastewater treatment: a story of antibiotics, pharmaceuticals, antibiotic resistance and microbial communities
Josephine Søborg Jensen	Using riparian wetlands for surface water purification: Effect on nutrient concentration and biological response

Posters

Poster presenters	Title of the poster
Anne-Lise Trøst Frisch Funding	PFAS distribution in Danish wastewater treatment plants (WWTP) – Identification of control measures for the distribution between sludge and water
Andrea Mongelli	Investigation of Quaternary Ammonium Compounds (QUATs) Pathways into Surface Waters: Implications for Urban Runoff and Wastewater Treatment
Lone Tang	Effect of organic compounds migrating from PE pipes on drinking water biofilms
Jiexi Zhong	Removal of micropollutants from effluent wastewater using activated biochar made from sewage sludge and wood pellets
Krzysztof Piotr Kowalski	Role of active carbon saturation with chlorinated compounds and operational factors on removal of PFAS and DMS in pump and treat plants
Borja Valverde Pérez	Can water resource recovery facilities participate in the stabilization of the energy system?
Mohammad Mahdi Agha Shirazi	Membrane crystallization for Li recovery from brines
Ramya Veerubhotla	Waste to Watts – Wastewater Powered Sustainable Batteries employing Electroactive Microbes
Emil Jespersen	Pollutant removal in bioswales
Thomas M. Odgaard	Helical Hollow Fiber Membrane Modules for Energy-Efficient Membrane Distillation of Industrial Wastewater

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Reserved the date already now:

Danish Water Forum Water Conference 2025:

Date: 30th January 2025

Venue: Aarhus University, Stakladen

Rethink groundwater management under Climate Change.

The summer of 2023 sent shivers across Europe due to extreme weather conditions with either prolonged draughts or extreme rain and hailstorms. In many places in Europe the conditions hit the water supply and showed a need to find new ways to protect and preserve water primarily for human consumption and secondary for other uses like industry and food production.

Plenum, Auditorium 1

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11:20	The Hidden wealth of nations; **Francois Bertone**, World Bank (Link to report)
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Nuno Brôco: Nuno Brôco has more than 20 years of experience in private and public company management and is currently the Chairman and CEO of Águas do Tejo Atlântico, the AdP group largest company on wastewater management. He´s also board member of Water Europe.

Previously he was Chairman and CEO of AdP VALOR, the AdP Group company responsible to foster innovation, digital transition, and circular economy.

For 11 years he has been Head of the Engineering Department of Águas de Portugal Group shared Services Company, Board Member of the Portuguese largest wastewater treatment company and also responsible for the Corporative Innovation in AdP Group, promoting partnerships with academia, public utilities and the private sector, applications to both national and international founding instruments and coordinating several R&D projects.

He started his career with SUEZ Group, as specialist in water and wastewater treatment processes, then as Head of the Degrémont Portugal Production Department and finally as Degrémont Iberia Country Manager for Portugal.

Viktor Pisotskiy Hello! My name is Viktor Pisotskiy, and in my daily work I am the Director for Strategic Planning of the water utility of the City of Mykolaiv on the South of Ukraine.

I'm graduated from State University named for Taras Shevchenko and Institute for the Word Economy and International Relations where I got a Ph.D.

My daily work is focused on the planning overall and immediate strategies for the development and implementation of the variety projects in respect of the development of Mykolaiv water utility in the middle and long-term perspective. Also, I'm taking care about relations of our enterprise with IFO and international Partners. One of our proudest and most important activities of the last two years is managing of international humanitarian support to our water utility, development of the water supply strategy in the war conditions and participation with my Danish colleagues in the project on development of the Masterplan (water sector) for the City of Mykolayiv.

François Bertone, a Senior Groundwater Specialist at the World Bank, boasts an extensive career in groundwater resource management across over 45 countries. His expertise spans engagements with private engineering firms,

industrial companies, drilling contractors, UN agencies, and diverse donors. Since joining the World Bank in 2020, François has been leading groundwater-related initiatives, focusing on analysis, policy dialogue, and lending to strengthen sustainable groundwater use worldwide. His primary goal is to support the emergence of the next generation of national groundwater experts, while promoting an interdisciplinary approach that fosters strong links between technical specialists, policy makers, water users, and academics.

Pernille Weiss: Pernille Weiss has as member of The European Parliament since 2019 been chair of MEP Water as water is one of her political focal points. She is a full member of the commitees of Industry, Energy and Research (ITRE) and Environment and Public Health (ENVI). Pernille is - together with EESC - the initiator to call heads of state for an EU-BlueDeal in the next legislative term and is also pushing and facilitating for a KIC Water to be established as soon as possible.

About an EU Blue Deal

Pernille Weiss, Member of the EU Parliament

Introduction and context

- The current mandate of the European Commission (2019-2024) has been focused on the development and adoption of the EU Green Deal: a package of legislative initiatives aiming to put the EU economy on track to reach its climate neutrality targets by 2050, in compliance with the Paris Agreement.

- This policy package includes numerous (about 30) concrete, binding, and ambitious legislations that seeks to address climate neutrality holistically: not only from a climate angle, but also from an energy, industrial, agricultural, trade, transport and environmental perspectives, among others.

- As we approach the end of the Commission's mandate in June this year, an overwhelming majority of the Green Deal policies have been successfully adopted. I have also been personally involved in three major files: as a lead negotiator on the Waste Shipment Regulation and as a group negotiator on both the Energy Efficiency Directive and on the Green Claims Directive.

- As we expect a new Executive to settle in this year - as well as a new Parliament: the elections will take place in Denmark on 9 June - the European Commission will have to find its new "raison d'etre", in other words, its overarching purpose for the next five years.

What is the Blue Deal and why is it important?

- In this context, and as a Chair of the MEP Water Group and Member of both the Environment and Industry Committee, I have been calling and pushing the European Commission to develop and adopt an **EU Blue Deal** for its next term. There is no "Green" without the "Blue".

- Together with the European Economic Social Committee (the voice of organised civil society in Europe), we have sent a joint letter in September last year to all the 27 EU heads of state and government to call for the support of such initiative. This letter was also embraced in the Parliament, being co-signed by numerous MEPs, coming from 16 different countries and from all the political groups.

- An EU Blue Deal is highly relevant and timely because, similar to climate concerns, water is essential for all sectors of our economy, our society, and our well-being. However, despite its profound impacts on our everyday life, water has been receiving very little attention. It is gradually changing - the increasing number of droughts and floods across Europe are making people more aware of its strategic importance - but this is happening too slowly; we need to act now!

- The purpose of a Blue Deal is to address water holistically: not only from an environmental angle, but also from an energy, industry, agriculture perspectives as well (these three sectors combined account for as much as 90% of water consumption in the world!). Currently, water is addressed in many different legislations, at different levels, which are not connected with each other and do not take into account the improvements of the water sector and its potential. Meanwhile, the water challenges are on the rise. We thus need an ambitious, overarching, and up-to-date framework for the future.

- There are many potential areas for improvement: just to name a few, water quality, re-use, recovery from wastewater, bringing innovation closer to the market, the creation of regulatory sandboxes... Stakeholders like you have so many ideas on what could be impactful going forward. Danish Industry also announced concrete ideas for an EU Blue Deal on behalf of their members.

- In addition, developing an EU Blue Deal would put us, as Europeans, on the right track to become front-runner globally in tackling water challenges and harnessing the benefits derived from that. This initiative would also enable us to become the first water-smart continent in the world, hopefully coupled with being the first climate-neutral continent as well. I am therefore convinced that the EU Blue Deal would bring tangible, positive benefits for everyone and for the environment, while raising the profile and importance of water globally.

What is the status of the Blue Deal?

- For now, the ball is in the court of the European Commission to come up with (or not) a Blue Deal initiative for the next mandate. However, this will largely depend upon the highly influential recommendations of the 27 Member States, via their heads of state and government. We therefore need to make our case clearly heard to our own government in Denmark, which is then able to speak and influence other countries at the EU table, and *in fine* set the agenda for the next Commission.

- Although we do not know yet if an EU Blue Deal will take shape or not, there is some positive indications that the topic of water recently climbed in the EU's priorities list. In March, the Commission will publish an initiative on "water resilience" and launch a public communication campaign designed to raise citizens' awareness on this issue.

Danish Water Research: International strengths and improvement opportunities

Room	Title	From	To
Room 2	Danish Water Research: International strengths and improvement opportunities	13.00	15.00
	Chair: Jesper Borg Christensen, Water Valley Denmark		

Danish Water Research:
International strengths and improvement opportunities

The Grundfos Foundation has granted a mapping of water tech research in Denmark to Water Valley Denmark.

The mapping identify the development in water tech research in Denmark, and it highlights international strength positions and improvement opportunities. The results give a better overview of water research in Denmark, and it provides decision-makers with a better basis for strengthening the framework conditions for research-based water innovation in Denmark.

The main results of the mapping will be presented as a starting point for a discussion on how to strengthen water tech research and water tech research infra-structure in Denmark.

Program

1. **The importance of research – welcome and introduction**
   by CEO Ulla Sparre, Water Valley Denmark & Program Manager Poul Toft Frederiksen, Grundfos Foundation

2. **Mapping of water tech research in Denmark**
   by Deputy director Frederik Gaardboe, IRIS Group

3. **Discussion on how to strengthen water tech research and research infrastructure in Denmark**

Panel participants:

- Country Market Director for Water Denmark Annette Raben, Rambøll
- Head of research program in water technology Ditte Andreasen Søborg, VIA University College
- Strategic Planner Martin Rygaard, HOFOR
- Programme Manager Poul Toft Frederiksen, Grundfos Foundation

4. **Questions & dialogue**

Moderator: CEO Ulla Sparre, Water Valley Denmark.

Time and place:
Danish Water Forum, 18th Annual Conference
30 January 2024 at 13.00 – 15.00
University of Copenhagen, Thorvaldsensvej 40, 1871 Frederiksberg
Room 2

Sign up for the conference:
http://www.danishwaterforum.dk/sign_up_events_2024.html

Contact:

Programme Manager
Jesper Borg Christensen
Tlf: +45 23 32 85 80
jbc@watervalleydenmark.com

DWF Danish Water Forum

POUL DUE JENSEN / GRUNDFOS FOUNDATION

WATER VALLEY DENMARK

Groundwater Parks: Strategic Water Supply Security -Concept and Cases

Room	Title	From	To
AUD 2	Groundwater Parks: Strategic Water Supply Security -Concept and Cases	13.00	15.00
	Chair: Tommy Mostrup, former Director, Hjørring Water and Lars Skov Andersen, ex. EU Adviser		

Time	Speaker	Topic
13:00 – 13:15	Lars Skov Andersen	Groundwater Parks: A Window of Opportunity
13:15 – 13:30	Lærke Thorling	Status of Groundwater - Now and in the future
13:30 – 14:45	Tommy Mostrup	Cost-Benefit analysis of Groundwater Parks
13:45 – 14.00	Loren Ramsay	Groundwater Quality and Treatment Operation Influence Drinking Water CCPP
14:00 – 14:15	Brian H Jacobsen	Socio-economic impact of nitrate in drinking water
14:15 – 14:30	Pernille Weiss	Integration of Groundwater Parks in EU Blue Deal
14:30 – 15:00	Lars Skov Andersen	Closing Remarks

Groundwater parks with strict regulation of land use are a technically and financially viable alternative to advanced treatment of groundwater and to ensure strategic long-term drinking water supply security. We have a Window of Opportunity to integrate Groundwater Parks in new land-use policies for increased biodiversity and mitigation of climate change demanded by the EU Green Deal and make Groundwater Parks an important tool of an EU Blue Deal.

Denmark is among a small number of countries that relies 100% on groundwater for its drinking water supply. Globally groundwater is also the main source for rural water supply, but less known it is also a major source for urban water supply throughout Europe and in northern China, for instance, 40%-60% of the water consumption of major cities is also based on groundwater.

Climate change already shows as increased rainfall and corresponding groundwater formation in northern and north-western Europe thus ensuring a stable supply, while erratic rainfall and increasing water demands puts groundwater resources at risk in southern Europe.

In Denmark, in contrast, the long-term water supply security is at risk due to wide-spread and increasing pollution by pesticides and nitrates, which now are observed in more than 60% of drinking water supply wells and in more than 80% of newly generated groundwater in shallow aquifers below agricultural land that constitutes 68% of Denmark.

In this session we present a Window of Opportunity for potential siting and scales of groundwater parks, the current status of groundwater quality in Denmark, and the long-term financial and socio-economic benefits of groundwater parks compared with continued and increasingly complex treatment that will be required to maintain supply of high-quality drinking water.

We close with a discussion how to incorporate Groundwater Parks in an EU Blue Deal currently considered to follow the EU Green Deal in 2024.

Groundwater Parks: A Window of Opportunity for Strategic Drinking Water Supply Security

Lars Skov Andersen* and Tommy Mostrup**

Abstract

The EU Green Deal provides a Window of Opportunity for Denmark to enhance its groundwater protection and achieve long-term drinking water supply security. The Danish water sector has the knowledge and technology required to formulate a strategy and program for sustainable groundwater-based drinking water supply security.

Introduction

In Denmark we have during the past 25 years developed the technology and generated the knowledge required to formulate a long-term strategy and corresponding action program to achieve groundwater-based drinking and food-processing water supply security.

So far, Denmark has started a piece-meal protection of groundwater wells within capture zones based on a 1-year travel time of rainfall from surface to the water intake ("BNBO"). This will create a patch-work of small, scattered protection zones across the landscape that already is recognised by the water sector as cumbersome and costly to manage and being inadequate for long term water security[1].

As a logical next step water companies have started to merge these protection zones within their main source areas into so-called Groundwater Parks, with capture zones based on travel times of 50-100 years[2]. Preliminary estimates indicate that Groundwater Parks with a total area up to 200,000 ha[3] may be required to protect all Danish drinking water intakes.

The EU Green Deal, which aims improve biodiversity and reduce climate impact, provides a Window of Opportunity to establish Groundwater Parks. In Denmark it is estimated that 150,000 ha of protected area is required to meet the Green Deal, mainly forest and fallow, that are suitable for Groundwater Parks or vice versa.

Groundwater Parks protecting important source areas are feasible for major public water companies to establish, but risks to leave the 2000, mostly small, cooperative rural water companies behind. A feasible inclusive solution may be to reserve major groundwater generating areas along water divides as Groundwater Parks shared source areas for future relocation of polluted water intakes in areas that border the Parks.

Take-Home lessons

Siting of Groundwater Parks is a logical extension of the "Areas with Particular Groundwater Interests" identified during 25 years of groundwater mapping.

Groundwater Parks may readily contribute to or be incorporated in the land use changes demanded by the EU Green Deal and may become an important component of a future EU Blue Deal under consideration.

1 Refsgaard, J.C. & Henriksen, H.J.2023. Principper for udpegning af grundvandsparker. Vand og Jord 3, 2023.

2 Bjerre, T.K, 2023. Grundvandsbeskyttelse i stor skala. Vand og Jord 3, 2023

3 Information, 07.08.2023

Groundwater Status in Denmark

Laerke Thorling – Chief Consultant - GEUS[*]

Abstract

The chemical status of groundwater in Denmark is at risk due to diffuse pollution, among others from pesticide compounds (active ingredient and metabolites from pesticides and biocides), noticeably plant protection products legally approved at the time of application, and biocides in outdoor paint used on wood. Nitrate still plays an important role for deterioration of groundwater quality, especially in the sandy parts of the country where at the same time there is a high density of livestock. Also, recently introduced monitoring of PFAS shows results of concern.

In the future, persistent mobile substances are expected to spread even deeper into the aquifers of relevance for water abstraction, calling for both knowledge-based groundwater protection in the long run and water technologies to treat the water in the meantime.

Introduction

Denmark is among a small number of countries which rely totally on groundwater for production of clean drinking water. To ensure future supply, the National monitoring program (1988 ff.) and the national groundwater mapping initiative (1998 ff.) have enabled a detailed understanding of the occurrence and quantity of groundwater, identifying valuable and potential future aquifers. This may be a precondition for groundwater protection, but not groundwater protection per se.

The national monitoring program (GRUMO) comprises both quantitative and qualitative data collection. The quantitative monitoring collects yearly data form all licenced water abstractions, like irrigation, water works and industries. In addition to this, groundwater level monitoring is done in *c.* 150 wells, some with timeseries dating back to the 1950ies.

The assessment of groundwater quality is reported yearly based on monitoring results from the water works wells and from special constructed monitoring wells where no water abstraction takes place. The results from this monitoring are presented, giving an overview of the quality issues for the national groundwater resources. An important point is that the volume of groundwater potentially vulnerable towards nitrate is constant due to the rather stable nitrate interface, where denitrification takes place. In contrast to this, the volume of groundwater affected by persistent and mobile pesticide compounds and other organic pollutants seem to increase, being controlled by the period of use, and groundwater transport time.

Take-Home lessons

The groundwater resources in Denmark show a clear response of the modern society. Even if increased groundwater protection is implemented today as a sustainable means to secure future water safety, it is inevitable that in the meantime some advanced treatment must take place at some water works. This is especially the case in areas where the availability of deep clean aquifers are limited.

[*] Lærke Thorling, Chief Consultant, GEUS Universitetsbyen 81, 8000 Aarhus C. mailto:lts@geus.dk

Groundwater Quality and Treatment Operation Influence Drinking Water CCPP

*Emilie. P. Haugan, **Loren Ramsay**, VIA University College*, L. Ramsay, VIA University College***

Abstract

The calcium carbonate precipitation potential (CCPP) of drinking water is a complex parameter. A correlation between oxygen levels and CCPP in treated drinking water in Denmark has previously been shown. In this paper, data from the Jupiter and Merkur databases were combined. However, the exact effect of drinking water treatment on the CCPP is difficult to ascertain due to widely varying CCPP in raw water from different wells, erroneous pH values, differences in sample collection dates, etc. We recommend collection of raw water and treated water samples simultaneously.

Introduction: For decades, a wealth of analytical results of water samples has been collected in the public database Jupiter. Recently (Dansk Vand Konference, 2022), this data was utilized by Rygaard (HOFOR) to determine the CCPP of treated water for all drinking water treatment plants in Denmark. CCPP is the amount of the mineral calcite that must precipitate or dissolve to reach equilibrium. Rygaard showed that 54% of the samples have elevated CCPP (CCPP> 10 mg/L) and that there is a correlation between high dissolved oxygen levels and high CCPP levels. This raises the question of whether intensive aeration during drinking water treatment explains the high CCPP levels.

Methods and data: In this study, we investigate the relationship between CCPP in groundwater sources, CCPP in treated drinking water and the aeration method utilized by the waterworks. Information about treatment methods is not recorded in Jupiter. Recently a new national database, Merkur, was developed with the intention of storing and visualizing design and operational data for waterworks. Currently, 80 waterworks are included in the database. CCPP was calculated according to the method described in Tang et al. (2020) using the geochemical model PHREEQC v.3.7.3 with the standard associated database.

Results: Aeration methods for the waterworks in the Merkur database are shown in Figure 1. Bubble basin aeration, cascade and compressed air injection are the most popular, in that order. Figure 2 shows the CCPP for active wells and treated water for two waterworks. In Waterworks A, the source water contains methane, and the treatment therefore includes Inka aeration, an aggressive method for stripping the methane. While the methane is successfully removed, the resulting drinking water is highly oversaturated, thereby giving the risk of precipitation and consumer complaints. In Waterworks B, the groundwater source is strongly undersaturated for calcite. Treatment at the waterworks includes dosing sodium hydroxide to neutralize the aggressive carbon dioxide, resulting in drinking water at equilibrium.

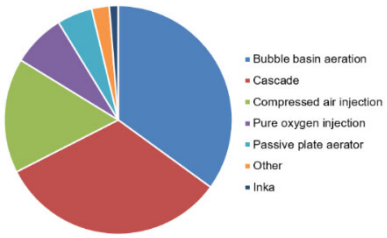

Figure 1. Aeration methods of waterworks included in the Merkur database (N=80)

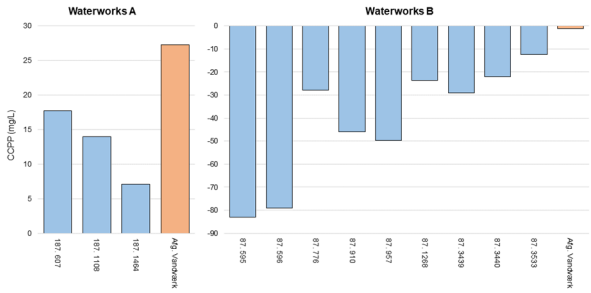

Figure 2. CCPP (mg/L) of waterworks A and B wells (blue bars) and treated water (orange bars)

Discussion and take-home message: Findings (including waterworks not in the graphs) show that wells even within the same well field can have widely varying CCPP. It is also shown that suspected erroneous pH values can skew the CCPP greatly. Finally, it is recommended that measurement of the combined raw water quality (inlet) and water leaving the filter (outlet) should be carried out simultaneously to determine the effect on CCPP of the water treatment process at waterworks. Unanswered questions remain, including why the calculated CCPP and the ion balance of groundwater wells is often oversaturated and negative, respectively.

* *ehau@via.dk: Banegårdsgade 2, DK-8700 Horsens, Denmark*

** *lora@via.dk: Banegårdsgade 2, DK-8700 Horsens, Denmark*

Economic gains from lower nitrate levels in drinking water

*By **Brian H. Jacobsen***, Birgitte Hansen and Jörg Schullehner from KU, GEUS og AU.*

Abstract

Denmark could save lives and more than $300 million dkk a year by reducing the amount of nitrate in its drinking water. The study shows that the amount of nitrate in some Danish boreholes increases the risk of colorectal cancer and that the benefits of lower levels is clearly higher than the costs.

Introduction

Drinking water with high levels of nitrate is a global problem linked to a variety of health problems including birth defects and cancer. For example, there is a growing body of scientific evidence to support that nitrate in drinking water increases the risk of colorectal cancer, a disease that affects more than 5,000 Danes annually.

Denmark follows the EU limit of no more than 50 milligrams of nitrate per liter of water. While concentrations are well below this ceiling across much of Denmark, amounts of nitrate in drinking water are significant enough to increase the risk of developing colorectal cancer in several areas (e.g. Ålborg). A large Danish population-based cohort study from 2018 and several international studies have demonstrated this.

An analysis of nitrate levels in Denmark's water supplies shows that roughly 10% of Danish drinking water has a nitrate concentration above 9 mg/L, and an additional approximately 10% is above 4 mg/L as an average for 2018-2021.

Protect groundwater, move boreholes or treat the water!

The costs associated with reducing nitrate levels is calculated based on three options. The first option is to protect groundwater by, for example, taking agricultural land out of use and converting it into protected zones. The second option is to relocate boreholes away from areas with excessive concentrations of nitrate. The third option is to clean the water of nitrate with technologies (such as denitrification, ion exchange and reverse osmosis). The researchers calculated the average costs to be $9 and $6 million annually for each of the two nitrate levels (4 and 9 mg/L) respectively.

The analysis finds that Danish society could save more than $300 million a year by reducing nitrate concentrations in drinking water and avoid 127 cases of colorectal cancer annually. Even with the highest costs to remove nitrate and the most pessimistic assumptions about health improvements, there is an economic gain by reducing nitrate levels to a maximum of 9 mg/L.

**Brian H. Jacobsen, brian@ifro.ku.dk*

Water and climate resilience in India – research and innovation needs

Room	Title	From	To
ROOM 1	India-Denmark Water Innovation Technology Network	13.00	15.00
	Chair: Bjørn K. Jensen, GEUS, Former Chairman of Danish Water Forum		

India is facing critical water challenges including access to clean drinking water, water shortage and pollution, and balancing between drought and flood management. In support of the Green Strategic Partnership and the India-Denmark Joint Action Plan (2021-2026), the India-Denmark Water Technology Innovation Network aims to explore research and innovation opportunities between Danish and Indian research institutes, universities, and other stakeholders for safe and secure water; to support Danish small and medium enterprises to improve their cooperation with Indian businesses; and to expand Danish research and technology collaboration with India.

At the seminar, the partners will introduce some of the most urgent of water challenges in India and present examples of recent research by Indian researchers to meet those challenges.

In the final panel discussion, the partners will discuss the potential for R&D collaboration in India – what are the most relevant topics to embark on, to which extent are Danish solutions useful in an Indian context and vice versa, and what kind of partnerships are needed to make a successful collaboration?

Themes that will be addressed at the seminar will e.g. include:

- wastewater treatment and resource recovery
- the nexus/interrelations between water supply, ground water, flooding and stormwater harvesting
- water related hazards, early warning systems and climate resilience.

The seminar targets participants who take an interest in water challenges and R&D needs in fast growing economies at scale and are curious to learn about and potentially connect with the R&D landscape in India - or attendants who simply wish to be updated on how relations between Denmark and India are developing to support the Green Strategic Partnership between the two countries. Participants can expect to leave with an understanding of current challenges and R&D needs in India within the three topics.

- **Speakers**
  Prof. Pennan Chinnasamy, IIT Bombay:" Challenges and opportunities for addressing the water supply-demand interrelations and reducing flood impacts".
- Prof. Swatantra P. Singh, IIT Bombay: "Wastewater technologies in India - opportunities and challenges"
- PhD Ashwini Keskar, Pune Knowledge Cluster; "River basin landscape approach in making a participatory Sustainable Water Action Plan for Pune metropolitan region."
- Dr. Kiril Manevski, Aarhus University: "The echo network – community of practice to map data flows, sources, verification, and analytics for sustainable water use in agriculture and cities in India".
- Nikhilesh Singh, IIT BHU: "Smart Laboratory for Clean Rivers in India" TBC

Session programme, January 30, 13-15 hrs, Moderated by Bjørn Kaare Jensen, GEUS/Water4All
13.00-13.05 Welcome: Anne Mette Holt, project manager, DHI (5 min)
13.05-13.15 Keynote by Indian Ambassador (TBC) (10 min)
13.15-14.20 Introduction of and presentations by speakers (65 min)
14.20-14.55 Panel Discussion, Danish and Indian partners (30 min)
14.55-15.00 Closing remarks; Anne Mette Holt & Bjørn Kaare Jensen (5 min)

About the partners
The India-Denmark Water Technology Innovation Network is a group of select institutions and organisations within the water research and development value chain, which aims to explore opportunities for research, innovation and demonstration projects for safe and secure water in the municipal water value chain. The partners are DHI, Force Technology, the cluster organisations Clean and Water Valley Denmark, Technical University of Denmark, Indian Institute of Technology Bombay and Pune Knowledge Cluster.

The project is funded by the Global Innovation Network Programme through the Danish Ministry of Higher Education and Research and will run for a two-year period, starting in 2023.

Nature Based Solutions (NBS) for Flood and Drought Resilience, Water Treatment and Reuse of wastewater in India: Case study of Pune.

Penney Chinnasamy*, P. Kolhe ** and S. Kolekar ***, Indian Institute of Technology Bombay**

Introduction: The water demand is increased due to population rise, climate change, and industrial development (Ganjegunte et al., 2017; Danboos et al., 2023). Developing countries are facing water scarcity problems. Up to 80% of illnesses in the developing world are linked to inadequate water and sanitation (Government of Canada, 2023). The United Nations Educational, Scientific and Cultural Organization (UNESCO) in the latest edition of the UN World Water Development Report, it has been stated that between two and three billion people worldwide will face a water shortage problem (UNESCO, 2023). Water scarcity is the main threat to food security. 70% of freshwater is being utilized for agricultural purposes (Kolekar et al., 2021). The scarcity of water is the main obstruction to profitable agriculture (Demir and Sahin, 2017). It is very important to find out an alternative to freshwater to fulfil the water demand for agriculture.

On the other hand, climate extremes such as floods and droughts have increased clean water scarcity issues. In developing nations such as India, the groundwater is over exploited during these climate extremes (e.g. groundwater pumped when surface water is contaminated during floods, and groundwater is pumped when the surface water is dry during droughts). Therefore there is a need to capture excess water and recharge aquifers by slowing down the runoff process.

Water reuse and recycle is often challenged when water quality data is not available. Reuse and recycle of wastewater is not readily accepted for irrigation and tertiary domestic water use (like gardening, washing of cars, etc.). In such instances, there is a need to identify systems that can treat wastewater by removing the harmful pollutants and have case studies to prove the use of treated wastewater. To cover all of the above issues, Nature Based Solutions (NBS) can have an efficient answer.

Methods and data: A region in Pune, Maharashtra was selected to showcase the efficiency of NBS in providing Flood and Drought Resilience, groundwater recharge and efficient reuse of wastewater for agricultural purposes. The NBS wastewater treatment system includes Anaerobic System (AnSys) and Constructed Wetland (CW) as a secondary treatment followed by Dual Media Filter (DMF) and Ultra-Violet (UV) Disinfection System as a tertiary treatment. DMF is primarily used for the removal of turbidity and suspended solids as low as 10-20 microns and UV to kill the pathogens. The wastewater was sourced from the Pune campus and was compared against the campus's traditional sewage treatment plant.

Results: The results indicate that the total phosphate, total nitrogen, chemical oxygen demand (COD), biological oxygen demand (BOD), and total suspended solids (TSS) removal efficiency for the wastewater treatment system is 62 %, 40%, 88 %, 91 %, and 96 % respectively. Results also indicated that the average crop height, number of branches, tomato fruits, and yield are 1.2, 1.8, 2.5, and 2.99 times more for the tomatoes grown with treated wastewater (TWW) in comparison with the freshwater (FW). The survey from farmers nearby also indicated that the groundwater levels in the agricultural fields have not depleted as previous years, as the irrigation water was supplied via the treated wastewater. In addition, during high flood events, the farmers noted that less water is lost from the watershed, and less groundwater dependence is there due to the NBS. More farmers were interested to collaboratively setup the system as the land needed for a constructed wetland needs some space. Results also indicated that, since domestic wastewater is available throughout the year, the NBS can be of utmost importance during peak summer seasons, wherein subsistence crops can be grown for local consumption (e.g. fodder for cattle, cotton and vegetables).

Discussion and take-home message:
While the NBS based wastewater treatment can be a long-term sustainable solution for the water issues in developing nation, the capital costs are high. Green infrastructure and sustainable development funds should be parked to encourage such NBS activities so that such environmentally friendly solutions can be done at large scale in a decentralized fashion. This provides opportunity to collaborate on mechanisms that can bring down the costs, effective application of water technologies and crop diversification.

* p.chinnasamy@iitb.ac.in : C-TARA, Indian Institute of Technology Bombay, India

** pravinkolhe@iitb.ac.in : C-TARA, Indian Institute of Technology Bombay, India

*** skolekar@iitb.ac.in : C-TARA, Indian Institute of Technology Bombay, India

Fabrication of Electroconductive Membranes for Emerging contaminant Removal and Biofouling Control for Desalination and Water Treatment

Najmul H Barbhuiya[1], Ashish Kumar[1], , Kritika Jashrapuria[1], Utkarsh Misra[1], **Swatantra P. Singh[1,2*]**
[1]Environmental Science and Engineering Department (ESED), Indian Institute of Technology Bombay, Mumbai-400076, India
[2]Centre for Research in Nanotechnology & Science (CRNTS) Indian Institute of Technology Bombay, Mumbai-400076, India
***Presenting Author: Swatantra Pratap Singh; Associate Professor, Indian Institute of Technology, Bombay. Email: swatantra@iitb.ac.in**

Abstract: Biofouling and selectivity permeability trade-offs are the leading challenges in membrane-based desalination and wastewater recycling. Electro-conductive membranes have shown its potential for controlling biofouling and selectivity permeability trade-offs. Laser-induced graphene (LIG) is a single-step, chemical-free method to fabricate graphene surfaces with a 10.6 um CO_2 laser. Single-step conversion of polyethersulfone (PES) membranes to LIG filters and further surface modification of these filters leads to UF composite membranes that have been demonstrated to have excellent catalytic and anti-biofouling properties. These electrically conductive filters and membranes achieved 6-log removal of mix culture of bacteria and antibiotics removal with applied voltage. With an applied voltage, the antibiotic rejection (~90%) and removal (~85%) were enhanced and further improved with radical generation in the presence of metal ions. Furthermore, these surfaces have been shown anti-biofouling properties due to their texture, and the biofouling has been characterized by Confocal Laser Scanning Microscopy (CLSM). The "catalytic mechanisms of these doped LIG filters and membranes are mainly due to LIG's graphene and 3D texture effect and further enhanced through doping of hetero atoms. These filters and membranes (single-step laser printed) have great potential in desalination and water treatment.

Methods: A computerized numerically controlled (CNC) 10.6 µm CO_2 laser (VLS2.3) was used to make LIG on our PES polymer substrates such as membranes and nonporous sheets. Membranes, filters, and surfaces were characterized by SEM, TEM, Raman, XRD, and XPS. The performance characterization of the membranes was done in crossflow and dead-end modes. Different chromatographic and colorimetric methods are used for groundwater and surface water contaminants.

Results: The optimized LIG-based fabricated electroconductive membrane has shown more than 90% removal for ciprofloxacin and Cr(VI) and applied voltages with very high flux, and these membranes are in the ultrafilteration range. These membranes have ~70% less biofouling as compared to the pristine PES membranes.

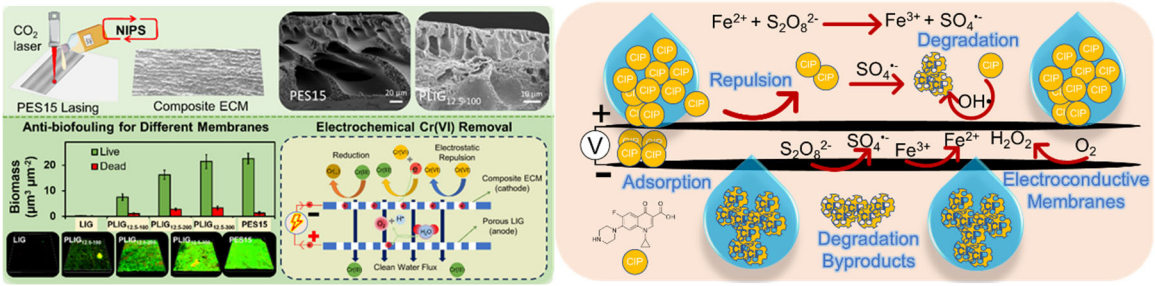

Fig. 1: LIG-based electroconductive membranes for emerging contaminant removal and biofouling control for desalination and water treatment

Discussion and take-home message:
Optimization on PES-based LIG porous filters and membranes is important. These optimized LIGs perform better than non-optimized LIGs due to better surface morphology and electrochemical properties. These surfaces have shown excellent performance for different emerging contaminants, such as antibiotics, and groundwater contaminants, such as Cr(VI). These LIG-based membranes also have excellent anti-biofouling properties. These electroconductive membranes and surfaces can be effectively utilized for desalination and water purification and help the world to deal with climate change.

References:
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River basin landscape approach to make a participatory Sustainable Water Action Plan (SWAP) for Pune Metropolitan Region

Dr **Ashwini Keskar Sardeshmukh** and Mr Shantanu Goel

Water underpins all life processes and activities. India supports 17% of the world's human population on only 2.5% of the world's land area through only 4% of the world's freshwater resources. Accordingly, to balance the rapidly growing Indian economy, planning process needs to maintain the nexus between water, food, livelihood, energy and environmental health by ensuring that there is enough awareness, capacity and synergy in the efforts of stakeholders.

Accordingly, PKC, with inputs from all stakeholders, wishes to create a participatory Sustainable Water Action Plan (SWAP) for the Pune Metropolitan Region (PMR), using landscape (geomorphology features of the river basin comprising of five rivers), their rivulets and streams and the numerous major dams and water bodies - based approach is about 6,736sq.km.

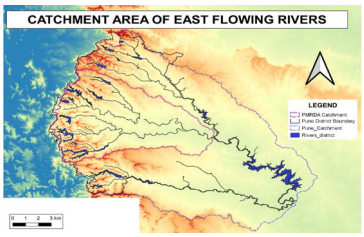
Pune also struggles with variable rainfall, higher risk of floods. Although there is high availability of water, there is a decline in groundwater tables, unequal distribution of water, poor water quality, pollution and discharge, wastage due to leakages and inappropriate usage.

Methods: The plan will be drafted by a consortium of stakeholders including researchers, government officials, urban planners and environment experts through understanding of biophysical, socioeconomic and governance features of water including uses, discharge and availability, rainwater and climate change impacts. The data requirement for the plan is water availability, rainfall, water usage as per sectors, discharge of used water, rainwater management, flood data.

Key outcome

The plan will involve creation of a decision response system and policy recommendations for water conservation and water security for PMR.

The plan will help the local governments, municipal councils, cantonments, towns and rural areas, industries, citizens, local communities in villages as well towards conscious decision-making and implementing necessary actions for protecting the health of water ecosystems.



The map is representing Pune district and the area of 6733 sq km which will be used for making a participatory Sustainable water action plan.

Contact information

Dr Ashwini Keskar Sardeshmukh
Email: ashwini.keskar@pkc.org.in Ph no : +919890303884

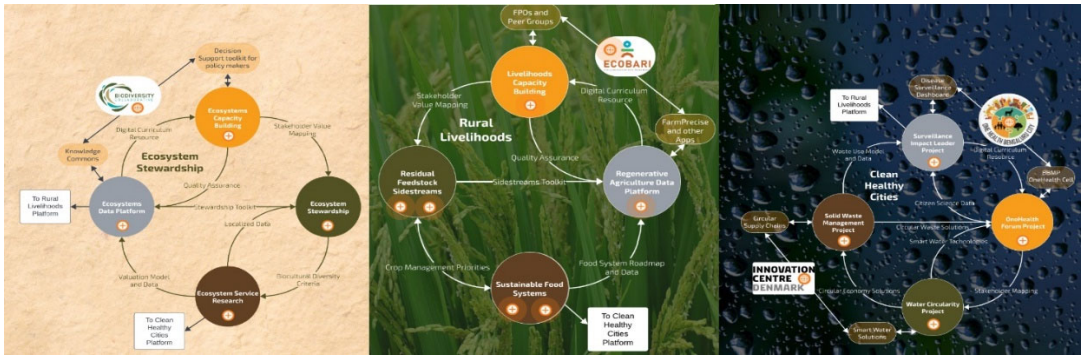
Applying Communities-of-Practice in Indian quadruple helix model of innovation dynamics to tackle real-world challenges.

Kiril Manevski**, Aarhus University*, Shannon Olsson, echo network

India and Denmark share the same challenges related to GHGs emission from cultivated land and water safety issues, climate change induced weather variability, environmental degradation, and harmful impacts on human health. The echo network is a social innovation partnership initiated in 2019 by the Principal Scientific Adviser to the Government of India along with multiple stakeholders to increase environmental and human health protection and contribute to the Indian green transitions important globally. The network engages Danish experts through new collaboration agreement between Innovation Centre Denmark in India and the Danish Academy of Technical Sciences.

The methodical approach of the echo network is a deliberate collaboration called "communities of practice" that considers the viewpoints of different stakeholder identified in the system, recognises common interest, and points of inflection and works iteratively together across the system. These communities of practice learn from each other, co-create standard solutions, and iteratively enhance solutions through regular interaction and re-evaluation of the process. Back in 2019, the echo network as a multidisciplinary platform gathered people from different walks of life with like-minded interests to identify three Concept Notes, namely, One Health, Regenerative Agriculture and Ecosystem Valuation, each further developed in a pilot project, including a fourth on Circular Economy. One Health utilizes the instinct link of human health to the health of the animals, ecosystems, and environments around communities to respond to community needs for dynamic prediction, detection, and response of health burdens. Regenerative agriculture tackles long-term, and evidence-based agricultural solutions across the entire agricultural value chain in order to account future impacts of climate variability, develop practices for improved crop yield and nutrition, soil and water conservation, and biodiversity conservation. Ecosystem valuation sets values and interests of local and non-human communities to reduce environmental degradation and associated socioeconomic and ecological disparity through research and implementation of climate-resilient and ecology-based practices while incentivising consumer demand and preferences accordingly. Finally, Circular Economy Identifies waste as a resource and offer market-driven support to ensure that one health, regenerative agriculture, and ecosystem valuation approaches are resilient and sustainable through identifying residues for plausible side-streams.

In 2023 the echo network gathered 130 participants from over 90 organizations to revisit the pilot projects using a theory of change approach in the "Sustainability Ambassadors Global Exchange" (SAGE) Program linking Indian and International MSc and PhD students with Danish and Indian mentors to identify knowledge gaps and project refinement. The SAGE program currently evolves into three PhD programs starting 2024 until 2026 on "Ecosystem Stewardship" aims to design models for incentivizing bioresource conservation and ecosystem restoration in rural communities through localized opportunities for financially viable ecosystem stewardship, "Rural Livelihoods" to promote ecosystem-based regenerative agriculture and localized food systems through stakeholder interactions, research, and data collection, and "Clean Healthy Cities" to develop sustainable and innovative solutions for urban challenges that will enhance One Health systems and infrastructure. The PhD studies engage leading Indian and international universities in proof-of-concept testing with communities, adaption and scaling of outputs to build knowledge and capacity.



** kiril.manevski@agro.au.dk: Blichers Alle 20, Tjele 8830, Denmark, ** shannon@echonetwork.in: 14th Main Rd, Agara Village 1st Sector, HSR Layout, Bengaluru, Karnataka 560102, India*

Smart Laboratory for Clean Rivers in India

Shishir Gaur, Anitha Kumari Sharma, D.P. Mathuria, **Nikhilesh Singh***

A river is a living entity, as it has its own metabolism in the form of its characteristics flora and fauna. The river systems are significant to the ecosystem and act as the planet's lifeline due to their diverse and deep impacts. It provides necessary habitation for the vast variety of species that support aquatic and terrestrial ecosystems and transports and exchanges nutrients. Beyond their ecological significance, rivers also play a crucial role in human society, supporting cultural, economic, and civilizational aspects. Globally, population explosion, industrial revolution, agricultural revolution, water pollution, groundwater exploitation and global climatic change etc, pose threats to the river system. As a consequence, free-flowing rivers are converted into narrow, encroached, dry-flow channels, polluted drains in the urban stretches, raise river water conflicts around the globe, flooding, overfishing and degradation of riparian zones, which urges revival of degraded waterbodies to achieve a healthy and free-flowing riverine condition.

Keeping these challenges in mind Indian government has initiated an innovative living lab i.e., Smart Laboratory for Clean Rivers (SLCR) to fight against river degradation in collaboration with Denmark. The Smart Laboratory for Clean Rivers (SLCR) functions as a dynamic living lab, actively engaging in the exploration, testing, and real-time extraction of insights from both social and technical innovations. Beyond serving as a testing ground, the SLCR operates as a collaborative space, facilitating the development and scaling of responses to intricate riverine challenges across diverse systems. This initiative not only showcases and tests ideas but also signifies a joint endeavor to establish a platform that harnesses the combined expertise of Denmark and India.

The overarching goal is to effectively tackle local challenges and experiment with globally sustainable solutions to restore rivers, ensuring enduring ecological health and flow. At its core, the living lab concept embodies holistic learning within the Varuna River watershed of the Ganga Basin. By convening all stakeholders under one roof, the SLCR promotes collaboration and serves as a collaborative space for incubating and co-creating solutions. This involves the iterative integration and testing of both local and global solutions to achieve a clean river. The SLCR focus on practical testing and implementation, providing an opportunity to discover new ideas and solutions in practice. This approach facilitates discussions on and addresses local river-related issues, leading to the derivation of sustainable solutions for achieving clean rivers.

SLCR adopts an integrated watershed management approach for the watershed. Addressing every parameter influencing river water quality, the strategy includes surface and groundwater management with sustained flow through managed aquifer recharge. Additionally, urban flow is managed through feed bed techniques and an IoT-based sewage treatment plant for effective wastewater treatment. The initiative aims to enhance hydrological connections by removing encroachments from the floodplain. Furthermore, the promotion of carbon-neutral and water-positive villages contributes to the self-sustainability of the watershed.

* nikhileshs.rs.civ16@itbhu.ac.in

Wastewater

Room	Title	From	To
AUD 1	Wastewater	13.00	15.00
	Chair: Søren Hvilshøj, Senior Market Director, NIRAS		

Speaker	Title of presentation
Sofie Zacho Vestergaard	Microflora Danica: Investigation of the microbiome of Denmark with focus on wastewater and wastewater treatment plants
Sabine Lindholst	Washing and recycling of PFAS-contaminated soil
Charlotte Skjold Qvist Christensen	Waste Derived Biochar Sorbents for Water Treatment of Long- and Short-Chain PFAS
Rune Dall Harpøth	Utilizing treatment train concepts to remove PFAS compounds from wastewater from sludge treatment reed beds
Yu Yang	National landscape of environmental resistome in Denmark
Leendert Vergeynst	High-rate Biological Phosphorus Removal using a Moving Bed Biofilm Reactor: Effect of Biofilm Thickness and Hydraulic Retention Time
Kai Bester	Single compound risk, cumulative risk or removal-based design of advanced wastewater treatment for micropollutants
Sara Brorson Jensen	A new tool for effect-directed analysis of drivers of endocrine disruption in wastewater: coupling state-of-the-art chemical analysis with in vitro bioassays
Francesco Savio	Enhancing sustainable biodegradation of organic micropollutants by methanotrophic microbiomes: insights into the interaction between heterotrophic and methane oxidizing bacteria

Microflora Danica: Investigation of the microbiome of Denmark with focus on wastewater and wastewater treatment plants

Sofie Z. Vestergaard*, G. Dottorini, A. Murguz, M. Nierychlo, V.R. Jørgensen, P.H. Nielsen*****

Introduction: Microflora Danica aims to describe the microbiome of Denmark through analysis of 10,000 representative samples that cover typical Danish habitats, including various water types such as lakes, streams, drinking water and wastewater. We developed and applied novel DNA-based tools that will allow to build a reference database for all microorganisms, and we will provide the first comprehensive overview of prokaryotes and small eukaryotes across Denmark. The vast majority of microorganisms are expected to be novel and previously undescribed. The results will provide the foundation for all future studies of the microbiology across Denmark. The project is funded by Poul Due Jensen Foundation for the period of 2019-2025. More info can be found on the webpage (www.microfloradanica.aau.dk). This presentation will give an overview of aim, methods, plans, and results, primarily from wastewater and wastewater treatment plants.

Methods and data: More than 50 sampling campaigns with collaborators have been carried out and more than 10,000 samples from most natural and urban habitats have been sampled, including metadata. Novel DNA extractions and sequencing procedures, such as full 16S or 18S rRNA gene operon sequencing, shallow metagenomes and deep metagenomics have been implemented and new bioinformatic pipelines developed. Presently, all 10,000 samples have been sequenced and further processed. Among those, biomass and influent from approx. 80 wastewater treatment systems have been analysed.

Results: The microbial diversity in more than 80 wastewater treatment plants has been analysed and more than 30,000 different species are recorded based on their representative DNA sequence. Most of these were novel and never seen before, so their function remains unknown. The majority, however, was present only in very low abundance in the treatment plants and not assumed to be important for the treatment processes. The more abundant fraction only contains few hundred species that are generally well described and constitute the process-critical bacteria, which is in accordance with our recent study related to MiDAS, the Field Guide to the microbes of activated sludge (www.midasfieldguide.org). The majority - but not all - of the abundant bacteria were actively growing in the plant highlighting the true functional important (process-critical) bacteria. In general, the microorganisms coming in high abundance in influent wastewater (the ones growing in the sewer systems) die off when entering the plants and are just present due to mass-immigration potentially from the sewer systems and are not process-critical for the treatment process. Many species were found across all the treatment plants in Denmark, but some variation could be observed in community composition and structure, depending on geographical location, plant size and fraction of industrial load in influent wastewater. Contrarily, the overall design, either chemical or biological P-removal, did not have a consistent effect on community structure. The same overall patterns were found in the influent wastewater, but with a bigger variation in community compared to activated sludge. As for our global wastewater treatment survey, we observe that biogeographical patterns apply for microbial activated sludge communities on a very local scale of a few hundred kilometers, the size of Denmark. These patterns include an overall distance decay and regional differences throughout Denmark and may be shaped by a combination of overall diversification and local source communities governing the immigrating microorganisms.

Discussion and take-home message: Microflora Danica aims to describe the microbiome of Denmark through DNA-based analysis of 10,000 representative samples that cover typical Danish soil and water biotopes. The study of Danish wastewater and activated sludge wastewater treatment plants provides a very comprehensive overview of microbial diversity present, including a complete list of taxa, and factors affecting their presence and abundance. It addresses some key questions about microbial ecology and biogeography, and it reveals a huge novelty although the number of novel abundant process-critical species is lower. These are of high priority to study more in depth, help guiding future plant operation and optimization. Furthermore, it is the first step forward toward a better understanding of microbial diversity and transportation among different part of the Danish waterways.

* *szv@bio.aau.dk: Department of Chemistry and Bioscience, Center for Microbial Communities, Aalborg University, Aalborg, Denmark*

** *phn@bio.aau.dk: Department of Chemistry and Bioscience, Center for Microbial Communities, Aalborg University, Aalborg, Denmark*

Washing and recycling of PFAS-contaminated soil

Sabine Lindholst*, C. Bruun Nielsen, Nordic Waste, T. Svendsen, Vandrensning.com, H. Hinrichsen, Envytech*

Introduction: Soil contaminated with environmental pollutants, such as PFAS, presents a growing risk to both the environment and human health. PFAS molecules are persistent, harmful, and can spread across extensive areas through water flow. The objective of the TUP project is to validate and enhance a soil washing technology that effectively removes PFAS, preventing its leakage into the environment. Additionally, the project aims to enable the reuse of the decontaminated soil fractions, such as sand and stones, for construction purposes. This approach promotes sustainability and minimizes the impact of PFAS contamination on both the environment and public health.

Methods: A pilot plant for soil washing was designed and constructed to closely resemble a full-scale soil-washer. The plant underwent testing using two distinct types of PFAS-contaminated soil, generating separated fractions of washed stones and washed sand. The testing process followed a Design of Experiments (DoE) approach, consisting of eight distinct washing scenarios conducted for each soil type. The purpose was to assess the effects of two adjustable parameters, namely the soil input rate and the water pressure/water volume, on the overall performance of the soil washing process. Subsequently, the silt/washing water fraction, which contained high concentrations of PFAS, underwent treatment employing various strategies. The primary objective was to enable the recycling of water for washing purposes while simultaneously reducing the waste fraction that necessitates expensive PFAS destruction methods. The treatment strategies were:

- Application of coagulants, flocculants and polymer followed by adsorption on ion exchange resins.
- Surface active foam fractionation (SAFF) on both the untreated and pretreated silt/washing water fractions.

Results: The experimental tests were performed on sandy soils, with one soil exhibiting high PFAS concentrations (1700 µg/kg TS) and the other soil containing low concentrations (6 µg/kg TS). After undergoing the soil washing process, the PFAS concentration in the washed sand fractions experienced reductions of 96% (highly contaminated soil) and 86% (less contaminated soil), in comparison to the initial, unwashed soil samples. Although the PFAS concentration in the washed sand fraction of the highly contaminated soil slightly exceeded the limit value of 10 µg/kg TS containing 60 µg/kg TS, it is expected to fall below the limit value after subjecting the sand fraction to additional washing. The sludge volume obtained after pretreatment of the washing water/silt fraction varied between 4 and 11 % for the two soil types and different washing strategies. The adsorption experiments and SAFF studies described in the Methods section are currently in progress, and the results will be presented at the conference.

Discussion and take-home message: Washing of PFAS contaminated soil is a very promising approach for the removal of PFAS from the soil, preventing leaching of these persistent substances to the environment. Simultaneously, recycling of sand and stone contributes to a more environmentally friendly utilization of a resource that is progressively diminishing in availability.

Pilot scale soil washer (left), washed stones, sand, and unwashed soil (middle), full scale soil washer (right)

* sbl@teknologisk.dk: *Kongsvangs Allé 29, DK-8000 Aarhus*

Waste Derived Biochar Sorbents for Water Treatment of Long- and Short-Chain PFAS

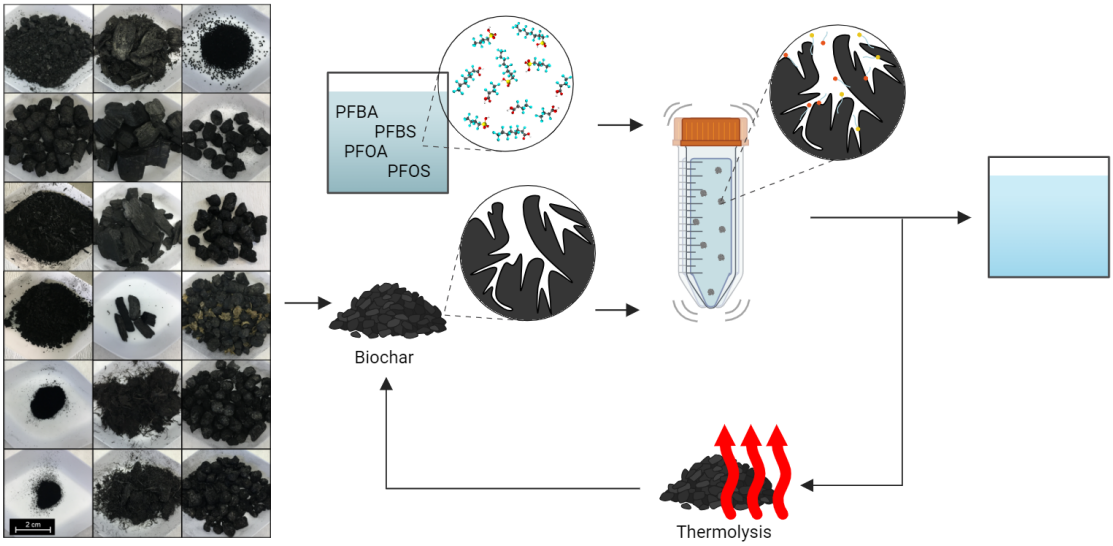
Charlotte S. Q. Christensen *& Z. Wei, Department of Biological and Chemical Engineering, Aarhus University**

Introduction: The occurrence of per- and polyfluoroalkyl substances (PFAS) in aquatic environments poses a large concern for environmental ecosystems and public health. At present, the predominant treatment method is adsorption of PFAS by activated carbon (AC). While somewhat effective towards legacy PFAS compounds, the reliance on AC has its limitations, prompting exploration into alternative materials. Biochar, derived from the carbonization of abundant and low-cost feedstocks such as agricultural or industrial by-products, could emerge as a promising and economically viable alternative to AC. However, overcoming the challenge of effectively removing short-chain PFAS and establishing an efficient regeneration strategy for biochar to mineralize toxic PFAS pollutants is crucial. Addressing these aspects is imperative to fully realize the potential of biochar as a PFAS sorbent.

Methods and data: We compared 17 biochar derived from various waste feedstocks and production processes to identify optimal physiochemical properties for simultaneous removal of short- and long-chain PFAS. Analyzing structural and chemical biochar characteristics (S_{BET}, V_T, V_{mic}, VM/FC/Ash, CHNS, PZC, etc.), we conducted batch sorption experiments using quaternary equimass PFAS mixtures (PFBA/PFBS/PFOA/PFOS) to identify key correlations. The adsorption mechanisms on three biochar sorbents were elucidated, and we evaluated the regeneration and recyclability through thermolysis at 900 °C.

Results: Significant discrepancies in PFAS adsorption were evident across biochars, with some showing minimal efficacy in short-chain PFAS removal. Long-chain PFAS predominantly relied on hydrophobic interactions, while effective short-chain removal resulted from the interplay between adsorption site availability and electrostatic interactions. Recyclability tests of regenerated biochar surprisingly demonstrated improved short-chain PFAS adsorption. LC-MS analysis verified complete degradation of adsorbed PFAS, and N_2 physisorption analysis revealed an increase in biochar microporosity upon thermolysis.

Discussion and take-home message*:* In intricate mixtures, PFAS adsorption proves highly complex. Even in well-performing cases, long-chain PFAS (PFOA, PFOS) exhibited notably faster adsorption rates and higher adsorption capacities compared to their short-chain counterparts (PFBA, PFBS). The heightened mobility of short-chain PFAS demands rapid and robust surface attraction. To enhance biochar's efficacy towards short-chain PFAS, one should target electrostatic binding sites and high microporosity for the size exclusion of longer PFAS. *Considering factors such as resource availability, technological developmental status, cost, and sustainability, the preparation of effective PFAS sorbents from waste-derived biochar does hold promise. However, focused research efforts should prioritize enhancing the adsorptive potential specifically for short-chain PFAS.*



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

Utilizing treatment train concepts to remove PFAS compounds from wastewater from sludge treatment reed beds

*N.S. Damgaard, **Rune D. Harpøth**, S. Lindholst, C. Kragelund, Danish Technological Institute*; F.M. Hansper, L. Adrian, DIN Forsyning A/S**; T.C. Svendsen, ECT2.com***; K. Tang, R.K. Chhetri, H.R. Andersen, DTU Sustain*****

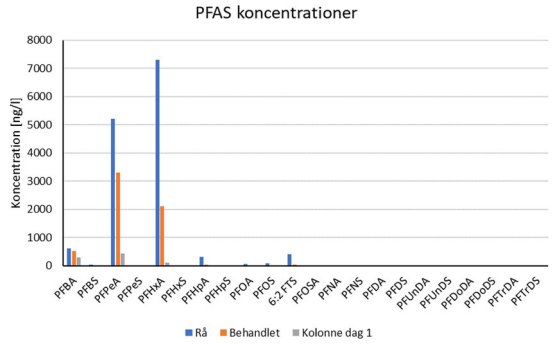
This project is partly funded by the Environmental Technology Development and Demonstration Program (MUDP).

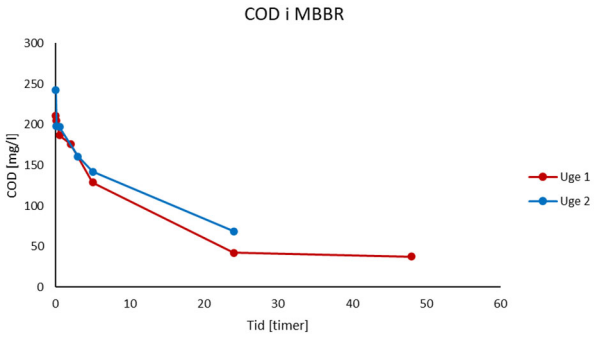
Introduction: In recent years PFAS have had large media coverage and a lot of remediation efforts have been put on removing PFAS from soils and water. PFAS compounds have been used extensively since the 1950's in firefighting foam, shoes, clothing, cosmetics, food wrapping etc., and many have become prohibited in a wide range of products, with more laws and regulations against their use planned to take effect in the coming years. However, wastewater treatment plants (WWTP) that receive water from industry, landfills, incineration plants etc. still measure high concentrations of PFAS. A wastewater treatment plant in Esbjerg, Denmark experiences this problem from their Sludge Treatment Reed Beds (STRB) where PFAS has been concentrated to very high levels. In this project several experiments were conducted to remove the majority of the PFAS leached from the STRB, before the reject water was led to the WWTP.

Methods and data: Polluted water from STRBs were led into a 1000 m3 water tank where 100 ml/m3 PAX, 100 ml/m3 fluorfloc and polymer were added to flocculate and coagulate any suspended particles and PFAS detected in the reject water. Afterwards the water was decanted and led into another 1000 m3 tank. The pre-treated water was then pumped through a 200 ml resin column with a flow of 1,5 l/h. Samples were taken of raw water, the pre-treated water and water after the resin column. Water after the resin column was sampled once every weekday for 21 days. Samples were sent to DTU and Eurofins for analysis of 22 PFAS.
A moving bed biofilm reactor (MBBR) was constructed to determine if biological treatment of the reject water would remove COD and thereby prolong the lifetime of the resin column. The microbes in the MBBR were subjected to pre-treated water at a 50% dilution. The water had a hydraulic retention time of 1 week.

Results: Pretreatments of the raw water with PAX, fluorfloc and polymer reduced the PFAS concentrations with a >50% reduction in all 22 PFAS. COD measurements revealed breakthrough of COD already on day 1 of resin filter operation, which suggests that breakthrough of some PFAS can be anticipated. This was also confirmed by PFAS analysis which revealed that the resin could remove 96% PFHxA and 87% of PFPeA, but only removed 44% of PFBA. Some long chain PFAS also broke through the resin column. COD measurements from the MBBR revealed that the microbes could reduce COD by 70-80% after 24 hours and 82% after 48 hours.

Discussion and take-home message: Results showed that the concentration of PFAS could be reduced by treatment with PAX, fluorfloc and polymer and could be further reduced via a resin filter. However, breakthrough on day 1 of PFAS/COD suggests that the COD in the pretreated water was too high. MBBR results revealed that a biological treatment step after pretreatment with PAX, fluorfloc and polymer and before the resin filter, could potentially prolong the lifetime of the resin filter. This will be tested in future pilotscale experiments conducted in December 2023. Results obtained closer to the conference will also be included in the presentation.





* nscd@teknologisk.dk: *Kongsvang Alle 29, 8000 Aarhus C*
** liadr@dinforsyning.dk: *Ulvsundvej 1, 6715 Esbjerg N*
*** ts@vandrensning.com: *Kildemarksvej 3, 4200 Slagelse*
**** hran@dtu.dk: *Bygningstorvet, Bygning 115, 2800 Kgs. Lyngby*

National landscape of environmental resistome in Denmark

Yu Yang*[*,#]*, Mantas Sereika[#], Thomas B.N. Jensen[#], Mads Albertsen[###], Per H. Nielsen[###], Caitlin M. Singleton[###]*

Introduction: Microbial antibiotic resistance genes (ARGs) present global health threats that call for multi-sectoral effort in combating their emergence and dissemination. The environment is an important ARG reservoir that not only has implications to human and animal health but also offers a rich resource of microbially produced natural products for new antibiotic drug development. As such, national-level environmental resistome profiling is both beneficial in understanding the role the environment plays in the spread of ARGs in Denmark, and in guiding the development of new nature-derived antibiotics to combat increasing microbial resistance.

Methods and data: Over 7,000 environmental samples were collected from various habitats across Denmark for establishing the national natural and urban landscapes of ARGs in sediments (including different types of saltwater and freshwater sediments), waters (including wastewater treatment plants (WWTPs), seawaters, fjord waters, drinking waters, and groundwaters), and soils, which generated 7,091 shallow Illumina metagenomes, representing >23.7 Tbp of quality trimmed data, and 112 deep Oxford Nanopore metagenomes.

Results: ARGs were highly diverse in the environment and exhibited habitat-level patterns in composition, which also differed by antibiotic drug types, across different habitats. Overall, the abundance of ARGs in natural environments was much lower than that of urban environments. Samples from WWTPs had higher proportions (10-20%) of ARGs that were found enriched in human habitats and present in human pathogens, than samples from soils, water sediments, and other waters (1-2%). Saline waters and sediments had lower ARG levels (by half) than freshwater waters and sediments. In addition, aqueous-phase waters overall had twice of the ARG abundances found in water sediments (e.g., in fjords, harbour habitats). Water treatment facilities are effective in reducing ARG levels by 1 order of magnitude. For example, WWTPs reduced ARG levels from 964 rpkm to 177 rpkm. Sand-filtration and drinking water treatment facilities reduced ARG levels from 307.5 rpkm in groundwater, which is the primary source of drinking water in Denmark, to ~ 35 rpkm in filtered and treated drinking water. Soils, as an important source of groundwater ARGs through seepage, were also investigated for the ARG abundances, which had ARG abundances between water sediments and waters. In terms of between-habitat dissemination, metagenome-assembled genomes from long-read sequencing suggested potential wide host ranges for 57 commonly abundant ARGs found in at least 2 sample types, as well as their diverse and mobile genetic backgrounds. As for within-habitat transferability, by comparison to genomes from other habitats, we demonstrated that ARGs in the environment (i.e., soils and sediments) are not as readily transferable within the habitat as ARGs in human-associated habitats (wastewater treatment plants, pig gut, human gut), marine environments and human pathogens. Additionally, deep long-read sequencing suggested limited contribution of phage- and plasmid-mediated ARG transfer in soils and sediments, compared to human-impacted WWTPs. However, at a finer resolution, some clinically relevant ARGs and their associated mobile genetic elements were found both in the environment and human pathogens.

Discussion and take-home message: Through national-level large-scale sampling, we showed that ARGs differed in abundances and compositions based on sample types, and samples from the natural environments had much lower ARG abundances and transferability than human-associated habitats. Water treatment facilities are effective in reducing ARG levels for protecting the health of human and the environment. However, the role the environment plays in the control of ARGs should not be neglected as some environmental ARGs have broad host range, variable genetic context, and high similarity to human pathogens. Additionally, our results established the lacking fundamental knowledge of the "normal" baseline of ARG abundances in the environment, which could guide future studies in locating environmental ARG hotspots that deserve prioritized actions. Overall, the results of this study could help guide the sustainable management of the environmental resistome.

** yuyang@bio.aau.dk: Department of Chemistry and Bioscience, Section of Biotechnology, Center for Microbial Communities, Aalborg University, 9220 Aalborg, Denmark*

[#] Department of Chemistry and Bioscience, Section of Biotechnology, Center for Microbial Communities, Aalborg University, 9220 Aalborg, Denmark

[###] cms@bio.aau.dk (Corresponding authors): Department of Chemistry and Bioscience, Section of Biotechnology, Center for Microbial Communities, Aalborg University, 9220 Aalborg, Denmark

High-rate Biological Phosphorus Removal using a Moving Bed Biofilm Reactor: Effect of Biofilm Thickness and Hydraulic Retention Time

Leendert Vergeynst**, Aarhus University*, Sandeep Rellegadla, Aarhus University**, Maria Piculell & Magnus Christensson, AnoxKaldnes, Jeppe Lund Nielsen, Aalborg University*****

Abstract: To enhance the recovery of phosphorus in wastewater treatment, we explored to boost the rates by using a moving bed biofilm reactor. Our investigation on the influence of biofilm thickness on phosphorus-accumulating bacteria revealed a peak in activity for biofilms of 100–500 µm thickness, with reduced rates in thicker biofilms due to mass transfer limitations. Thicker biofilms exhibit a higher abundance of potential phosphorus-accumulating genera, while thinner biofilms were dominated by competing acetate consumers. The study highlights the potential application of biofilm-based biological P recovery in wastewater treatment.

Introduction: This study addresses the critical need of recovering phosphorus from wastewater to be recycled as fertilizer in agriculture. We explored the possibility of increasing phosphorus removal rates in wastewater treatment by using biofilms and investigated the influence of biofilm thickness and low hydraulic retention time on the activity and microbial community of phosphorus-accumulating bacteria in a moving bed biofilm reactor.

Methods and data: To investigate the influence of biofilm thickness, a 3-litre sequencing batch reactor was operated at 15°C, filled with a mixture of 5 AnoxK™ MBBR carriers, including four from the Z-MBBR series (Z-50, Z-200, Z-400, and Z-1000) and one (K5) from the AnoxK™-series representing biofilms of 50 to 1000 µm thickness. The reactors were fed with a minimal medium including acetate as carbon source. Microbial community analysis was conducted to assess the community composition of phosphorus-accumulating organisms (PAO) among the different biofilms and their correlation with phosphorus removal activity. To investigate the effect of hydraulic retention time, we gradually reduced the cycle times down to 100 min.

Results: The study revealed that biomass-specific phosphorus release and uptake rates exhibited an intriguing pattern. These rates increased with biofilm thickness up to 110 µm but declined for thicker biofilms ranging from 550 to 1000 µm. The reduction in rates in thicker biofilms may be attributed to substrate mass transfer limitations, while the low activity observed in thin biofilms could be linked to a high turnover rate due to heterotrophic growth. Microbial community analysis demonstrated that thicker biofilms had a higher relative abundance (40–58%) of potential phosphorus-accumulating genera, including *Zoogloea*, *Acinetobacter*, *Dechloromonas*, and Ca. Accumulibacter. In contrast, thinner biofilms were dominated by the genus *Ferribacterium* (34–60%), potentially competing with phosphorus-accumulating bacteria. Measurements under decreasing hydraulic retention time and batch cycle times showed constant biomass-specific phosphorus uptake and release rates, while, area-normalized rates increased six-fold, indicating an enhanced performance under high-rate conditions.

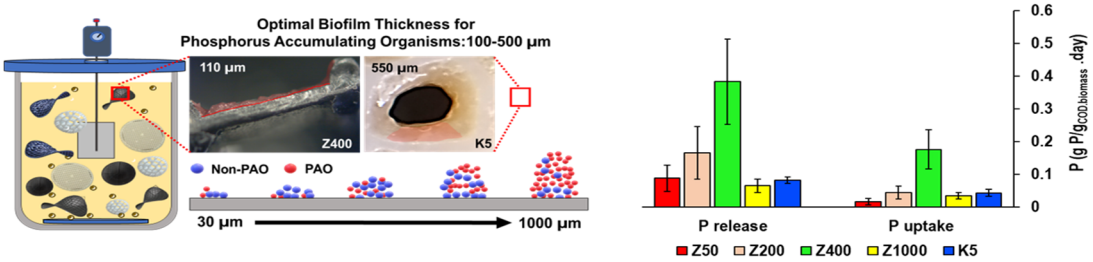


Figure: PAO activity was highest in 100–500 µm biofilms (Left). The Z400 carriers exhibited higher biomass-normalized rates than biofilms exceeding 500 µm, indicating mass transfer limitations in thick biofilms (Right).

Discussion and take-home message: A) Biofilm thickness influences PAO activity, peaking in 100–500 µm biofilms but faces mass transfer limitations in thicker 500–1000 µm biofilms.

B) Biofilm-based systems show up to 7 times higher volumetric phosphorus removal rates than conventional systems.

C) High-rate biological phosphorus removal has a high potential to enhance the performance.

D) The results have been published in: **Rellegadla *et al*. *Water Res*earch, 245, 120599 (2023)**.

** leendert.vergeynst@bce.au.dk, ** sandeepr@bce.au.dk: Department of Biological and Chemical Engineering, Ole Worms Allé 3, 8000 Aarhus. *** Klosterängsvägen 11A, 226 47 Lund, Sweden. **** jln@bio.aau.dk: Department of Chemistry and Bioscience, Fredrik Bajers Vej 7, H, 3-501, 9220 Aalborg.*

Single compound risk, cumulative risk or removal-based design of advanced wastewater treatment for micropollutants

Frances Spilsbury[1], Vaidotas Kisielius[2], Thomas Backhau[13], Jørgen Skarup[4], Britta Sevelsted[5], ***Kai Bester[6]***

Introduction: Advanced treatment of wastewater can be triggered in multiple ways: 1) Defining point sources (hospitals) assessing the relevant emissions (130 pharmaceuticals) and assessing compound by compound the risk via PEC/PNEC (which is the current Danish approach), 2) calculating the cumulative risk (summing all PEC/MNUC), 3) assuming all wastewater treatment plants emit water that is still detrimental to the environment and prioritising by size asking for a removal of selected marker compounds (Urban wastewater directive). In this contribution we will compare the three different approaches and discuss outcomes and implications.

Methods and data: Wastewater from several WWTPs including one pilot plat operating a Ozone-GAC process was sampled and analysed for 50 wastewater compounds (mostly pharmaceuticals plus a corrosion inhibitor). Successively single PEC/PNEC assessments were performed. In a second step the PEC/PNEC ratios were summed up to achieve a mixture risk quotient.

Results: Both single compounds and mixture risk resulted in all WWTP effluents tested were above risk quotient 1 (meaning influencing the environment negatively). Especially the mixture risk assessment resulted in single numbers that are relatively easy to communicate but also show high exceedance (up to hundred times) of risk quotient 1. All three approaches result in WWTP effluents need to be treated. The two risk-based assessments indicate that not a single technology but only the combination ozone – GAC can tackle the risk to reach a risk quotient below 1. However, also in combination, the ozone dose can be considerably reduced in comparison to the stand-alone approach.

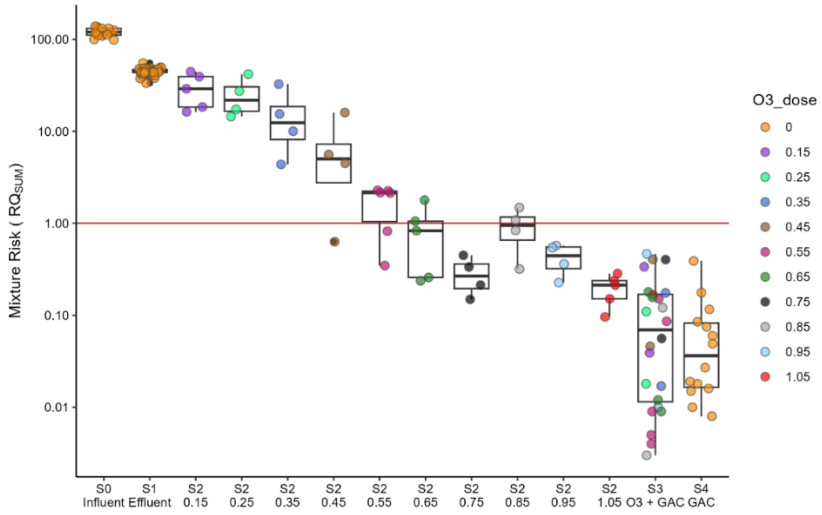


Figure 5: Mixture risk for untreated influent, conventionally treated effluent, and post-treatment with GAC and varying doses of ozone. The boxes represent the 25th and 75th percentiles, the whiskers show the minimum and maximum values, and the dots indicate minimum or maximum values that may be considered outliers.

Discussion and take-home message:

Probably all WWTPs will need to remove micropollutants in the long run

The combination ozone-GAC is feasible

Information on the best operation parameters needs to be obtained

It is currently not possible to perform a proper risk assessment including metabolites and other transformation products.

1)francis.spilsbury@bioenv.gu.se, University of Gothenburg, Gothenburg 40530, Sweden
2)vk@envs.au.dk, Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde
3)thomas.backhaus@bioenv.gu.se, University of Gothenburg, Gothenburg 40530, Sweden
4) josk@hfors.dk, Hillerød Forsyning, Solrødgårds Alle 6, 3400 Hillerød
5) bsl@hfors.dk, Hillerød Forsyning, Solrødgårds Alle 6, 3400 Hillerød
6) kb@envs.au.dk; Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde

A new tool for effect-directed analysis of drivers of endocrine disruption in wastewater: coupling state-of-the-art chemical analysis with in vitro bioassays

Sara B. Jensen**, D. Orazbayeva, L. Vergeynst, Aarhus University*, M.H. Schausen, Aarhus Vand

Abstract: Endocrine disrupting compounds originating from wastewater cause a continuous burden on aqueous life and are high on the scientific and political agenda. However, current analytical methods cannot identify the multitude of pollutants causing estrogenic toxicity in wastewater. We took up the challenge to identify the currently unknown drivers of estrogenic toxicity in wastewater by coupling state-of-the-art *in vitro* bioassay with chemical analysis based on liquid chromatography – mass spectrometry. Our emerging hyphenated approach called effect-directed analysis (EDA) provides unmatched capabilities for detecting and identifying unknown estrogenic chemicals in wastewater.

Introduction: Thousands of pollutants including endocrine disrupting chemicals enter the aquatic environment though wastewater. The current monitoring based on chemical analysis of a list of prioritized pollutants inevitably overlooks a substantial portion of the toxicity caused by unknown pollutants and mixture effects. More than 95% of the toxicity measured in wastewater effluent cannot be explained based on the currently known micropollutants. For a more holistic water quality assessment, *in vitro* bioassays are increasingly applied to assess toxicity of chemical mixtures in water and have been recommended to be included in the next Water Framework Directive. However, bioassays do not provide information regarding the specific chemicals causing the observed toxicity. Such information is essential for developing solution-oriented policy and for improving the treatment efficacy of wastewater treatment.

Methods: We coupled liquid chromatography (LC) - high-resolution mass spectrometry (MS) with planar yeast oestrogen screens (PYES). After LC separation, one portion of the eluate is sent to the MS, and the other is deposited onto a thin-layer chromatography (TLC) plate for PYES (Fig1A). Our optimized interface uses a solenoid valve to 'print' LC eluate as µL-droplets on the TLC plate as a nearly continuous trace. As proof-of-concept, we applied our new EDA approach on known mixtures of oestrogens as well as influent and effluent of the wastewater treatment plant of Egå.

Results: The effect of solenoid valve frequencies on droplet formation and areas of the respective spots created on the surface of TLC plates was evaluated with different mobile phase compositions and flow rates. At the optimal frequency of the solenoid valve, the spots with average diameter of 2.8 to 5.6 mm were achieved for the 50 µL/min of the eluate deposited onto the TLC plate. Our novel approach was demonstrated using a mixture of 3 oestrogens (Fig1B). EDA of influent (Fig1C) revealed the presence of several oestrogens including estriol, estrone and 4 unknown oestrogens, to be further identified by mass spectrometry. Oestrogens were also detected in the effluent, but at substantially lower levels.

Discussion and take-home message: The proposed EDA approach is a promising tool for identification and quantification of the most potent hormone disrupting chemicals and, in perspective, many other toxicants in water. Further improvement of the resolution will enhance the sensitivity of the method. Our EDA approach will provide relevant information to policy developers and wastewater treatment plants to undertake solution-oriented actions.

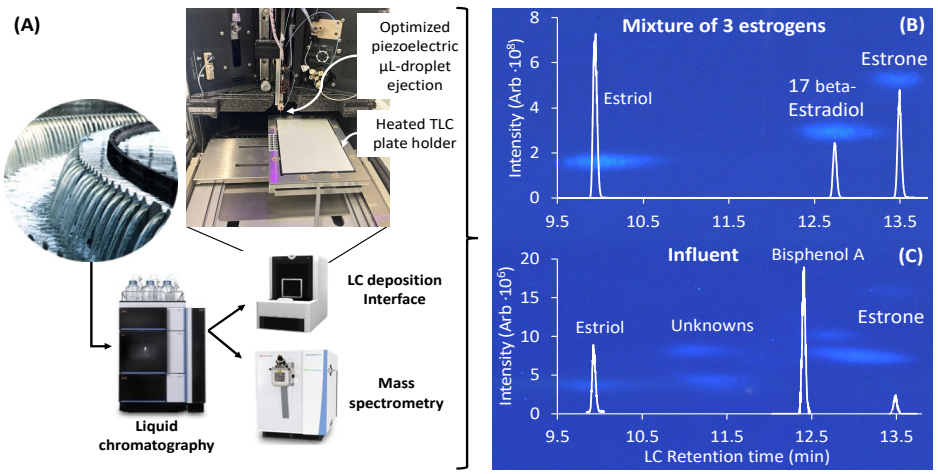


Figure 1. Demonstration of the proposed EDA approach (A) for a standard mix of 3 estrogens (B) and for influent (C). Estrogens on the PYES produce a light-blue spot, which can be identified by overlaying the LC-MS chromatogram.

*leendert.vergeysnt@bce.au.dk: *Department of Biological and Chemical Engineering, Ole Worms Allé 3, 8000 Aarhus*

**mille.schausen@aarhusvand.dk: *Hasselager Allé 29, 8260 Viby J*

Enhancing sustainable biodegradation of organic micropollutants by methanotrophic microbiomes: insights into the interaction between heterotrophic and methane oxidizing bacteria

Francesco Savio, *Hugo Möller, Alen Simonic, Theodoros Theodoridis, Anders T. Mortensen, Borja Valverde-Pérez, DTU Sustain*

Introduction: Danish monitoring programs show that organic micropollutants (OMPs) occurrence in water works wells has increased in the last decade (Thorling & Geus, 2021). Most of the current technologies employed for OMPs removal in raw drinking water facilities have shown either limited removal efficiencies or very high operational costs (Shahid et al., 2021). It is therefore necessary to find sustainable and economical solutions to implement at drinking water facilities. Organic micropollutants can be biologically degraded through primary metabolism or co-metabolism. In co-metabolic processes, microorganisms transform micropollutants by unspecific enzymatic activity without assimilating carbon or obtaining energy (Benner et al., 2013). Efficient biodegradation of OMPs through co-metabolic activity of methane oxidizing bacteria (MOB) has been reported (Hedegaard et al., 2018), (Papadopoulou et al., 2019). Previous studies have shown that aerobic heterotrophs present in methanotrophic microbiomes play a significant role in the biodegradation of OMPs (Mortensen et al., 2023). In the latter study, the effect of CH_4 loading rates was investigated in a hybrid membrane biofilm reactor (hMBfR), leading to 100 % and 88 % removal efficiency of sulfamethoxazole (SMX) and 1H-benzotriazole (BZT), respectively (Fig. 1). Strikingly, BZT was mostly biodegraded by the suspended biomass, poor on MOB. Little information is available on the effect of operating conditions on interactions of heterotrophs and MOB, and biodegradation potential of mixed enrichments of those communities. In the present study we investigated effect of solid retention time (SRT), nitrogen source, methane loading, O_2/CH_4 ratios and preadaptation to OMPs on biodegradation potential of frequently occurring OMPs in Danish groundwater systems.

Methods: Three different sets of inoculums were sampled from a fermenter, a groundwater treatment plant, and a hospital wastewater treatment plant. Enrichments were cultivated in 250 mL serum bottles in batch mode. Cultures were exposed to diluted nitrate and ammonium (dNMS and dAMS) solutions, continuously shaken at 25°C. They were exposed to two different SRTs (5 and 15 days), two different methane initial concentrations (6.07 and 3.03 mg CH_4/L), and different O_2/CH_4 ratios. Preadaptation of cultures to OMPs was ensured by spiking a stock solution containing seventeen (17) parent compounds and transformation products. Three batch experiments in sequence were run for culture adaptation and characterization (growth rates, methane, and oxygen yields). At the end of the third growth curve, a 48h batch test was run to characterize OMP removal.

Results: Indigenous cultures from the three different sources were successfully enriched under methanotrophic conditions and utilized to investigate effect of operating parameters on co-metabolic activity of heterotrophs and MOB. OMPs biokinetics are not included due to space limitations.

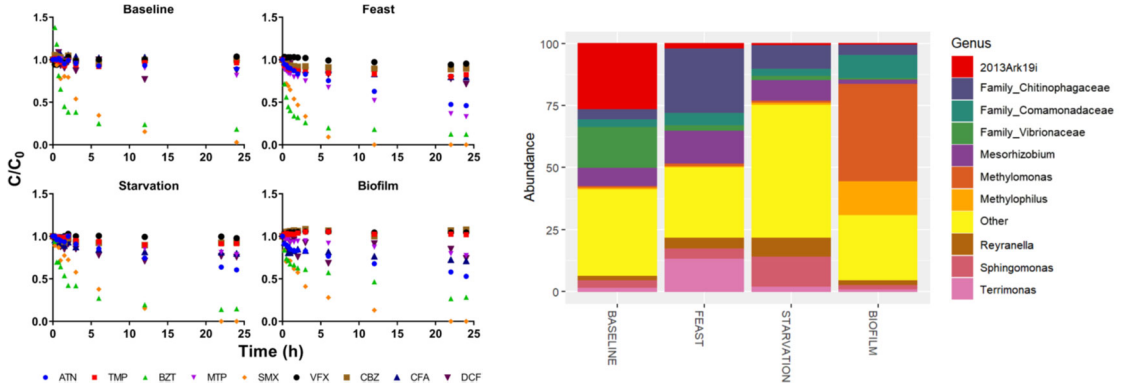


Figure 1. Degradation of OMPs and relative abundance of bacteria at genus level during batch tests at three CH_4 feeding regimes, and biofilm (Mortensen et al., 2023).

Sensors, energy and mine discharge

Room	Title	From	To
ROOM 1	Sensors, Energy and Mine discharge	15.30	17.30
	Chair: Uffe F. Thomsen, WATEC, Aarhus University		

Speakers	Title of the presentation
Wenyu Zhao	Membrane distillation for the production of ultrapure water for power to X
Qipeng (Helen) Liu	Analysis of green oxygen from PtX for wastewater treatment applications
Williane Vieira Macêdo	The Sludge2Fuel project: Integrating hydrothermal liquefaction in wastewater treatment plants for biofuel production from sewage sludge
Tanzila Sharker	MgAl-LDH doped porous carbon material as CDI electrode for selective recovery of phosphorus from eutrophic lake water
Quynh Nguyen	Gas phase N2O sensor development and process control for WWTPs
Adrian-Florin Florea	Phosphorus release from rewetted organic soils varies strongly in dependence of the phosphorus sorption capacity
Tamlyn Sasha Naidu	Valorising Wastewater: A Novel Approach for Critical Raw Materials Recovery from Acid Mine Drainage
Jayaluxmi Indu	Tracking Surface water from Space using SWOT mission: Impacts on Indian Hydrology

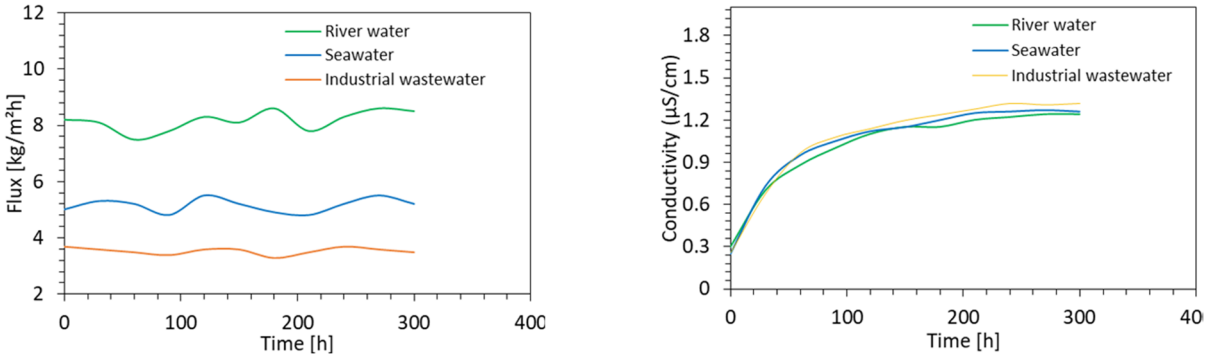
Membrane distillation for the production of ultrapure water for power to X

Wenyu Zhao**, AAU Energy*, Vincenzo Liso, AAU Energy**, Cejna Quist-Jensen, AAU BIO ***, Aamer Ali, AAU Energy**

Introduction: The growing demand for clean and sustainable energy has spurred increased interest in hydrogen as a versatile and eco-friendly fuel. Hydrogen production through electrolysis, utilizing water as the primary feedstock, has emerged as a promising method to generate "green hydrogen" with minimal environmental impact. However, electrolysers have stringent water quality requirements, with conductivity thresholds of lower than 1 µS/cm. It is foreseen that Denmark will need 32 million tons of ultrapure water each year to fulfil its aspiration of green hydrogen production by 2050. The demand for ultrapure water will potentially be met by extracting it from a wide range of sources including seawater, surface water, industrial wastewater, and greywater. The current water treatment and desalination technologies, however, are not inherently designed to meet the water quality requirements for electrolysis. Membrane distillation (MD) has emerged as an interesting solution to produce ultrapure water from different water sources and can be operated by using waste-grade heat. 20-25% energy input to the electrolyser is converted into heat, therefore, integration of MD with an electrolyser offers an interesting opportunity to produce ultrapure water by using the waste heat inherently produced by the electrolyser unit. The current study investigates experimentally the potential of MD to produce ultrapure water from seawater, river water, and industrial wastewater for the production of green hydrogen through electrolysis.

Methods and data: Seawater and river water were artificially synthesized in the laboratory whereas the industrial wastewater was provided by an international beer producer. MD tests were performed at different feed temperatures ranging from 45 to 75°C. The membrane module used in this work is composed of polypropylene hollow fibre with an average diameter of 3 mm, a mean pore size of 0.2 µm, and a porosity of 73%. The permeate production rate was monitored using a weight balance. The conductivity of the permeate was monitored by using a conductivity meter.

Results: It was noted that MD was able to produce stable pure water flux (Figure (a)) when using seawater, river water, and industrial wastewater as feed solutions. The difference in flux for different feed solutions is attributed to different applied temperatures and different module characteristics for each of the tests. It was observed that the conductivity of permeate gradually increased from around 0.3 µS/cm to around 1.3 µS/cm during the tests as shown in Figure (b). The investigations are on the way to study the effect of different feed temperatures on water flux and its conductivity.



(a) (b)

Figure: (a) MD flux using river water, seawater, and industrial wastewater as the feed solution (b) conductivities of the obtained permeates

Discussion and take-home message: Although the conductivity of the water produced by MD remains slightly higher than the maximum conductivity acceptable for an electrolyser, the difference is minimal, implying that MD could be an efficient and promising technology for the treatment of ultrapure water from groundwater. A final polishing step could bring the conductivity of the permeate within the acceptable range for electrolysers. Calculations also demonstrate that heat generated from splitting one cubic meter of water in an electrolyser could generate up to 3 cubic meters of freshwater through MD.

** wzha@energy.aau.dk: Pontoppidanstræde 111, 9220 Aalborg Ø, Denmark*
*** vli@energy.aau.dk: Pontoppidanstræde 111, 9220 Aalborg Ø, Denmark*
****cejna@bio.aau.dk: Fredrik Bajers Vej 7H 9220 Aalborg Øst*
**** aal@energy.aau.dk: Pontoppidanstræde 111, 9220 Aalborg Ø, Denmark*

Analysis of green oxygen from PtX for wastewater treatment applications

***Qipeng P. Liu**, X. Flores-Alsina, E.Ramin, K.V. Gernaey, DTU Kemiteknik**

Introduction: New EU standards on wastewater (2022), water reuse (2023) and drinking water (2023) are emphasizing the importance on elimination of emerging pollutants, such as endocrine disruptor, PFAS, as well as micro-pollutants. Meanwhile, the energy system is under huge transition for renewable and energy conversions. The PtX capacity is planned to reach 6 GW in Denmark, whereas green oxygen (99.3% purity) from water electrolysis is estimated to generate ~23040 ton per day. Such green oxygen provides a great opportunity for wastewater treatment plants to conduct aeration and oxidation with better efficiency, than conventional methods using air.

Methods and data: Benchmark Simulation Model No.2 (BSM2) is a plant-wide simulation platform for conventional secondary wastewater treatment plant. The BSM2 represents a 100,000 people equivalent (p.e.) treatment plant and consists of primary and secondary clarification units, activated sludge reactors, an anaerobic digester, a thickener and dewatering units. The model can perform one-year dynamic simulation with 15-minute intervals. To evaluate the implementation of PtX for wastewater treatment applications, the International Water Association (IWA) BSM2 serves as a standardised simulation platform. Three types of potential integration between PtX and wastewater treatment were evaluated at steady state: green hydrogen for bio-methanation of carbon dioxide from anaerobic digester; green oxygen for aeration in the aeration tank; green oxygen for ozone oxidation at the effluent discharge point.

Results:

- 0.67 MW, 1.82 MW and 3.11 MW capacity of water electrolysis are required respectively for bio-methanation, aeration and ozone oxidation for full-scale BSM2 application.
- Three electrolysers' combination of 1 MW, 2 MW, 2 MW can be an option for dynamic control and scheduling.
- Total green oxygen demand for all DK UWWTPs to implement pure oxygen aeration and effluent ozone oxidation requires ~4000 ton oxygen/day.

Discussion and take-home message:

- The applications can be partial and intermittent, if the electricity is from renewable source, e.g. wind.
- Onsite storage units can be considered to balance the demand and supply, for both hydrogen and oxygen.
- PtX has to be managed with caution at the discharge points of wastewater treatment plant (for example, ozone oxidation, hydrogen to oxygen impurity, etc).

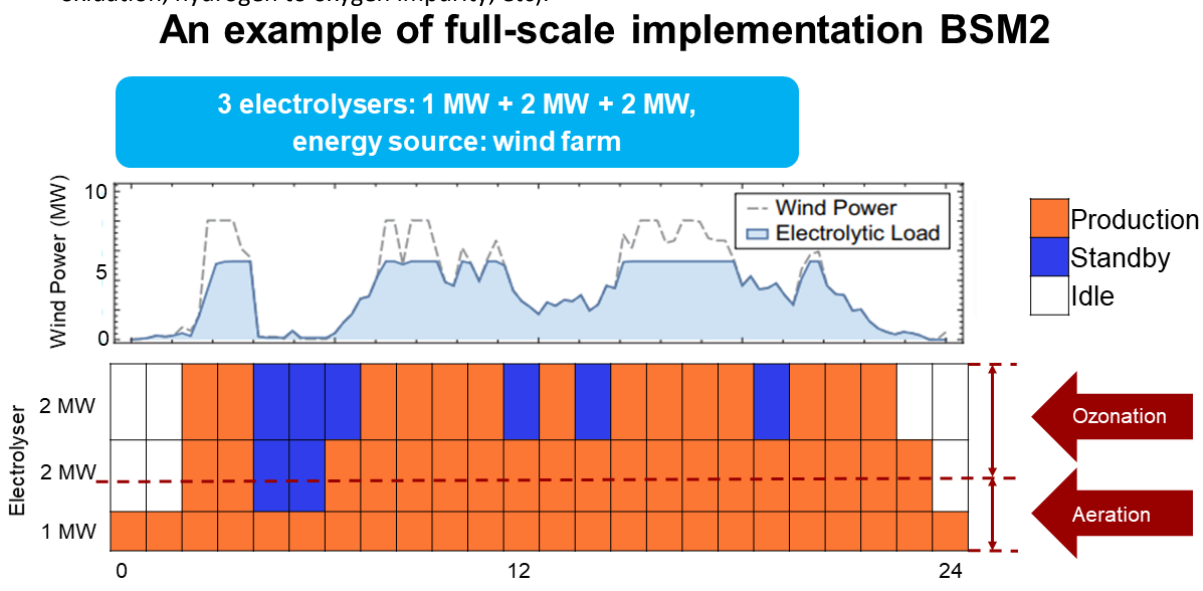


Figure 1. An example of electrolysers' control state for full-scale application of PtX at BSM2

*qipli@dtu.dk; xfa@dtu.dk; elhr@dtu.dk; kvg@dtu.dk; Søltofts Plads, Bygning 227, 2800 Kgs. Lyngby

The Sludge2Fuel project: Integrating hydrothermal liquefaction in wastewater treatment plants for biofuel production from sewage sludge

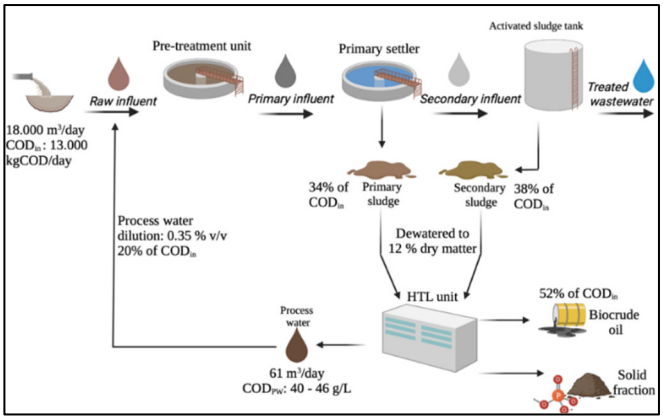
Williane Vieira Macêdo*, *Patrick Biller***, *Leendert Vergeysnt****

Abstract: Hydrothermal liquefaction (HTL) is a promising technology for converting sewage sludge from wastewater treatment into biofuel and phosphorus fertilizer. Yet, concerns arise over the toxic nature of resulting process water (HTL-PW). This study explores biodegradation and inhibitory effects of HTL-PW in activated sludge and anaerobic digestion systems.

Introduction: Safe disposal of sewage sludge poses challenges due to its high content of heavy metals, micropollutants and microplastics and accounts for a substantial portion of treatment costs. HTL emerges as a promising alternative, converting sewage sludge into a green biocrude oil. Operating at 250-350°C temperature and high pressure, HTL breaks down biowaste into biocrude, gas, hydrochar from which >90% phosphorus can be recovered, and an aqueous waste fraction. HTL has proven a positive energy balance with an energy return on investment of 340%. The EUDP Sludge2Fuel project will establish the first full-scale HTL plant at the WWTP of Fredericia. The oil will be upgraded by Crossbridge Energy refinery. The HTL plant will be built by Circlia Nordic and Krüger supports the implementation.

Methods: The HTL process was carried out at 325°C at our pilot plant, and the HTL-PW was used for inhibition and biodegradation studies. Nitrification inhibition, aerobic oxidation of organic matter and denitrification assays were conducted in 4-6h batch incubations. The adaptation potential of activated sludge biomass to increasing loads (5 to 146 mgCOD/L) of HTL-PW has been tested in two continuous sequencing batch reactors (SBR) operated at a hydraulic retention time of 20h and solids retention time of 15 days for over a year. Semi-batch anaerobic reactors were used to test biomethane potential of the HTL-PW. The removal of ca. 50 organic pollutants in HTL-PW was analysed by GC-MS.

Results: Upon recirculation of the HTL-PW into the wastewater treatment plant, the chemical oxygen demand (COD) in the influent is expected to increase by 157 mgO_2/L. Batch assays showed that HTL-PW is a nearly as good carbon source as acetate. Under aerobic conditions, hetero-trophic degradation of organic nitrogen and organic matter remained unaffected up to 223 mgO_2/L COD, with COD removal >94%. However, at the expected HTL-PW load, nitrification assays revealed an inhibition of 44% (IC_{50} of 197 mgCOD/L) for non-adapted biomass. The long-term SBR experiments showed that there was no effect of HTL-PW on the COD, organic nitrogen and total Kjeldahl nitrogen removal when exposing activated sludge to HTL-PW levels up to 146 mgCOD/L, with removal efficiencies above 95%. Nitrification tests showed an adapted nitrifying biomass that was able to degrade the inhibitory compounds. Co-digestion of manure with HTL process water from sewage sludge efficiently produced methane with a 43% yield at concentrations up to 12.8 gCOD/L, but the methane production was completely inhibited at 17 gCOD/L. Among the monitored pollutants, only N-containing heterocyclic compounds showed poor removal in the SBR system. Among the monitored pollutants, most pollutant were effectively degraded, except for N-containing heterocyclic compounds such as pyrazines.



Discussion and take-home message: There was no impact on COD removal and denitrification activity. Even though substantial nitrification inhibition was observed for non-adapted biomass, the nitrifying community in activated sludge can adapt over time and there was no effect on the nitrogen cycle upon exposure to HTL-PW at 146 mgCOD/L. Sludge2fuel is ready to test the full-scale integration. However, the fate of N-containing heterocyclic compounds is a key issue that needs further evaluation to enable full HTL-WWTP integration.

* williane@bce.au.dk, *** leendert.vergeysnt@bce.au.dk: *Ole Worms Allé 3, Bygning 1171, 8000 Aarhus, Denmark*
** pbiller@bce.au.dk: *Hangøvej 2, 8000 Aarhus, Denmark*

MgAl-LDH doped porous carbon material as CDI electrode for selective recovery of phosphorus from eutrophic lake water

***Tanzila Sharker*[1]*, *Jens Muff*[1]**, [1] *Department of Chemistry & Bioscience, Aalborg University, Niels Bohrs Vej 8, 6700 Esbjerg, Denmark. * tsh@bio.aau.dk .** jm@bio.aau.dk (Supervisor)*

Capacitive deionization (CDI) technology emerges as a promising solution for addressing the pervasive environmental issue of phosphorous removal from water. Although nitrogen often dominates discussions, Danish lakes face a more critical challenge with phosphorus acting as the main instigator of eutrophication [1]. The Danish news has been dominated by concerns over oxygen depletion throughout the summer and into the fall, portraying a grim scenario of practically lifeless sea bottoms [2,3]. This problem is mirrored in Danish lakes, causing catastrophic repercussions for biodiversity and climate. Despite its detrimental effects, phosphorus remains a valuable resource for agriculture, underscoring the urgency of developing recycling methods.

The electro-assisted adsorption process – CDI operates based on the principles of electrostatic attraction and the capacitive storage behaviour of porous carbon-based materials. This study is dedicated to advancing CDI electrode materials to facilitate highly efficient and selective phosphorus recovery. The composites of MgAl layered double hydroxide (MgA-LDH) doped on the surface and pores of Graphite felt (GF) and Biochar, were prepared using the co-precipitation method. Prior to MgAl loading, GF underwent activation through heat treatment at 600°C for 5 hours in an oxygen environment. This treatment enhanced wettability by fostering the formation of oxygen-containing functional groups (hydroxy, carbonyl, and carboxyl groups), increased specific surface area and pore volume, and reduced electrical resistance, thereby improving conductivity. Conversely, the biochar was derived from sediment sourced from Lake Ormstrup, Denmark. Ongoing testing of MgAl-LDH/biochar composites using CDI technology is in progress, and the results will be available in the near future.

Phosphorus removal from Ormstrup Lake water, initially spiked with a phosphorus concentration of 10 mg/L, was studied. The impact of the Mg-Al LDH active layer was assessed through passive adsorption. The results demonstrated a substantial decrease in phosphorus concentration from 10 mg/L to 3.6 mg/L. Passive adsorption using MgAl-LDH/GF material achieved an outstanding 100% selectivity over other competing anions such as chloride, nitrite, bromide, nitrate, and sulphate. On the contrary, pristine GF exhibited no phosphate adsorption, including other ions. The primary mechanisms driving phosphate removal included electrostatic interactions, ion exchange, and the formation of inner-sphere complexation.

Figure – Eutrophic Lake Ormstrup, Denmark (Left), and CDI system for phosphorus removal and recovery (Right)

Acknowledgement: This work is funded by the Poul Due Jensen Grundfos Foundation as part of the Circular Lake Restoration – rePair project.

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Gas phase N2O sensor development and process control for WWTPs

Quynh Nguyen*, J. Lembcke Andersen, S. Lindholst, A-L. Trøst Frisch Funding, V. Jørgensen, Teknologisk Institut,*

R. Bendsen, Duotec, D. Viereck Vestergaard, BlueKolding

Introduction:

Wastewater treatment plants currently account for 0.4% of the total greenhouse gas emissions in Denmark, with the potent greenhouse gas nitrous oxide (N2O) being the major contributor. There is significant political focus on limiting these emissions, including the introduction of emission limits. Currently, there is a very limited selection of measurement technologies available for measuring emissions from wastewater treatment plants. The most used approach involves measuring N2O in the water phase and estimating the actual emissions to the atmosphere based on a model. Direct measurement of nitrous oxide in the gas phase above the tanks at the wastewater treatment plant will provide a more accurate measurement of the actual nitrous oxide emissions. Thus, there is a need for the development of a cost-effective and low-maintenance system for this purpose. The objective was to develop a robust sensor solution for nitrous oxide that can continuously and with high temporal resolution directly measure in the gas phase above all liquid surfaces at a wastewater treatment plant. The system was calibrated and validated. Based on the collected data, functions were built to provide warnings of impending nitrous oxide generation and to support the management strategy aimed at reducing nitrous oxide emissions.

Methods:

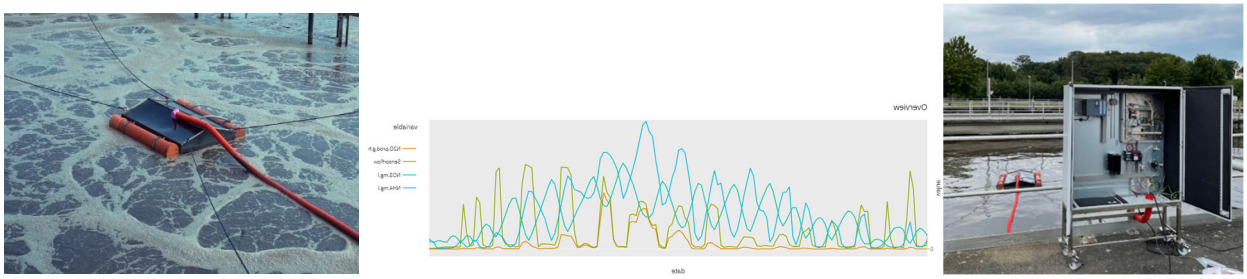
Based on experiences at EAWAG in Switzerland, a hood with an area of 1 m2 floating in the WWTP basin, was designed and constructed to capture and the released air (CO_2 and N_2O) from the basin and measure it with IR-sensors. The CO_2 signal is used for correction of the N2O signal. The commercially available N_2O and CO_2 sensors were calibrated in the laboratory, and the whole system was tested in a 6-month period on site at BlueKolding WWTP. The N_2O measurements were verified on site, as well as in the lab, with a cavity ringdown spectrometer. Additionally, the following parameters, among others, were measured in the basin: NH_4, NO_3 and NO_2.

Results:

The N2O sensor system was developed and tested successfully on-site. The signal stability has been ensured during the tested period and is expected to remain stable with maintenance twice a year. The N_2O signal from the sensor system showed excellent agreement with the cavity ringdown spectrometer. Based on the combination of the parameters N_2O, NH_4 and NO_3, a model was developed, providing input for the control strategy of the plant to minimize the formation of N_2O. The control strategy is currently being implemented and the results will be presented at the conference.

Discussion and take-home message:

The developed N_2O sensor system is suitable for accurate and prompt measurement of N_2O directly in the gas phase of a WWTP basin. The system is relatively affordable and can contribute to a better understanding of N_2O emissions from WWTPs.



Floating hood (left), raw data (middle), complete sensor system (right)

* thnq@teknologisk.dk: *Kongsvangs Allé 29, DK-8000 Aarhus*

Phosphorus release from rewetted organic soils varies strongly in dependence of the phosphorus sorption capacity

Adrian F. Florea*[1], *Goswin Heckrath*[2], *Dominik H. Zak*[2], *Maarit Mäenpää*[2], *Hans Christian B. Hansen*[1]

Rewetting of former drained agricultural lowland soils can reduce carbon dioxide emission but is followed by the risk of increased phosphorus (P) release to downstream systems, thereby challenging their restoration as nutrient and carbon sinks for years to decades. While extensive knowledge is available on P mobilization under anaerobic conditions caused by reductive iron(III)-oxide dissolution, the net P release (P_{sol}) to the aqueous phase is not well quantified due to unknown significance of P re-sorption to aluminum (Al) oxides and non-reduced iron (Fe)-oxides.

We hypothesize that P_{sol} is a function of the sorption capacity of Al oxides and non-reduced Fe oxides. A comprehensive set of 47 Danish top- and sub- lowland soil samples were incubated at room temperature in a batch soil incubation experiment.

Oxalate extractable Fe, Al, and P (Fe_{ox}, Al_{ox} and P_{ox}) varied greatly, with Fe_{ox} ranging between 1.8 and 1590 mmol kg^{-1}; Al_{ox} and P_{ox} also showed high variation but with max contents of 883 and 153 mmol kg^{-1}, respectively. Oxalate extraction data were used to calculate the degree of P saturation (DPS) and P sorption capacity (PSC).

The extent of Fe(III) reduction measured as 0.1 M HCl extractable iron(II)($Fe(II)_{HCl}$) was well described by first-order kinetics with rate constants ranging between 0.01 and 0.3 d^{-1}. The calculated maximum amount of Fe(II) formed, $Fe(II)_{max}$, ranged between 3 and 1490 mmol Fe(II) kg^{-1} and there was a significant correlation between $Fe(II)_{max}$ and Fe_{ox}, with Fe_{ox} corresponding to $Fe(II)_{max}$ values very closely.

For most soils almost full dissolution of the entire Fe_{ox} pool was achieved within 21 days of incubation at room temperature. While the P released could not be correlated with Fe:P ratios of the sediment, degree of P saturation (DPS) or other measures, the investigations revealed an exponential correlation between the residual sorption capacity (RSC) of the soils, i.e. P sorption capacity subtracted the sorption capacity of the Fe(III) oxides reduced, and the P_{Sol}/P_{ox} ratio, with 300 mmol kg^{-1} soil of the RSC as a critical threshold for elevated P release. According to our model, soils with a high sorption capacity should result in a low P release risk during anoxic Fe oxides reduction events, regardless of the DPS. In soils with average to low Al and Fe contents, P release risk could be assessed based on the Fe reduction degree of the soil. If the RSC is still high, between 100 – 300 mmol kg^{-1}, the risk of P release is moderate. Based on our model, a high Fe reduction during anoxic events, in soils with low Al and Fe content, will result in high P risk release, regardless the P content of the soils.

This finding suggests that Al oxides content of the soil is very important in predicting P risk release, and the residual sorption capacity of the soils could be considered in a new risk assessment tool for explaining the relationship between P mobilized from the Fe fraction and P released to solution.

[1] - Department of Plant and Environmental Science, Faculty of Science, University of Copenhagen, Thorvaldsensvej 40.

[2] - Institut of Ecoscience, Aarhus University, Bygning 1130-407, C. F. Møllers Allé 3, 8000 Aarhus C.

Valorising Wastewater: A Novel Approach for Critical Raw Materials Recovery from Acid Mine Drainage

Tamlyn S. Naidu*, KU-PLEN, C.M. Sheridan**, University of the Witwatersrand, P.E. Holm***, KU-PLEN

Introduction: Mining wastewater and Mining Influenced Water (MIW) represent formidable environmental challenges globally. Acidic mine drainage (AMD), in particular, has gained increased attention in recent years, following the 2015 Gold King Mine spill – leading to its classification by the United Nations as the second largest environmental issue worldwide. This AMD and MIW concern extends beyond mining regions, impacting global resource management due to its pervasive and enduring nature. Traditional AMD treatment methods, often chemical or energy-intensive like reverse osmosis, are neither economically nor environmentally sustainable. Moreover, the prevalence of AMD intensifies climate change-related issues, including soil degradation, biodiversity loss, and adverse socio-economic effects. However, recent studies have revealed a silver lining: many AMD streams contain substantial quantities of rare earth elements (REEs), battery elements, and other critical raw materials (CRMs) such as arsenic. These streams also exhibit other characteristics that can be harnessed for value extraction, like high acidity, rich iron content, and strategic geographic locations, often near other waste sources (proximity which presents opportunities for developing a circular economy by combining various waste streams). This paper/study delves into a segment of a broader AMD valorisation research, proposing an innovative approach to extract value from AMD, focusing on CRMs, particularly REEs. By integrating various treatment methodologies – ion exchange (IX) technology in particular for REE extraction – this approach redefines AMD from a costly waste liability to a valuable secondary resource. Such a paradigm shift not only mitigates the environmental impact of AMD but also significantly enhances global access to CRMs, addressing a crucial need in the face of depleting natural resources.

Methods and Data: This research focussed on the extraction of REEs from coal mine AMD in the Emalahleni region of South Africa (an area that has been plagued by both the social and environmental effects of MIW for decades). The research involved a detailed characterization of AMD to identify and quantify the presence of REEs. Ion-exchange (IX) technology was then evaluated as a method to extract these CRMs from the wastewater. The efficacy of different cationic and chelating resins, specifically chosen for their high affinity for trivalent cations, was assessed. Both batch and column studies were conducted to determine the effectiveness of these resins in extracting REEs from AMD. A thorough analysis of the adsorption capacities of different resins, an examination of adsorption isotherms and kinetics, and the assessment of desorption efficiencies was undertaken in this research.

Results: AMD samples revealed concentrations of REEs with a recovery value of nearly 1 Euro/m^3 of AMD. It was found that both chelating and cationic resins closely followed the Langmuir adsorption isotherm model for most REE species, with the chelating resin also aligning to the Temkin model for Yttrium and Lanthanum. This indicated a strong interaction between adsorbate and adsorbent for REEs in AMD. The cationic resin displayed a greater overall adsorption efficiency (80 – 95%) than the chelating resin (33 – 45%) for the range of REEs tested – in the case of Gd, adsorbing up to 5 times more than the chelating resin. In batch kinetics studies, both resins exhibited pseudo-second order behaviour, suggesting that chemisorption is the rate-limiting step in both these systems. Findings from the breakthrough studies suggest that the cationic resin saturated with iron much sooner than with REEs – signifying that iron has a prominent effect on the performance. Desorption experiments with varying concentrations of EDTA and sulfuric acid demonstrated varying efficiencies, with higher concentrations of these eluates generally yielding better desorption results. Desorption was not entirely successful, especially with lower EDTA concentrations, indicating the need for further investigation.

Discussion and Take-Home Message: This study underscores that AMD holds significant concentrations of valuable CRMs. IX technology proves effective for extracting these CRMs, with the research detailing the kinetic behaviour and efficiency of different IX systems. The presence of iron in AMD poses a challenge, affecting the efficiency of REE extraction and necessitating further research to enhance the process. Successful lab-scale results indicate potential for this method to address both wastewater treatment challenges and CRM recovery, promising transformative impacts if scaled effectively.

* *Tamlyn@plen.ku.dk: Thorvaldsensvej 40, 1871 Frederiksberg C*

** *craig.sheridan@wits.ac.za: 1 Jan Smuts Avenue, Braamfontein, 2000*

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

Tracking Surface water from Space using SWOT mission: Impacts on Indian Hydrology

Girish P*, Manu K Soman**, Nitish Kumar***, **Jayaluxmi Indu**** , Subhankar Karmakar*****

Abstract

The Surface Water and Ocean Topography (SWOT) mission shall provide unprecedented observations of river water elevation, width and slope. For regional and global analyses, the vector-based dataset made available from SWOT mission is expected to provide a comprehensive framework to understand river discharge dynamics. The hydraulic properties of dynamic rivers in India propagate at a faster rate than the temporal sampling of altimetry missions like SWOT. This work shall summarize the novel approaches to examine the potential of SWOT data for hydrodynamic modelling in case study regions of India. In particular, the preliminary results from three research hypothesis shall be presented: a). Impact of SWOT based discharges to facilitate calibration a hydrological model b). Examining the potential of data assimilation for reducing uncertainties in hydrodynamic modelling and c). Whether SWOT water levels can be used as a proxy for deteriorating lake volumes. Preliminary results of data assimilation framework are presented using CaMa-Flood model for the Mahanadi river basin, India. Assimilation was found to improve the accuracy of simulated water surface elevations.

*gp14@iitbbs.ac.in: Department of Civil Engineering, Indian Institute of Technology Bombay, Powai

** manuks.1250@gmail.com: Department of Civil Engineering, Indian Institute of Technology Bombay, Powai

***nitish1996.nk@gmail.com: Department of Civil Engineering, Indian Institute of Technology Bombay, Powai

**** indus.j@gmail.com: Department of Civil Engineering, Indian Institute of Technology Bombay, Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay, Powai

*****subhankar.karmakar@gmail.com Environmental Science and Engineering Department, Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay, Powai

Drinking water

Room	Title	From	To
AUD 1	Drinking water	15.30	17.30
	Chair: Hans-Jørgen Albrechtsen, DTU		

Speaker	Title of the presentation
Tabea Mumberg	Understanding the effects of artificial infiltration on DOC and PFAS in the Uppsala Esker using stable water isotopes (d18O and d2H)
Denitza Voutchkova	Mapping drinking water hardness in Denmark
Nicolaj Schmidt Damgaard	Rotor induced sand filtration – a novel sustainable technology for effective drinking water production
Sanin Musovic	ReGEN: On-site regeneration of pesticide-saturated activated carbon filters at Danish waterworks
Jan Benecke	Pilot-scale performance and benchmarking study of Aquaporin Inside® CLEAR series low energy BWRO membranes
Loreen Ople Villacorte	Boosting water efficiency of reverse osmosis (RO) for low brackish groundwater desalination
Wei Han	Non-revenue water (NWR) management in an innovative and digitalized way in water stressed Indian city, Pune

Understanding the effects of artificial infiltration on DOC and PFAS in the Uppsala Esker using stable water isotopes (d18O and d2H)

Tabea Mumberg*, *Frida Brännlund***, *Lutz Ahrens****, *Philipp Wanner**, *Philip McCleaf*****

Introduction

Stable oxygen and hydrogen water isotope ratios ($d^{18}O$ and $d^{2}H$) have been used successfully as a tool for tracking the movement of surface and groundwater and for determining the origin of groundwater abstracted long distances from its point of infiltration [1,2]. Groundwater in the Esker is the primary source of drinking water in Uppsala, Sweden. To meet approximately 50% of the City's water demand and to prevent overexploitation of the Esker's groundwater, it is enriched by artificial infiltration of surface water from the nearby Fyris River. However, Fyris River is subject to the effects of climate change with increasing levels of dissolved organic carbon (DOC) and is impacted by anthropogenic pollutants such as per- and polyfluoroalkyl substances (PFAS) with concentrations close or above the newly proposed Swedish drinking water guidelines (LIVSFS 2022:12) of 4 ng L^{-1} for the sum of four PFAS (PFOA, PFNA, PFHxS, PFOS). The aim of this study is to assess the effect of artificial infiltration on DOC and PFAS levels in the Esker's groundwater. To understand the transport of DOC and PFAS through the Esker, stable water isotope ratios are used to track the relative contribution of the artificially infiltrated water to the natural groundwater system. The results from this investigation are a critical component for planning Uppsala's future drinking water supply wherein an additional 10 million cubic meters of groundwater is required to meet the projected population increase from the today's 190 000 inhabitants to 300 000 inhabitants in 2050.

Methods and data

The Uppsala Water Company has completed a 11-year sampling and analysis campaign using stable oxygen and hydrogen water isotope ratios ($\delta^{18}O$ and $\delta^{2}H$) combined with DOC and PFAS measurements in surface- and groundwater as well as in soil cores to determine the dynamics of water recharge, movement, and quality in the Uppsala Esker [3]. In 2023, an additional three months of bi-weekly sampling with detailed analysis of PFAS and DOC composition as well as stable oxygen and hydrogen water isotope ratios was conducted.

Results and discussion

Results from over 500 $\delta^{18}O$ and $\delta^{2}H$ analyses indicate that water recharged at existing sites has a unique $\delta^{18}O$ and $\delta^{2}H$ "signature" allowing for tracking of the infiltrated water through the Esker. The infiltrated water mixes with and is diluted by the natural groundwater. Due to this interaction, varying water age and physio-chemical water quality as well as composition of PFAS and DOC are found down gradient from the infiltration site. While DOC concentrations are significantly decreasing during infiltration, PFAS concentrations stay constant or are slightly increased after infiltration. In addition, the PFAS composition changes to increased concentrations of the regulated longer-chained PFAS compounds PFOA, PFHxS, and PFOS. This can be a result from PFAS accumulation within the infiltration layer, breakdown of precursor compounds into persistent PFAS, remobilization, or contribution from an unknown PFAS source. Practical application of these results on future water resource planning includes the ability to explain PFAS and DOC levels for water extracted within Uppsala's existing artificial infiltration scheme and providing a tool for minimizing PFAS and DOC concentrations when planning for expansion of the system.

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Mapping drinking water hardness in Denmark

Denitza D. Voutchkova *[1], C.T. Thomsen [2], B. Hansen [3], L. Thorling [4], B. Pjetursson [5],*

Geological Survey of Denmark and Greenland (GEUS)

Introduction: There has been an increased societal interest in drinking water hardness in Denmark recently, especially due to (potential) changes in hardness caused by implementing softening technologies. The Geological Survey of Denmark and Greenland (GEUS) hosts a national map of drinking water hardness at the municipality level, on its online viewer (https://tinyurl.com/DWhardness). However, the map is outdated, as it is based on data from 2010. We will present the updated version of the map and will discuss some of the challenges in providing this societal service.

Methods and data: The new map is based on Ca and Mg analyses of treated drinking water of the public waterworks in Denmark. The data was downloaded from Jupiter database in Sep 2023; it was quality checked, obvious reporting errors were addressed, and outlier detection and removal were implemented. The hardness was calculated at the sample level based on the clean Ca and Mg data. The data was further aggregated to the waterworks level by using annual mean. At the national level, water supply areas (WSA) (Schullehner 2022) were used, instead of municipality polygons. For that, the latest complete annual data for the WSA was used. Weighted average was calculated based on the reported abstraction volumes to Jupiter database.

Results: Figure 1 shows the distribution of public waterworks by hardness class in time. The reporting prior to 1980s was sparce. Since 1980-1990, there is a gradual decrease in the number of waterworks supplying very hard and extremely hard drinking water. The updated national map of drinking water hardness at the WSA level will be presented for the first time during the talk. Further, we will present similar overview as Figure 1, but accounting for the volumes of drinking water in each hardness class (as opposed to number of waterworks).

Discussion and take-home message: Up-to-date nationwide drinking water hardness is needed, however there have been few challenges to providing this societal service. Some of them stem from the complexity of the de-centralised Danish drinking water supply and how to represent it spatially in the most optimal way; other challenges are due to delayed, incomplete, or wrong reporting to Jupiter database.

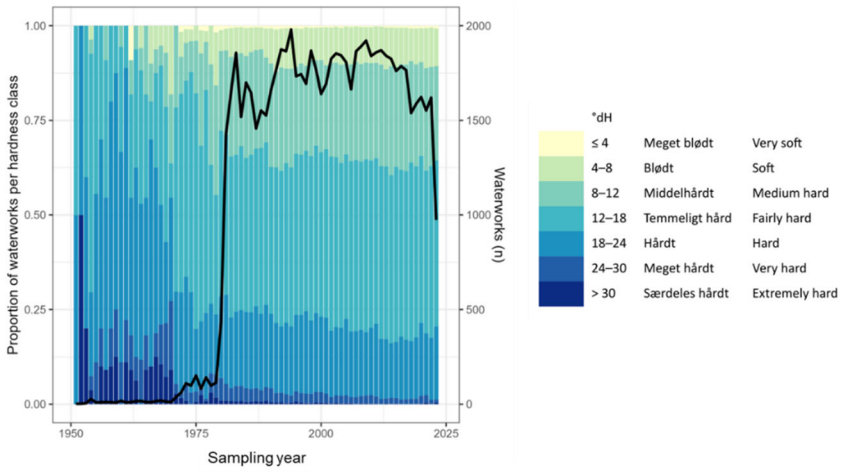


Figure 1 Annual data on drinking water hardness in Denmark; the coloured bars show the proportion of waterworks per hardness class at the annual level, the black line shows the number of waterworks with data for the specific year (right y-axis); the reporting for 2023 is incomplete, as the data-download was made in Sep 2023.

Schullehner (2022) Danish Water Supply Areas and their links to water production facilities: an open-access data set https://doi.org/10.34194/geusb.v49.8319

[1] dv@geus.dk ; [3] bgh@geus.dk; [4] lts@geus.dk ; Universitetsbyen 81, Building 1872, 6. floor, 8000 Aarhus C

[2] ctt@geus.dk ; [5] bpj@geus.dk ; Øster Voldgade 10, 1350 København K

Rotor induced sand filtration – a novel sustainable technology for effective drinking water production

Nicolaj Schmidt Damgaard**, J. Bruun Jensen and S. Musovic, Danish Technological Institute*, R. Vogelius, Hillerød Forsyning**, T. Vogn Kjeldsen, Vand og Teknik A/S, and S. Schiødte Schmidt and S. Schnedler Wengel, Verdo*****

Introduction. A widespread challenge when producing drinking water from groundwater is the precipitation of iron during the aeration process. Iron precipitation leads to the clogging of sand filters and the traditional method to remove the layer of iron precipitates is to use backflushing. However, this technique requires a considerable amount of water estimated between 1-4% of the total drinking water production which is consequently lost. The regular backflushing also negatively impacts the amount of microbes in the sand filters, which in turn negatively impacts the removal of ammonium, pesticides etc. The project aims to develop and test a novel technology to solve this problem at the top of the sand filters without impacting the lower part of the filters and at the same time reducing the water and energy lost through backflushing. Data presented at Annual Meeting of DWF 2023 revealed that a motor driven rotor solution could effectively lift the iron precipitates without affecting the microbes in the sand filter. Since then, pilot scale studies have been completed at waterworks in Randers and Hillerød, using open columns. Semi-full scale is now under development where the effect of pressure will be tested.

Methods and data. Pilot scale setups were constructed and set up first at a Hillerød waterwork and later at a Verdo waterwork. The design of the pilot scale setups was similar to laboratory scale, albeit with larger columns and a stronger commercially available motor driven rotor. Most importantly, the pilot scale set-up tested raw groundwater, to make it as authentic as possible. Raw groundwater was pumped into the columns and iron precipitate was allowed to settle on the sand filter. The setup consisted of three columns, which were subject to either 1) backflushing every 2.5 weeks, 2) rotor run every 3-4 days and backflushing every 2.5 weeks, 3) rotor run every 3-4 days. Column no. 3 was not included at Verdo as the column was damaged during disassembly and transport.

We measured the ammonium- and iron concentrations in the water and microbial DNA in the sand both before and after the rotor run/backflushing. Turbidity was measured at different points and times; after the filter column (1h before and 1h after the rotor run/backflushing) and in the water on top of the filter column (1 h before and during the rotor run/backflushing). The turbidity measurements in water on top of the filter column combined with visual evaluation were used to compare and monitor differences between rotor and backflushing as an indicator to evaluate their capability/efficiency to lift the iron sludge into the water phase, where it was drained out the column above the filter.

Results. Turbidity measurements showed that both rotor and backflushing can efficiently lift the sand filters top layer where iron sludge is deposited without compromising turbidity at the outlet of the filter 1h after. This was also confirmed with the iron concentration in the drain-water from the rotor runs/backflushing. Furthermore, the difference between rotor and backflushing efficiency was negligible looking at both the iron concentration and turbidity. No immediate change in ammonium concentration was observed after the rotor run regardless of rotor type. Total bacteria amount was not reduced over time with either rotor or backflushing.

Discussion and take-home message. Results indicate that rotor both alone and in combination with backflushing have the capability to lift the iron sludge off the sandfilter and reduce traditional backflushing frequency and water consumption. Impacts of the rotor technology on the sand filter and microbial communities were similar for both concepts tested. However, results will need to be further investigated and confirmed in a semi-full scale level pressurized column under conditions closer to later on real-life application of the technology.

** nscd@teknologisk.dk; juje@teknologisk.dk; smu@teknologisk: Kongsvang Allé 29, 8000 Aarhus C, Denmark ** revo@hfors.dk: Solrødgårds Alle 6, 3400 Hillerød, Denmark *** tvk@vandogteknik.dk: Rosbjergvej 26, 8220 Brabrand, Denmark****sssc@verdo.com; stwe@Verdo.com: Agerskellet 7, 8920 Randers NV, Denmark*

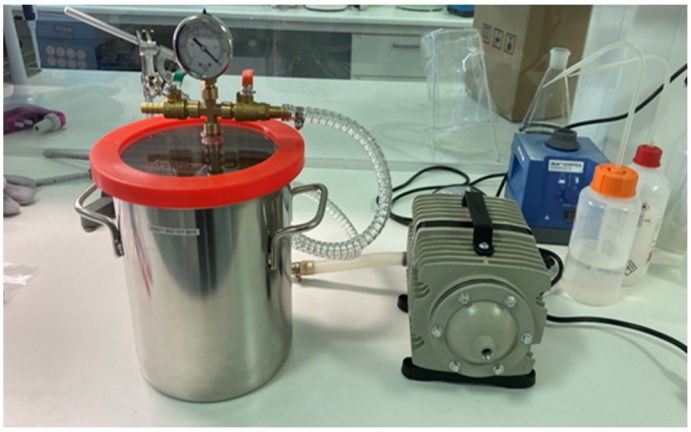
ReGEN: On-site regeneration of pesticide-saturated activated carbon filters at Danish waterworks

Sanin Musovic**, N. S. Damgaard and R. D. Harpøth, Danish Technological Institute*; D. A. Søborg, VIA University College**; T. V. Kjeldsen, Vand & Teknik A/S*

An increasing occurrence of pesticide residues in groundwaters in EU and around the world over the last few decades, is challenging. Groundwater is a primary source for drinking water production in Denmark, and the current findings of pesticides residues in groundwater challenge the future supply of safe drinking water to consumers. An increasing number of waterworks are in a direct need to apply an advanced water treatment, where the most applied action at waterworks is filtration thru an activated carbon (AC) filter.
N,N- dimethylsulfamide (DMS) is a pesticide residue frequently found in the groundwater (33% of Danish water supply wells, GEUS 2021). Unfortunately, DMS is also a pesticide residue that saturates AC-filters extremely fast and imposes frequent annual replacements of AC in filters. To be reused, DMS-saturated activated carbon needs first to be transported thousands of kilometers away for the regeneration process at specialized establishments. Routinely, during the regeneration process, the activated carbon of different origins and types get mixed together. Therefore, the majority of waterworks prefer to apply newly produced activated carbon upon each replacement of saturated activated carbon in filters. The frequent replacements are therefore very costly for the water utilities, along with the fact that one-time-use of AC is not an environmental sustainability practice.

The aim of the project is to identify and verify sustainable chemical processes for an on-site regeneration of DMS-saturated activated carbon at the waterworks. Once the most suitable processes have been determined, these will be applied in development of a stationary ReGEN technology in a form of specialized AC-pressurized filter, and in the form of "a mobile ReGEN technology", aiming to ensure that waterworks with different types of AC-filters can gain advantage of the ReGEN-technology in the future.

A range of chemical treatments were tested on DMS-saturated activated carbon from two Danish water utilities, with pressurized AC-filters containing AquaSorb. These also included combination of different solvents (e.g. ethanol, acidic or basic solutions, hydrogen peroxide, heat, vacuum, microwaves, etc.). At the lab scale level, using DMS-saturated activated carbon from waterworks, the project partners could successfully evaporate DMS from saturated activated carbon- and via distillation processes they could collect DMS in the water phase. Furthermore, a novel method applying simple dyes for a quick indication of AC-saturation level was investigated.
In these months the observations are about to be verified via pilot scale trials and under on-site conditions.



** smu@teknologisk.dk, rdh@teknologisk.dk, nscd@teknologisk.dk; Kongsvangs Allé 29, DK-8000 Aarhus C, Denmark*
*** dans@via.dk; Banegårdsgade 2, DK-8700 Horsens, Denmark*
**** tvk@vandogteknik.dk: Rosbjergvej 26, DK-8220 Brabrand, Denmark*

Pilot-scale performance and benchmarking study of Aquaporin Inside® CLEAR series low energy BWRO membranes

K.H. Le, J. Vogel**, **Jan Benecke**, Aquaporin A/S, Denmark, X.T. Nguyen, W. Wang, W.H. Ho, G. Sun, X. H. Lim, Aquaporin Asia. Pte Ltd, Singapore, L. Tai, N. Peng, PUB, Singapore*

Introduction: Reverse Osmosis (RO) processes have become the dominant technology in the desalination industry and wastewater treatment. RO developments in membrane technology have resulted in a variety of advancements, including lower pressure requirements, as energy makes up the largest component of the operation and maintenance cost at 44% of the total. We developed the Aquaporin Inside® CLEAR series which consists of low-energy / high-flux industrial brackish water (BW) RO elements made by incorporation of aquaporin proteins into the selective RO membrane layer. The incorporation of aquaporin proteins aims at increasing water production per operational energy input and at maintaining or improving the quality of produced water. In this project, we aim to (I) proof stable performance of the Aquaporin Inside® CLEAR series in a pilot system during three months of operation, (II) achieve target water quality according to WHO and NEWater standards (PUB – Singapore's National Water Agency), and (III) demonstrate 20% energy reduction against commercially available BWRO membrane products.

Methods and data: Aquaporin Inside® CLEAR series membranes were fabricated by optimized polyamide interfacial polymerization with proprietary Aquaporin Inside® formulation, on polysulfone substrate and polyesther mesh. For pilot-scale investigations, membrane flat-sheets were rolled into spiral wound 4040 elements. Commercial competitor products were acquired through local distributors. Pilot-scale benchmarking was conducted using a 2-staged (2x7 + 1x7 array) system operated with MBR permeate as feed, at 75% recovery and 3 m3/h permeation. Operated membranes include Aquaporin Inside® CLEAR Plus 4040XL (CLEAR), Aquaporin Inside® LE prototype (PTYP), commercial fouling-resistant membrane (M1), and commercial low energy membrane (M2).

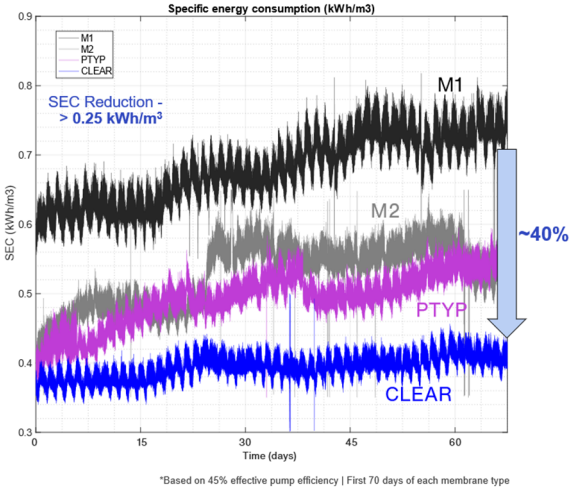


Figure 2: Specific energy consumption (kWh/m3) for all four operated membranes CLEAR, PTYP, M1 and M2 during the first 70 days of operation.

Results: CLEAR average permeate conductivity was 23.6 µS/cm. Although it is marginally higher than M1 (19.6 µS/cm) and M2 (17.8 µS/cm), it is well within the targeted permeate quality of 100 µS/cm as dictated by the NEWater guidelines by PUB, and well below the limits of 250 µS/cm. Additionally, other important NEWater parameter limits like TOC (<0.5 mg/L), chloride (<20 mg/L), ammonia (<1.0 mg/L), TDS (<150 mg/L), silica (<3 mg/L), or nitrate (<5 mg/L), are all met by all membranes.

Further, CLEAR was able to operate at significantly lower feed pressure of 4.9 bar compared to the 8.3 bar and 6.5 bar of commercial BWRO membranes M1 and M2. The increased water permeability of CLEAR and resulting reduction of hydraulic pressure leads to a reduced specific energy consumption (SEC) of the pilot system when operating CLEAR (0.4 kWh/m3) compared to the commercial membranes M1 and M1, as depicted in Figure 1. CLEAR also exhibits the most stable operation with minimal SEC increase within the observed timeframe, whereas M1 and M2 show a distinct rise in SEC to maintain the constant production of 3 m3/h permeate. This could indicate superior resistance of CLEAR towards the feed, leading to a specific energy reduction of up 40% compared to M1.

Discussion and take-home message: The Aquaporin Inside® CLEAR series showed (I) stable performance in pilot system during three months of operation running with MBR permeate as feed, (II) while fulfilling target permeate water quality according to WHO and NEWater standards, and (III) demonstrated 20-40% compared to other commercial BWRO membranes.

* khl@aquaporin.com: Nymøllevej 78, 2800 Kongens Lyngby

** jvo@aquaporin.com: Nymøllevej 78, 2800 Kongens Lyngby

Boosting water efficiency of reverse osmosis (RO) for low brackish groundwater desalination

Loreen O. Villacorte*, *Sebastien D'Antonio**, *D.M. Dominiak**, *V.A. Yangali-Quintanilla**

Background: Water desalination using reverse osmosis (RO) is currently one of the leading technologies to address clean water supply demand issues in industries and the utility sector. RO can remove most unwanted contaminants from surface or ground water including bacteria, viruses, salts and persistent micropollutants (e.g., PFAS). However, there are some downsides of applying RO such as high energy consumption and the discharge of process wastewater (brine) which can be harmful to the environment. Most RO systems discharge at least 25% of the water they treat as waste brine. Further reducing this brine discharge flow by increasing water recovery is highly limited by RO scaling and fouling issues, which often results in unwanted downtime and costly chemical cleanings.

Method: Increasing the water recovery of a brackish RO to 90% from a conventional 75% recovery will decrease the brine discharge volume by 60% and feed water consumption by 15%. Such reductions can be attained by designing and operating the RO plant in batch or semi-batch configuration instead of the standard continuous configuration. Both techniques require operating the RO in short cycles of filtration with full concentrate recycling and flushing/purging/draining, whereby the salinity of the feed stream is up-concentrated within the filtration cycle. The short periods of variable salinity and flushing can minimize the development of scaling and (bio)fouling. It can also reduce the specific energy consumption, thereby allowing the RO unit to substantially increase water recovery without compromising on operational cost. We have developed an alternative solution to boost RO water efficiency by installing a smart brine controller to upgrade a standard RO system to operate at semi-continuous mode while delivering comparable performance as a semi-batch RO. For this, we replaced the brine regulating valve with a brine manifold skid which is a compact add-on unit comprising digital pumps, valves, sensors, pipes, and a controller. The skid enables up-concentration of brine to a certain salt concentration threshold and then followed by short rapid flushing to purge brine and hydraulically clean the RO membrane. The filtration cycle and flushing are controlled autonomously by a control algorithm to maximize net water recovery (volume of clean water produced/volume of feedwater used) of the RO unit. The smart brine controller skid can be configured as a direct fully integrated unit for new projects or retrofitted to existing RO installations.

Preliminary findings: To validate the smart brine controller (SBC) concept, we have retrofitted a standard pilot RO unit (Figure 1) and a small-scale commercial RO unit (1 m3/h) desalinating a low brackish groundwater in Denmark. Preliminary results show that precisely controlling the filtration cycle and flushing time using the SBC allows stable operation (low scaling/fouling) of the RO system up to 90% water recovery with antiscalant or up to 85% with softener. This is equivalent to 47-67% reduction of brine waste discharge and 11-17% reduction of water consumption relative to the 75% water recovery of a standard RO. Performance comparison of SBC with a commercial high recovery RO (with concentrate recycling), showed 1.6 to 4 times longer stable runtime for SBC. Silica and calcium concentrations in the feedwater are the main limiting factors for maximising water recovery.

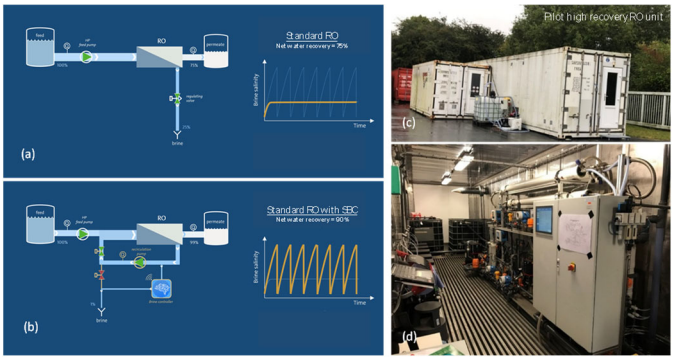


Figure 1. Illustration of (a) steady state operation with conventional RO, (b) brine salinity cycling during operation of RO with smart brine controller and (c-d) containerized pilot RO unit for validating concept for groundwater desalination.

* *Grundfos Holding A/S, Poul Due Jensens Vej 7, 8850 Bjerringbro. Contact email: lvillacorte@grundfos.com.*

Non-revenue water (NWR) management in an innovative and digitalized way in water stressed Indian city, Pune

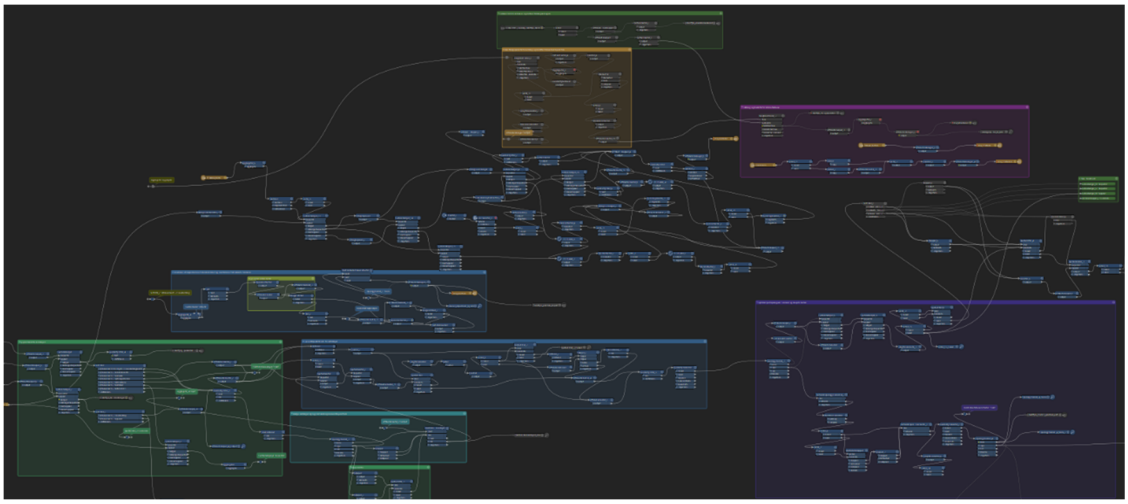
Wei Han**, Ramboll Water*, C. Stagne, Ramboll Water

Introduction: Many Indian cities are facing water scarcity problems. In the selected DMA in northern part of Pune, the max. daily NRW reached 56% according to simple comparison of the inlet to the DMA and total drive-by flow data at all of the consumers. It was believed the 56% NRW was pure physical water loss. However, should the 56% NRW be unthinkingly concluded physical loss, and calculated in percentage on daily basis with the condition of inconsecutive water supply, uncontrolled number of water meters for each single consumer, as well as the structure in combination of large underground water reservoir and roof tank? Secondly, what does raw flow and pressure data mean for the next step – leakage detection in sub-DMA? Are we going to use the raw drive-by data directly for further calculation or analysis, or even conclusion? The answer is negative – these data need a thorough screening and treatment before taking any step forward.

Methods and data: The raw pressure and flow data have both been analysed before being applied in water balance calculations, especially the latter. The comparison of inlet and total flow at the consumers was carried out in Python and visualized in the subsequently created dashboard. The analysis of raw flow data was executed by using FME and Excel. The flow data has been screened in layers in order to calculate the most actual result. The screening has taken many aspects into account, and these considerations have been materialized by using the tools mentioned above. These aspects include 1) are all water meters in the area listed in the data sheet? 2) How to group the water meters, and thus calculate corresponding total flow for each single consumer? 3) The meters showing ”nil”, “0”, or even negative values – how are we going to handle them? 4) Is there any meter permanently closed as they are grouped with other meters for a single property? 5) 6) 7)….etc. All of the data treatment processes are combined with onsite survey. The project is not finalized by now, but the next step would be combining the dashboard, raw data and data treatment and thus the dashboard will be more dynamic and effectively used with fresh data onwards.

Results: At this moment, it can be already concluded the data inaccuracy takes up a significant percentage in NRW. The faulty readings have been largely identified, and the work continues. The data analysis brought a more realistic composition of the real loss in water balance calculation for continuing the project with onsite leakage detection. In addition, the digitalized way of treating data will bring new thinking to a new, dynamic and flexible way with data application.

Discussion and take-home message: Raw data treatment is essential for water balance analysis in overall NRW reduction. This part has been proved to be digitalised and can be applied in other metropolises with massive raw data and high NRW percentage. The treatment process remains to be completed and applied adaptable for different data qualities.



* weih@ramboll.dk: *Hannemanns Allé 53, 2300 København S, Denmark*

** crln@ramboll.dk: *Hannemanns Allé 53, 2300 København S, Denmark*

Groundwater

Room	Title	From	To
ROOM 2	Groundwater	15.30	17.00
	Chair: Ida Holm Olesen, Chief specialist, Novafos Utility		

Speakers	Title of the presentation
Enrico Pizzi	Building a Synergistic Vision for Multi-Objective control of WRRFs through Stakeholder Engagement
Case van Genuchten	Life cycle assessment of disposal strategies for arsenic-rich groundwater treatment sludge
Ka Wang	Molecular-scale characterization of groundwater treatment sludge from around the world: Implications for potential arsenic recovery
Caroline Kragelund Rickers	Treatment of water from two generational pollution sites utilizing the treatment train concept
Jinxin Zhao	Efficient trichloroethylene elimination by granular nitrogen-doped biochar supported zero-valent iron
Andreas K.-Rasmussen	Screening IoT sensing approaches to support real-time groundwater quality monitoring

Building a Synergistic Vision for Multi-Objective control of WRRFs through Stakeholder Engagement

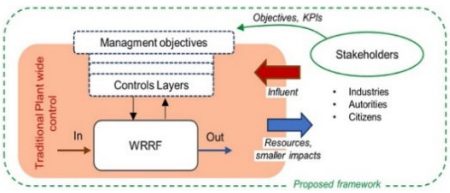
Enrico Pizzi*,**,C.F. Fratini**, A. D. Mishra*, P. Ingildsen*, P. S. Mikkelsen**, B. Valverde Pérez**, L. Vezzaro**.*

Introduction: The pursuit of improved eco-efficiency in operation of Water Resources Recovery Facilities (WRRFs) is an absolute priority in modern environmental management. The opportunities created by advanced data collection systems, combining online sensors and cloud storage solutions, integrated with Digital Twins (Therrien et al., 2020), pave the way for plant-wide controls. These represent a precious tool to improve plant performance with limited infrastructure investments, promoting environmental sustainability and economic benefits in dynamic ecosystems (Regmi et al., 2019). In the development of plant wide control, the first layer in the control hierarchy (Larsson and Skogestad, 2000) implies the definition of the (multiple) control objective(s). This step is often overlooked, potentially leading to neglecting processes that can play a significant role in improving the WRRF eco-efficiency and thus creating an unbalanced model. This study introduces a comprehensive framework that encompasses stakeholders such as industries, public authorities, and environmental regulators outside the Hillerød WRRF (Danmark) is presented. The framework involves identifying influential factors conducting stakeholder interviews, co-creation of Key Performance Indicators, assessing environmental challenges and regulatory pathways, and anticipating future challenges (e.g. increasing inlet loads, demand for lower emissions), while considering economic and energy implications. These external stakeholders contribute to the definition of multiple objectives (quantified through Key Performance Indicators). **Methods and data**: This study presents a comprehensive framework for identifying influential factors for establishing an effective control strategy in WRRFs. The framework is illustrated through a practical case study of the Hillerød Forsyning WRRF in Denmark. The proposed method employs structured interviews with key stakeholders directly engaged with the plant, including internal staff, major industries discharging into the facility, the local municipality, and the community. The questions were tailored and selected based on the stakeholders' specific roles to ensure better alignment with the contextual requirements. The analysis subsequently considers the bottleneck involved in the implementation of the control strategies, focusing on the economic and energy implications of the different scenarios. Additionally, an examination of the environmental status and relevant regulations was explored, incorporating valuable perspectives from internal biologists directly engaged in the management of outflow basins. The discussions with industrial representatives primarily focused on key performance indicators (KPIs) related to their discharges and sustainability practices, the possibility of adjusting their processes to meet treatment requirements, potential benefits achievable through a cooperative relationship with the plant (e.g., clean water, heat, energy), strategies for managing and potentially sharing output data with utility providers and local communities, as well as projections for future growth and anticipated requirements. Lastly, data was gathered from the municipality of Hillerød and the local community, with a focus on citizen well-being, upcoming legislative changes, the community's perception of the WRRF, and potential actions and initiatives to enhance the integration of the plant within the community. **Results**: Results are shown in the Tab 1:

Table 1. Overview of the involved stakeholders, their primary interests, potential for data sharing, potential benefits from interacting with WRRF.

Stakeholder	**Primary Interest**	**Benefit**	**Activities**	**Data**	**KPI**
Major Industries	Taxes, ESG policy, Energy.	Public opinion, Clean water	Neutralization strategy, control system for their discharge, Storage during rainfall, Integrated sewers.	Confidentiality	Ph, P, $N_{tot,}$ E, Chemicals
Citizen	Environmental status	Taxes reduction	Awareness activities with data sharing	x	COD, P, N_{tot}
Authorities and Municipality of Hillerød	Limits	Anticipate obligations	Detection of environmental priority.	Possibility of an integrated data system to share	Q, COD, P, N_{tot}, E,

Figure 1. Schematic representation of the proposed framework



**HFORS enpi@hfors.dk, epiz@dtu.dk **DTU 2800 Lyngby luve@dtu.dk*

Life cycle assessment of disposal strategies for arsenic-rich groundwater treatment sludge

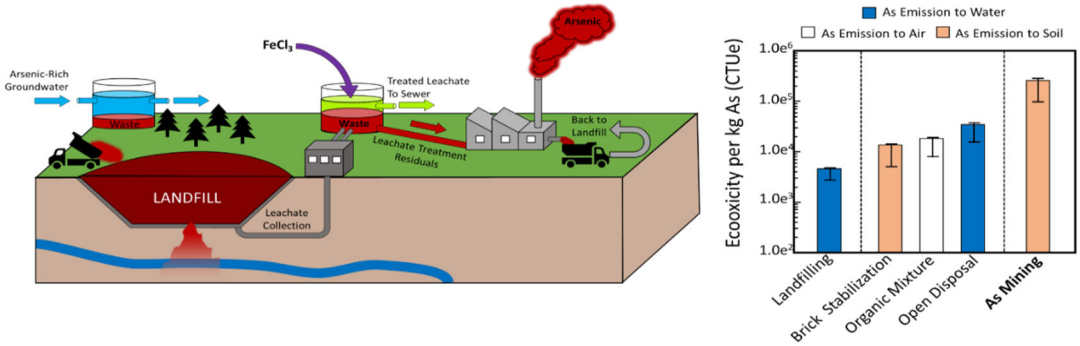
***Case M. van Genuchten**, GEUS**

Introduction: Hundreds of millions of people are exposed to naturally occurring arsenic (As) in groundwater at levels above the World Health Organization recommended limit of 10 μg/L, with the large majority living in South Asia. To decrease the negative health effects of carcinogenic As, groundwater treatment based on As sorption to iron (oxyhydr)oxides is widely practiced in both high- and low-income regions. Although Fe-based treatment methods can improve access to safe drinking water, these methods generate toxic As-rich Fe oxide water treatment sludge that must be disposed of as part of the operational process of the water treatment technology. Research to determine the most effective and environmentally sound option of the many practiced As-rich sludge disposal strategies is critical to lessen the human health and environmental impacts from this carcinogenic waste.

Methods and data: In this work, life cycle assessment (LCA) following the ISO 14040 series is applied to compare the toxicity impacts of four common As-rich sludge disposal strategies that have different infrastructure requirements and waste control: (i) landfilling, (ii) brick stabilization, (iii) mixture with organic waste, and (iv) open disposal. The As toxicity impacts from disposal (functional unit = 1.0 kg As) are compared and benchmarked against impacts of current methods to produce marketable As compounds via As mining and concentrate processing. The analysis compares the impacts of As-rich sludge disposal strategies across many midpoints (e.g., toxicity, global warming potential, and smog), but primary focus is given to human toxicity and ecotoxicity impacts.

Results: The LCA indicated that landfilling had the lowest non-carcinogen toxicity (2.0×10^{-3} CTUh), carcinogen toxicity (3.8×10^{-5} CTUh), and ecotoxicity (4.6×10^{3} CTUe) impacts of the four disposal strategies, with the largest toxicity source being As emission via sewer discharge of treated landfill leachate. Although landfilling had the lowest toxicity impacts, the stored toxicity of this strategy was substantial (ratio of stored toxicity/emitted As = 13), suggesting that landfill disposal simply converts direct As emissions to an impending As toxicity problem for future generations. The remaining disposal strategies, which are frequently practiced in low-income rural As-affected areas, performed poorly. These strategies yielded ~3–10 times greater human toxicity and ecotoxicity impacts than landfilling. However, by far the largest toxicity impacts were generated from As mining (functional unit = 1.0 kg As contained in As-bearing products).

Discussion and take-home message: Although the LCA results indicated that landfill disposal outperformed the other practices, all disposal options have disadvantages. One of the major shortcomings of landfilling is the conversion of deposited As to stored toxicity. In other words, even if the waste in a landfill is fully controlled, As is merely converted to a toxic waste management problem for future generations, which is a particular concern given repeated accounts of catastrophic landfill failures. Despite the disadvantages of landfill disposal, the LCA indicated far greater toxicity impacts from brick stabilization, organic mixture and open disposal. Unfortunately, the geographic areas with the highest levels of naturally occurring As in groundwater, and thus with the largest populations at risk of As poisoning (i.e., Bangladesh and India), also tend to be regions that rely on these other disposal strategies. Taken together, the LCA results highlight the urgent need for new methods to recover As from sludge and convert it into valuable As compounds, which would simultaneously decrease the stored As toxicity and As emissions from both sludge disposal and from mining As ore to produce As compounds.



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

Molecular-scale characterization of groundwater treatment sludge from around the world: Implications for potential arsenic recovery

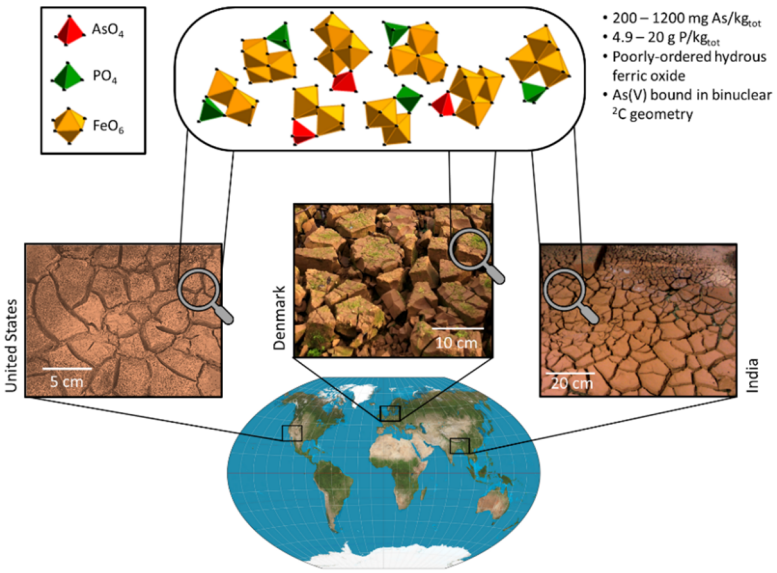
Ka Wang**, GEUS*, P.E. Holm, KU-PLEN**, U. Brinkmann Trettenes, VandCenter Syd, C.M. van Genuchten, GEUS*****

Introduction: Iron (Fe)-based treatment methods are widely applied to remove carcinogenic arsenic (As) from drinking water, but generate toxic As-laden Fe (oxyhydr)oxide waste that has traditionally been ignored for resource recovery by the water sector. However, the European Commission recently classified As as a Critical Raw Material (CRM), thus providing new incentives to re-think As-laden groundwater treatment sludge. Before As recovery techniques can be developed for groundwater treatment waste, detailed information on its structure and composition is essential.

Methods and data: A suite of characterization data were collected for As-rich sludge generated from a variety groundwater treatment plants in different geographic regions. The data set includes a combination of macroscopic measurements (e.g., total element composition from acid digestions, leaching tests, BET surface area) and molecular-scale solid-phase analysis by Fe and As K-edge X-ray absorption spectroscopy (XAS).

Results: We found that the As mass fraction of all samples ranged from ~200–1200 mg As/kg (dry weight) and the phosphorous (P) content reached ~0.5–2 mass%. Notably, our results indicated that the influent As level was a poor predictor of the As sludge content, with the highest As mass fractions (940–1200 mg As/kg) measured in sludge generated from treating low groundwater As levels (1.1–22 µg/L). The Fe K-edge XAS data revealed that all samples consisted of nanoscale Fe(III) precipitates with less structural order than ferrihydrite, which is consistent with their high BET surface area (up to >250 m^2/g) and large As and P mass fractions. The As K-edge XAS data indicated As was present in all samples predominantly as As(V) bound to Fe (III) precipitates in the binuclear-corner sharing (^2C) geometry. These molecular-scale characterization data indicate that the sludge generated from Fe-based As removal had similar As and Fe speciation regardless of the wide variety of treatment processes and As levels in the raw water.

Discussion and take-home message: Our results suggest that sludge generated from Fe-based As treatment can be a candidate for As recovery, which will help create local sources of CRMs, in agreement with the Critical Raw Materials Act. While not currently practiced, advanced As recovery from As treatment sludge can provide several key benefits. **First**, As-rich waste disposal via landfilling (high-income areas), sewer discharge, or open disposal to soils and surface water (low-income areas) leads to unacceptable toxicity impacts from As emissions. **Second**, the disposal of this waste leads to the loss of As and other CRMs, especially the eutrophying-nutrient P, which was present in the sludge at levels up to 2 mass%. **Third**, current methods to produce As compounds, which are based on mining and concentrate processing of As mineral ore, are notoriously damaging to the environment, with large fractions of excavated As emitted to soils nearby mining processing. Therefore, new methods to convert As-rich treatment sludge into valuable As compounds would simultaneously decrease the environmental impacts of current sludge disposal methods, while creating local sources of CRMs, which would also lessen the reliance on environmentally degrading mining practices.



*kawan@geus.dk: Oester Voldgade 10, 1350 Copenhagen-K, DK
** peho@plen.ku.dk: Thorvaldsensvej 40, 1871 Frederiksberg C, DK
*** ubt@vandcenter.dk: Vandværksvej 7, 5000 Odense, DK
****cvg@geus.dk: Oester Voldgade 10, 1350 Copenhagen-K, DK

Treatment of water from two generational pollution sites utilizing the treatment train concept

*N.S. Damgaard, **Caroline Kragelund**, Danish Technological Institute*; T.C. Svendsen, ECT2.com**; H. G. Andersen, FMC ***K. Tang, R.K. Chhetri, H.R. Andersen, DTU Sustain*****

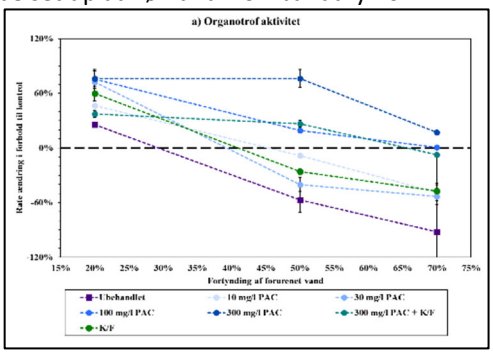
This project is partly funded by the Environmental Technology Development and Demonstration Program (MUDP).

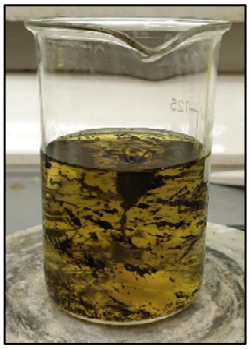
Introduction: In Denmark, numerous sites and sources of water pollution have been identified. Among the most conspicuous are 10 old industry sites identified as 'generational pollutions'. The complex and extensive pollution at these sites will remain a problem for generations as the pollutions are complex or extraordinarily persistent and recalcitrant. However, this is no easy task, as these specific pollutions are also characterized by a substantial monetary cost to examine and remediate (min. estimates amounts to 6.7 Mio. €). This study aimed to evaluate treatment options for polluted groundwater from two industrial sites located in Denmark. Site 1 was used for pesticide production since the 1950s and Rønland is the adjacent active modern plant, resulting in soil pollution that require the groundwater to be pumped up to prevent spreading the pollution to the environment. The main pollutants are the reactant for parathion production, 4-nitrophenol, and the solvent isopropanol. Specifically, for Rønland, the polluted groundwater also constitutes almost 50% of the WWTP load which can potentially impact production of new more modern pesticides.

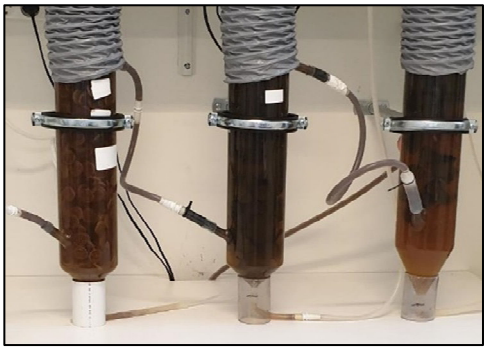
Methods and data: Polluted water from two sites, Site 1 and Rønland, were collected, and the extent of microbial inhibition was determined with oxygen uptake rate experiments. These were supplemented by measurements of chemical oxygen demand, ammonium, nitrite, and nitrate, to quantify the microbial nitrification- and organotrophic-activity. Experiments were completed to examine the effect of activated carbon and coagulation/flocculation as a pre-treatment step prior to biological treatment. The potential for microbial treatment was examined in moving bed biofilm reactors (MBBRs), where the microbes were subjected to both untreated water from the two sites and water pre-treated by activated carbon and coagulation/flocculation.

Results: Chemical- and oxygen uptake measurements revealed differing degrees of microbial inhibition in the water from the two sites. No inhibition was detected in water from Site 1, while complete inhibition was measured in water from Rønland at 70% concentration. Pre-treatment experiments revealed a huge potential to treat the water from Rønland with activated carbon, as it significantly lowered inhibition caused by the water, thereby enabling biological treatment as subsequent treatment.
Measurements of chemical oxygen demand in the MBBRs revealed active and stable reduction of organic material (potentially pollutants), while both ammonium reduction and accumulation of nitrite and nitrate revealed active and stable nitrification.

Discussion and take-home message: Microbial treatment of wastewater is often cheaper than other physical or chemical solutions, but as it has been shown in this project, microbial communities are susceptible to inhibition. However, combinations of pretreatments can enable efficient microbial degradation of problematic wastewater as documented in the present project. The next step is pilotscale experiments to test the treatment combinations, which will be set up at Rønland from January 2024.







* nscd@teknologisk.dk: *Kongsvang Alle 29, 8000 Aarhus C*
** ts@vandrensning.com: *Kildemarksvej 3, 4200 Slagelse*
*** hran@dtu.dk: *Bygningstorvet, Bygning 115, 2800 Kgs. Lyngby*

Efficient trichloroethylene elimination by granular nitrogen-doped biochar supported zero-valent iron

Jinxin Zhao*, *Dominique J. Tobler, Weizhao Yin, Hans Chr. Bruun Hansen*

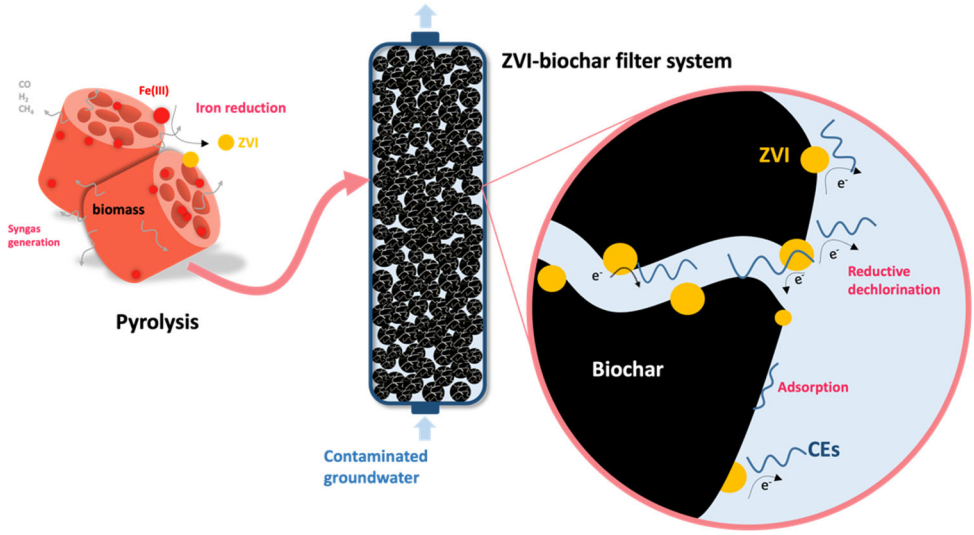
Abstract: In this study, granular nitrogen doped biochar supported zero-valent iron (ZVI) was prepared by high temperature pyrolysis and used for trichloroethylene (TCE) removal through reductive dehalogenation. ZVI formation was successfully obtained by a one-step pyrolysis of iron-impregnated carbon-rich materials under inert atmosphere. The reactivity of ZVI@CC was significantly improved by nitrogen doping, with the most promising granular material enabling a TCE dechlorination capacity of 81.3 mg TCE/g Fe in 48 h. In the dechlorination process, TCE was reduced to mainly acetylene. Efficient TCE elimination performance remained also under high initial TCE concentrations up to 600 uM with a pseudo-first-order rate constant of 0.156 h^{-1} while the pseudo-first-order constant was 0.319 h^{-1} at an initial concentration of 100 uM. This work provides a formula for fabrication of low-cost granular biochar supported ZVI, allowing for design of filters for chlorinated ethylene dechlorination.

Introduction: ZVI is a reductant material which can be employed for remediation of soil and groundwater contaminated with chlorinated ethylenes. Biochar is a porous carbonaceous material with large specific surface area and abundant surface functional groups that is produced by pyrolysis of biomass under oxygen-free conditions. Numerous studies have demonstrated that CE dechlorination rates by biochar supported ZVI materials are considerable higher compared with ZVI or biochar alone. One-step pyrolysis is considered as an environmentally friendly and economic method for biochar supported ZVI materials production compared to traditional formation of nano-ZVI via borohydride reduction. The objective of this study is to develop biochar supported ZVI filter materials with great stability and excellent reductive dechlorinated capacity that could for example be used in filter system but also be used for permeable reactive walls.

Methods and data: Granular biochar supported ZVI was prepared by high temperature pyrolysis of iron-impregnated charcoal. XRD and SEM-EDX were applied for characterization of biochar supported ZVI, and batch experiments were carried out to determine rate of TCE reduction, products and ZVI reduction capacity.

Results: Granular biochar supported ZVI can be prepared by one-step pyrolysis. ZVI@CC showed great potential for TCE removal. Nitrogen doping improved the reductive dechlorination performance of biochar supported ZVI via enhanced the electron transfer. Acetylene was the main dechlorination product in ZVI@CC system.

Discussion and take-home message: This study developed a highly potential biochar supported ZVI filter material with efficient TCE elimination which has bright prospects on CEs contaminated groundwater remediation.



* zhao@plen.ku.dk: *Thorvaldsensvej 40, 1871 Frederiksberg C, Denmark*

Screening IoT sensing approaches to support real-time groundwater quality monitoring

E. Andreas Kann-Rasmussen*, R. B. Ø. Madsen**, O. Schultz***, L. M. G. Coelho****, DTU Eng. Technology*

Introduction: Public authorities are currently looking for ways to acquire groundwater quality characterization to enable real-time data acquisition for more informative parameters beyond pH, conductivity and temperature. This monitoring network can provide a better understanding of the dynamics of pollution migration in highly polluted sites as well as enable faster identification and contingency actions in case of contamination incidents. So, the goal of this study is to provide a framework addressing the development of low-cost *in-situ* IoT-connected water monitoring stations. The main idea of the project is to combine optical and electrochemical processes with the Internet of Things approach to implement a low-cost remote real-time water monitoring system.

Methods and data: First of all, a literature review was carried out to select the potential methods for the detection of different groundwater parameters divided by groups. Scientific papers included in the review were obtained in the following scientific repositories: IEEE, ScienceDirect, Springer and Wiley. The target water quality parameters were divided in two groups: organic compounds (PAH, BTEX) and heavy metals. Based on the preliminary screening investigation of the methods, further studies were carried out to compare the different potential approaches and develop a framework for a IoT-connected system. For each one of the 2 aforementioned groups, a detection method or a combination was chosen. Then a framework defining the recommended measuring method for each group was defined. Based on that, the physical principles and the technical specifications of the sensors for each parameter were defined based on previous scientific studies. Finally, electronic systems were developed for each one of the measuring methods chosen in the previous steps. The proposed system was defined considering the following criteria: low-cost components, portability, cloud-based monitoring, off-grid power system and wireless communication.

Results: From the investigation 3 preliminary methods were selected: potentiometry, spectroscopy and voltammetry. The two latter approaches were preferred over the former. Spectroscopy based on fluorescence was preferred for organic compounds detection and differentiation and voltammetry was suggested for heavy metals quantification. Concerning voltammetry the study delves into the theory behind voltammetry, particularly cyclic voltammetry, square wave voltammetry, and stripping voltammetry in combination with new materials science technology to the development of screen printed electrodes to facilitate the portability and customization of specific detection of different heavy metals. The study outlines the importance of supporting electrolytes, and the modification of electrode surfaces for improved sensitivity as well as the critical role of the potentiostat in controlling potential and current measurements. For spectroscopy the combination of UV spectroscopy and fluorescence-based sensors could be an efficient way for the deployment of field portable testing of the aforementioned target compounds (BTEX, PAH) in groundwater wells.

Discussion and take-home message: The screening process provided insightful inputs that enabled the definition of the approaches to be followed for each target compound. Based on the framework and screening outcomes, the prototyping phase was initiated by designing and running preliminary testing to enable the implementation of spectroscopy and voltammetry-based probes for the detection of organic compounds and heavy metals, respectively. The research underscores the potential for these electrochemical and optical methods to revolutionize water quality monitoring due to their cost-effectiveness, speed, and ability to provide accurate measurements. It identifies the critical parameters affecting the analysis, such as scan rates and deposition times, and suggests the practical application of in environmental monitoring by local governmental bodies. Next steps will consist in establishing a portable system and testing it in real case studies by monitoring groundwater wells. In conclusion, the study advocates for the implementation of these methods in affordable and portable IoT-connected monitoring stations, enabling continuous, real-time monitoring of groundwater quality at various levels of government to ensure a sustainable and healthier ecosystem.

**AndreasKR@outlook.dk*: Lautrupvang 15, 2750, Ballerup, Denmark*
***s200262@student.dtu.dk*mailto:*linco@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark*
****osch@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark*
*****linco@dtu.dk*: Lautrupvang 15, 2750, Ballerup, Denmark*

Urban water and wetlands

Room	Title	From	To
AUD 2	Urban water and wetlands	15.30	17.30
	Chair: Ole Mark, Senior project manager, Krüger		

Speakers	Title of the presentation
Marie Riisgaard-Jensen	The sewer microbiome: Source of the process-critical bacteria in wastewater treatment plants
Antonio Vigueras-Rodriguez	Assessment of the overflow reduction potential of a plan to install extensive rooftop SUDS on Cartagena's buildings
Niels Eisum	Water retension and peak flow reduction measured during 5 years from full scale green roofs
Lineker Goulart Coelho	Assessing the performance of a green downspout solution to handle rainwater by using IoT based monitoring system
Mark Frenstrup Tørner Hansen	Satellite-based Mapping of Flood Extent and Depth in Denmark
Vasileios Chrysochoidis	Assessment of current practice model structures for predicting TSS load from Combined Sewer Overflow (CSO) discharge point
Alba Martinez I Quer	Constructed wetlands to remediate cyanotoxins - a story of microbes, design, and transformation products.
Pedro Carvalho	Treatment wetlands for wastewater treatment: a story of antibiotics, pharmaceuticals, antibiotic resistance and microbial communities
Josephine Søborg Jensen	Using riparian wetlands for surface water purification: Effect on nutrient concentration and biological response

The sewer microbiome: Source of the process-critical bacteria in wastewater treatment plants

Marie Riisgaard-Jensen*, Rodrigo Maia Valença**, Miriam Peces Gomez**, and Per Halkjær Nielsen**

Introduction: Today it is widely recognized that the efficiency of wastewater treatment plants (WWTP) using activated sludge (AS) is highly dependent on the microbial community. Understanding the biological mechanisms driving microbial community assembly in AS is crucial for enhancing plant performance and stability, and recent studies highlight the impact of microbial immigration from incoming wastewater. It prompts the question of the origin of process-critical bacteria within the AS. An obvious candidate is the sewer system which, besides receiving bacteria from multiple sources, harbors a distinct microbiome of growing bacteria adjusted to the cold and nutrient-rich sewers.

Methods and data: We have conducted a one-year study sampling in domestic sewers in the municipality of Aalborg. The sewer samples were coupled with influent wastewater to WWTP (IWW) and AS sludge from the two downstream WWTPs. The sewers encompassed both gravity mains (n = 7) and pressure mains (n = 2) and we collected various sample types including biofilm, sediment, and sewer wastewater (SWW), and performed 16S rRNA amplicon sequencing to study community composition.

Results: A distinct microbial community was observed in all sample types (AS, IWW, SWW, biofilm, and sediment). In the SWW, 40% of the total abundance was comprised of gut bacteria while 35% of the abundance consisted of bacteria from the general core sewer microbiome, which were defined as species present in >50% of all sediment and biofilm samples. In the IWW, the fraction of gut species was halved, while the core sewer bacteria increased to >50% of the relative abundance, indicating that bacteria able to grow in the sewer system make up most of the microbial community entering WWTPs. In AS the fraction of gut species were only 2%, while the general core sewer microbiome made up 30% of the abundance, signifying a substantial representation of sewer-originating species in the AS community. Precipitation (rain) was found to cause suspension of biofilm and sediment, as SWW microbial communities resembled these during rainfall. In correspondence, sewer core species also had a higher abundance in the IWW during days with rain (>1 mm). A special focus was on the process-critical bacteria in AS and one of the goals was to locate potential sources in the sewer system. Especially in the biofilm of pressure sewers, we found many distinct species involved in removal of N and P and known to grow in AS, with an average of 163 distinct species comprising >7% of the abundance in the biofilm. Additionally, analogous seasonal patterns between AS and sewer environments were observed; investigated using soil temperature rather than seasons.

Discussion and take-home message: This study reveals that a considerable portion of the bacteria in AS originates from the sewer system microbiome and that the influx of these species increases during rain events. The findings underscore the need to consider bacterial immigration from the sewer system as well as other sources when studying microbial community assembly in AS. Understanding the sources of process-critical bacteria can be a key tool in ensuring a stable operation of wastewater treatment plants, as it enables the prediction and management of the immigration of both functional important and the problematic species in WWTPs.

*mari@bio.aau.dk, Department of Chemistry and Bioscience, Section of Biotechnology, Center for Microbial Communities, Aalborg University, 9220 Aalborg, Denmark (Corresponding author)

**Department of Chemistry and Bioscience, Section of Biotechnology, Center for Microbial Communities, Aalborg University, 9220 Aalborg, Denmark

Assessment of the overflow reduction potential of a plan to install extensive rooftop SUDS on Cartagena's buildings

***Antonio Vigueras-Rodriguez**, J.T. García, J.M. Carrillo, F.J. Pérez de la Cruz, UPCT-Hidr@m**

Introduction: Spanish cities are starting to analyse the possibilities of reducing water bodies pollution due to combined sewer overflows through the implementation of Sustainable Urban Drainage Systems (SUDS). Cartagena is a mid-sized city of about 200 000 inhabitants located in a semiarid region. The city is mostly flat, although is surrounded by steeped hills and mountains. Frequent high groundwater phreatic levels limit the possibilities of infiltration. Nevertheless, rooftop SUDS can be an interesting possibility, as most people live in apartments with flat roofs. In this work, an extensive preliminary assessment is carried out to estimate the possible impacts of the application of this technique on different ratios of rooftop SUDS penetration and for different types of events.

Methods and data: Data from buildings surfaces is obtained from OpenStreetMap, due to its high quality in the polygonal representation of the buildings. It is assumed that the potential surface of rooftops is limited by the typical roof area ratio of the buildings according to typical residential morphologies [1]. The sewer system has been modelled through EPA SWMM [2]. The rooftops have been based on the model and parameters assessed in [3], being replaced a ratio of each building surface belonging to a subcatchment by the model using for that purpose the library swmmio [4]. Extensive simulations have been done for the different penetration ratios, evaluating the influence for different types of events (registered or hystorical and design events). The water quality improvements caused by the rooftops has been neglected, being the analysis focused only on the sewer overflow reduction, and specially the overflows to the harbour.

Results and discussion: The effect can be quite relevant in lower rains, and negligible in greater events. Further analysis can be carried out to evaluate which areas of the city have a greater influence. This kind of analysis is relevant and should be a requirement before elaborating a SUDS city plan.

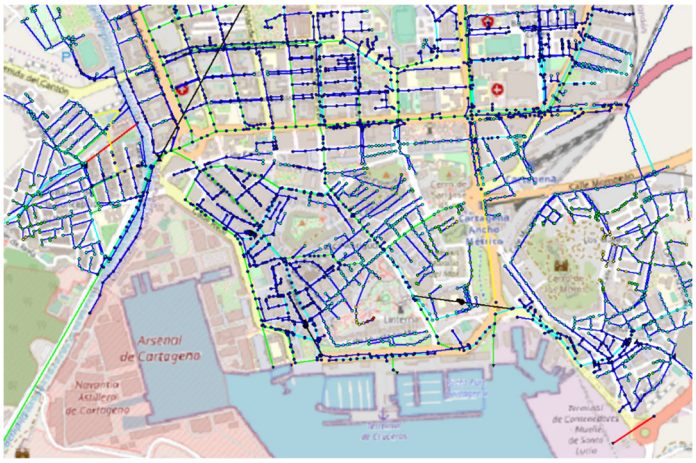


Figure 1: Part of the sewer system in the city center, including some of the overflow points, with Open Street Map background.

***References**:*

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avigueras.rodriguez@upct.es: Hydraulic & Environmental Engineering Universidad Politécnica de Cartagena (UPCT - Hidr@m), Paseo Alfonso XIII, 52, 30203 Cartagena, Spain

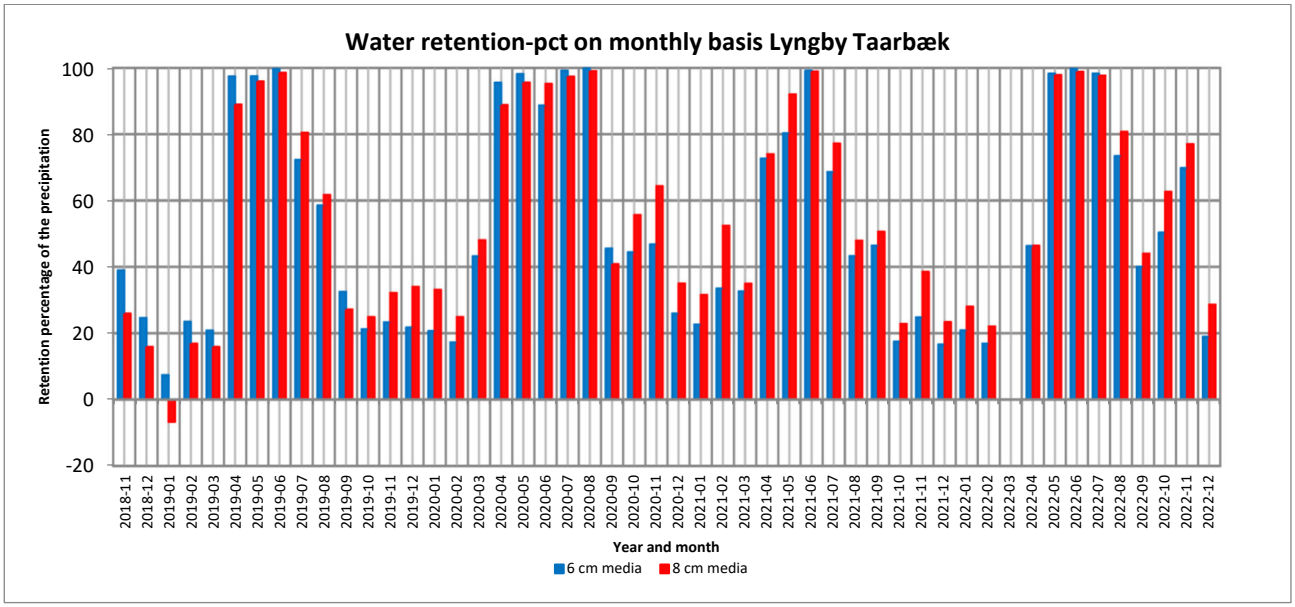
Water retension and peak flow reduction measured during 5 years from full scale green roofs

Niels Henrik Eisum**, Huginn Consult ApS*, O. Mark, Krüger**, K Bertelsen, Nature Impact, T. Dalkvist, DHI A/S*****
*R. Roestenberg, Lyngby-Taarbæk Forsyning******

Introduction: What is the effect of a green roof in comparison with a conventional roof? This study will describe the practical results of measurements of the water retension on a monthly basis and the peak flow reduction under heavy rain during continued measurements through more than 5 years. Measurements are performed at 2 sites (Mølleåværket, Lyngby-Taarbæk and Nature Impact A/S, Fyn) with full scale green roofs delivered from Nature Impacts A/S – each with 2 different types of sedum with 60 or 80 mm building heights and compared with a conventional hard roof. This project is thankful for received financial funding from RealDania.

Methods and data: Data from the roofs are measured with a magnetic inductive flowmeter installed in the drain pipe from each type of roof and data are compared with the precipitation measured with a rain gauge. Data are collected every minute using DIMS.CORE data collection system from DHI A/S. One test site has 59 m^2 on each roof and the roofs are flat. The other test site has 86 m^2 on each roof and with 20 degree one sided slope.

Results: On a yearly basis the overall result is that the water retension is measured to be between 41% and 57% of the run-off from the reference roof, but with large variation during the year. For the 80 mm building heights the average is 50%. During winter time the retension is typically around 20%, but in the summer time the water retension is up to 90% or even more. The total time with a peak flow larger than 110 l/s/ha is reduced with a factor of approx. 3 for the green roofs compared to the conventional roof.



Discussion and take-home message: Approx. half of the yearly precipitation is retained in the green roofs and the duration of high peak flow is reduced with a factor of 3. The green roofs can typically hold back the first 10 to 15 mm of a rain event after a dry period.

** niels@eisum.dk: Enemærket 50, DK-8240 Risskov, Denmark*
*** oma@kruger.dk: Gladsaxevej 363, 2860 Søborg*
**** kb@natureimpact.com: Søndre Højrupvejen 130, 5750 Ringe*
***** tda@dhigroup.com: Åbogade 15, 8200 Aarhus N*
****** rro@ltf.dk: Firskovvej 38, 2800 Kongens Lyngby*

Assessing the performance of a green downspout solution to handle rainwater by using IoT based monitoring system

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

Introduction: Local rainwater retaining systems distributed all over a watershed can contribute to reduce peak flows, minimize flood risks and enable rainwater harvesting being an complementary solution to reduce the demand for huge centralized infrastructures as retention basins. On the other hand, digitalization associated with such solutions are essential to support real time monitoring aiming a active control systems and integrated water management of the distributed retaining systems. So, the main purpose of this paper is to implement and evaluate an IoT sensor system as a tool to support monitoring and assessment of a green downspout solution system based on rockwool substrate.

Methods and data: The experimental apparatus was installed in the Technical University of Denmark - Ballerup Campus. Two setups with different highs were tested in this research. Both systems present a thickness of 20 cm and a width of 60 cm, one of them is 1m high and another 1.5m high. As presented in Figure 1, the green downspout pilots consisted of unplanted batches made of a perforated metallic structure filled with mineral wool. In a conventional downspout, water collected from the roofs will be drained and sent to a vertical pipe reaching almost immediately the main drainage system. In the case of the green downspout instead of having only a vertical pipe, there is an intermediate porous media made of mineral wool, which will be used to delay the rainwater by two processes: reducing the water velocity as the flow passes through a porous media and temporary storage of the water in the porous media.

Results: The water collected from the roof is distributed in the top of the mineral wool using a perforated pipe and flows through the batch from top to down, a perforated pipe at the top of the batch is used as a water inlet, and at the bottom, it is collected by a plexiglass tank connected to the outlet pipe. The system presents water flow meters, temperature, and moisture sensors. All the results are exported to the cloud and can be visualized in real time in an open data-based platform. The pilot system was tested using different water flows and configurations. The system showed different peak flow delayed times ranging from 4 to 8 min. As expected, the batch with 1,5m presented a higher retention and delay than the 1m, and the real-time monitoring system enabled to clearly follow the differences in terms of the filling and emptying process enabling better understand and analyze water flow over time.

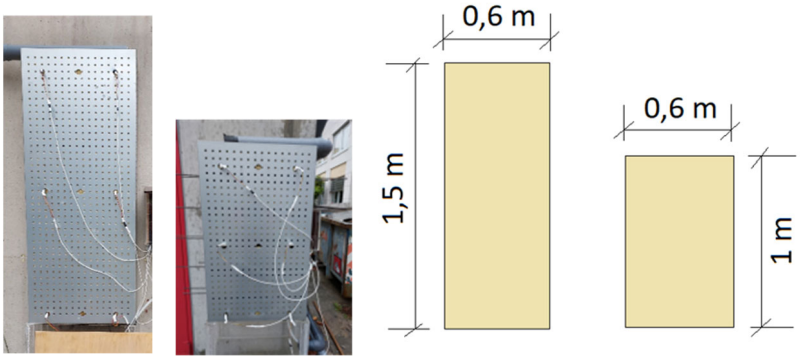


Figure 1: Overall dimension and real images of the green downspout pilot system.

Discussion and take-home message: The IoT monitoring was able to provide insightful information on a real-time basis to the system, with remote monitoring, facilitating data management, and system performance analysis. The hydraulic results showed that the water retention capacity and delay increase with the height of the batch, which indicates that such solutions have a high potential to be used as downspouts and delay rainwater in vertical buildings. Future steps include testing higher pilot systems to check scalability as well as water quality analysis.

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

Satellite-based Mapping of Flood Extent and Depth in Denmark

Mark F.T. Hansen and J. Koch**

Abstract:

Flooding stands out as the most frequent and economically damaging natural disaster in Denmark. With the eventual impact of climate change, the threat of intensified infrastructure damage, increased economic losses, and potential human casualties grows. Consequently, state authorities are proactively developing an advanced flood warning system to enhance resilience and minimize flood-related socio-economic impacts.

The project involves mapping floods, with the primary objective of creating a Danish flood extent catalog. This catalog will support large-scale susceptibility mapping and the further development of local hydrodynamic models by providing calibration and validation data. The flood mapping relies on open Synthetic Aperture Radar (SAR) data, primarily from ESA's Sentinel 1 (S1) satellites, which have been available since 2015. Earth observation satellites, specifically the ones equipped with SAR instruments, have become the standard tool for such tasks due to (1) repeatedly acquiring data consistently, (2) their sensitivity toward land use differences and (3) all-weather day–night imaging capabilities. A large-scale application of SAR data to map flood extents in Denmark is still outstanding. Various methods, such as SAR image thresholding, region growing, and flood shoreline delineation combined with high-resolution elevation models, will be compared across different flood events in Denmark, with a focus on their applicability under Danish conditions.

Methods and data:

To classify water on terrain, multiple methods were used and developed to binarize S1 SAR imagery into water and background respectively. A simple and fast K-Means algorithm was introduced to identify water clusters to binarize the imagery. Two different adaptive thresholding algorithms with one, using quadtree decomposition and the other, box decomposition, along with integrated region growing were developed and effectively implemented. Both adaptive approaches are governed by the same bimodality search principle, where the algorithm searches for a balanced distribution of water and non-water, so that a local minimum can be determined which is then used as input for a region growing segmentation, resulting in binary images with meaningful and contextual water extent delineations. Furthermore, we determined water depth by employing a second round of region growing, this time utilizing both the mapped flood shoreline obtained from the segmentation process and digital elevation data.

Results:

Flood events across several municipalities in Denmark, spanning from 2015 to 2023, have been effectively analyzed. The spatio-temporal evolution of the flood events was analyzed by segmentizing S1 SAR images before, during, and after the flood event. Thus, the processed images offer valuable insights into the scale and evolution of various floods. High quality ground truthing data are scarce which hinders a comprehensive quantitative performance assessment.

Furthermore, our methods have been developed with adaptability and real-time implementation in mind. They can seamlessly utilize not only Sentinel-1 Synthetic Aperture Radar (SAR) imagery but also other SAR products due to their dynamic, autonomous, and flexible nature.

Assessment of current practice model structures for predicting TSS load from Combined Sewer Overflow (CSO) discharge point

Vasileios Chrysochoidis[*1], *Günter Gruber*[**], *Thomas Hofer*[***], *Peter Steen Mikkelsen*[*], *Luca Vezzaro*[*]

Introduction:

Combined sewer overflows (CSOs) pose a significant threat to water quality and public health, as they release untreated wastewater into natural water bodies during medium/big rainfall events. These discharges cause environmental problems like eutrophication and oxygen depletion, and they are further exacerbated by climate change and increasing urbanization. Despite the increasing awareness about this issue, recently stressed by new European Legislation, assessing CSO impacts on natural water remains a challenge. The complexity of underlying processes and limited resources for monitoring have historically limited data collection activities, and modelling approaches are often focused solely on quantifying the discharged water volume. Available modeling approaches on water quality range from detailed hydrological methods to data-driven models. However, the lack of data, the complexity of underlying processes, and the tendency to focus only on a single modelling tool without proper performance assessment have led to overparameterized models that lack accuracy and transferability. This study addresses these gaps by exploring the influence of model complexity on CSO pollutant load predictions and on temporal variability during precipitation events, with the aims to provide more accurate tools to quantify pollutant emissions to the environment.

Methods and data

In this study, four distinct model structures were examined, accounting for varying levels of complexity in the representation of processes taking place in a sewer network: (1) a detailed hydrological and hydraulic model, using the Sain-Venant equations (SWMM); (2) a simplified conceptual model, employing a lumped approach for the catchment area and a linear reservoir (WEST DHI); (3) a stochastic and (4) an empirical data-driven method (developed in MATLAB). The stochastic model uses dry weather patterns, flow, water level, velocity, and rainfall data in a decision tree regression. The empirical model relies on multi-regression analysis, considering water level, velocity, and rainfall. All the four models were evaluated at the CSO discharge point by using high-resolution data from an Austrian catchment (Graz-West). The model prediction of total suspended solids (TSS) was compared by using mean average percentage error (MAPE) and dynamic time warping (DTW). Further, an event-clustering approach, based on integrated mass-volume curves for each event, was used to enhance model performance.

Results

On average, the performance of the four models varies significantly across the analyzed 59 rainfall events. The detailed model shows the best DTW on average, while the conceptual model performs the worst. When looking at aggregated performance, it seems that the complexity of the SWMM model pays off and leads to higher accuracy. However, a closer look at individual events reveals substantial variability in model performance (Fig.1). This finding highlights the initial misconception about the best model structure, masked by averaging results across events. When plotting observed and predicted TSS loads for each event, in some cases the detailed model fails to capture pollution and temporal variability, unlike other models. This variability in model performance is observed for all events and for all structures, suggesting that not a single model structure is able to represent the observed phenomena. Event clustering was applied to the chosen stochastic model, without improving its performance. This suggests that, despite grouping events showing patterns of first, uniform and late flush pollution, the existing model structures are not able to represent the complex processes driving CSO water quality, and new modelling approaches are thus needed.

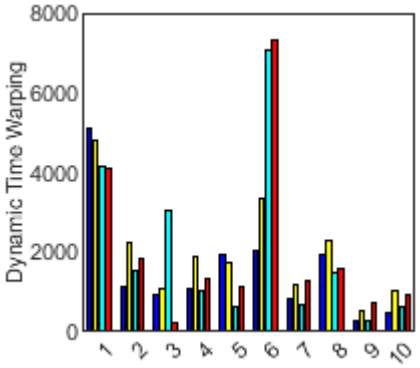


Fig 1. DTW for detailed (blue), conceptual (yellow), stochastic (cyan) and empirical (red) in 10 random events

Key findings

- Absence of optimal model structure to predict the water quality from CSOs in all events
- Model enhancements could not improve the already insufficient models
- New advanced models must address underlying process randomness

Constructed wetlands to remediate cyanotoxins - a story of microbes, design, and transformation products.

Alba Martínez i Quer**, AU-ENVS*, A. Johansen, AU-ENVS and AU-WATEC**, C.A. Arias AU-Bio and AU-WATEC ***, P.N. Carvalho, AU-ENVS and AU-WATEC

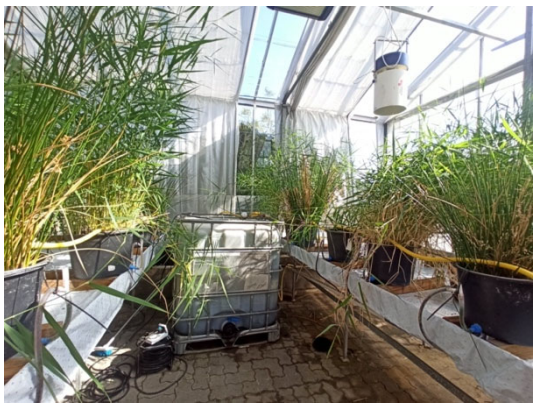
Introduction: Drought and higher temperatures occur more often in our environment, together with too much fertilization in agriculture, is leading to eutrophication and shortage of freshwater resources. When episodes of water scarcity occur, vulnerable populations may be forced to irrigate crops with water contaminated with cyanotoxins from cyanobacterial blooms. Consequently, indirect, or direct human consumption of cyanotoxins happens, which may lead to cytotoxic pathologies. Constructed Wetlands (CWs) are a promising approach for cyanotoxin bioremediation, although the removal mechanisms are not clear. Therefore, we tested two hypotheses: 1) CW systems can efficiently remove cyanotoxins while leaving the nutrients for crop irrigation; 2) The indigenous CW microbiota (bacteria and fungi) is essential for the removal and the cyanotoxins which on the other side influence the composition of the microbial community.

Methods and data: We set up thirty-two 12-L systems using different reed species, porous media, operational modes, and different seasons. Control and spiked systems were fed using synthetic eutrophic lake water. The spiked systems were fed using a 10 µg/L of microcystin-LR and cylindrospermopsin, mimicking a cyanobacterial bloom. Removal percentages, analysis of bacterial and fungal communities' structures and screening of transformation products were carried out intending to disclose removal mechanisms by taking a holistic approach.

Results: Mesocosms CWs in two operational conditions (Saturated and Unsaturated) showed removals of up to 99% for both cyanotoxins. We reported cylindrospermopsin removal, by CWs mesocosms, for the first time. For both operational modes, the variables influencing the cyanotoxin removal were consistent; plant type had the highest influence, followed by the operational mode and then the porous media type. The evapotranspiration factor was taken into consideration in summer campaigns, allowing us to calculate mass removals and different water quality scenarios. Taking mass removal into consideration, *Phragmites australis* is by far, the best plant species, while for better effluent quality (lower evapotranspiration) *Juncos effusus* is preferrable. Moreover, transformation products data show no coincidence with the available knowledge on cyanotoxins TPs, indicating that the known enzymatic pathways from the literature might not be occurring in complex environments. Microbial communities responded to the spiking of toxins, more profoundly in Spring season. Differential abundance tests in Saturated systems indicated that several bacteria associated with cyanobacterial blooms were statically more present in the spiked mesocosms, This indicates that the CW systems were robustly mimicking natural blooms, however it is not clear if the associated bacterial community is responsible for the cyanotoxin removal.

Discussion and take-home message: Data is consistent through the seasons demonstrating promising technical application of the CWs for controlling cyanotoxins contamination. Different scenarios depending on the perspectives of different regulatory policies will be presented at the conference. The study advocates the importance of gathering prior information before full-scale implementation, as the design highly impacts the performance and highlighting the importance of the associated bacterial communities, often disregarded in such systems usually applied as black boxes.

Acknowledgements: This work was supported by the Independent Research Fund Denmark – project WETCYANO, and the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement No 823860.



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

***WATEC– Centre for Water Technology, Aarhus University, Ny Munkegade 120, Aarhus 8000, Denmark ***carlos.arias@bio.au.dk: Department of Biology, Aarhus University, Ole Worms Alle 1, Aarhus C 8000, Denmark*

Treatment wetlands for wastewater treatment: a story of antibiotics, pharmaceuticals, antibiotic resistance and microbial communities

Arianna Mingoli[1], Edoardo Parisi[1], Gian Luigi Garbini[2], Paola Grenni[2], Anna Barra Caracciolo[2], Alba Martinez I Quer[3], Vaidotas Kisielius[3], and **Pedro N. Carvalho[3]**

Treatment wetlands are among the most efficient and frequently implemented nature-based solutions for wastewater treatment. As for all wastewater treatment systems, there are increasing concerns on how such systems deal with contaminants of emerging concern. While treatment wetlands application for classical pollutants is well described in the literature, data on organic micropollutants is still mostly from laboratory and mesocosm scale studies. The potential to control the emission of pharmaceuticals by treatment wetlands is known. However, reports on the performance of full-scale systems over long monitoring cycles are scarce. Moreover, the fate of antibiotic resistant genes in such systems remains unknown, as existing literature points in different directions (either removal or accumulation). To address these gaps, a full-scale treatment wetland was monitored for two years to gain knowledge on real-life efficiency and seasonal performance.

The selected treatment wetland is in full operation since 2014, and treats the wastewater from 100 PE in Tjørnelunde, Denmark. Water and sediment were sampled to analyse organic carbon and nitrogen, microbial community, organic micropollutants (mostly pharmaceuticals and antibiotics), and antibiotic resistance genes.

Results show not only the efficiency of the treatment wetland for nutrient removal from wastewater, but also its capacity to reduce, in general, organic micropollutants. From the 16 compounds measured in the system, 3 antibiotics were sporadically quantified. In Autumn, the sum of all compounds was 31 µg/L in the inlet and 4 µg/L in the outlet, with an overall decrease of 87%; while in Winter, it was 21 µg/L in the inlet and 9 µg/L in the outlet, with an overall decrease of 59%. The removal efficiency for organic micropollutants seems to be influenced by seasonality, presumably due to the different plant vegetative states during the year. Regarding the antibiotic resistance genes, the treatment wetland was particularly effective in reducing the number of copies in the autumn, but an increase was observed for the winter. No correlation could be established between resistant genes and occurrence of antibiotics. These and other results will be expanded on during the conference. The study site is an example of how nature-based solutions can be applied as efficient and sustainable decentralized treatment technologies for preventing water pollution.

[1] The Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy

[2] Water Research Institute, National Research Council (IRSA-CNR) SP 35d, km 0,7, 00010 Montelibretti, Rome, Italy

[3] Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Using riparian wetlands for surface water purification: Effect on nutrient concentration and biological response

Josephine S. Jensen*, *A.K. Dybdahl**, *E. Jespersen**, *C. A. Arias**,**, *T. Riis**,**

Introduction: Nutrients (i.e., inorganic nitrogen and phosphorus) are major diffusive pollutants originating from agriculture and wastewater treatment plants. Excess nutrient availability in steams and downstream lakes and coastal areas can lead to massive ecosystem disruptions, such as eutrophication and hypoxia, leading to degradation of biodiversity on a global scale. To mitigate the negative effects of high nutrient concentrations in aquatic ecosystems, receiving agricultural and urban runoff, we propose to install riparian constructed wetlands for nutrient transformation and removal. The study investigates the use of riparian hybrid constructed wetlands to improve stream water quality and assesses the biological response in terms of biofilm structure and function.

Methods and data: Five riparian constructed wetlands were installed along an agricultural-urban catchment receiving water from the adjacent streams with different proportions of agricultural and urban runoff. The water was fed to an unsaturated vertical flow system, followed by a saturated horizontal flow bed, both embedded with plants. To assess the purification efficiency of the constructed wetlands, water samples were collected from the inlet and outlet biweekly during a one-year period and analyzed for nutrients and organic matter. To examine the biological response of the treatment, pre-colonized biofilm samples were incubated in a mesocosm supplied with treated and untreated stream water for one month. Structural and functional parameters on the biofilm were evaluated post-incubation to investigate the relation between the water quality and the biological response.

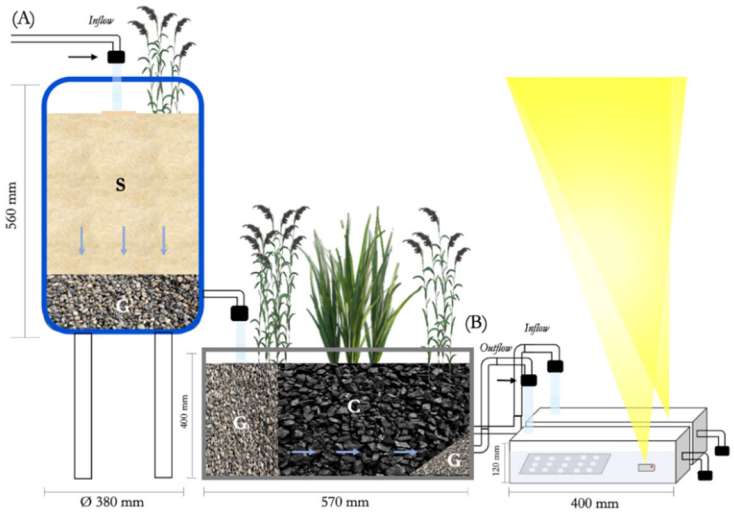


Figure 3. Experimental setup (x2) of the riparian constructed wetland with vertical flow (VF) (A) and horizontal subsurface flow (HF) (B) and biofilm mesocosm at the constructed wetland inlet and outlet. Blue arrows indicate waterflow and black arrows indicate the water taps for inflow and outflow. Filter media is indicated with S (sand, 0-2 mm), G (coarse gravel, 8-16 mm) and C (coke, 2-4 mm, 39% porosity).

Results: The river water exhibited low nutrient levels, with no clear trend along the urban-agricultural gradient, except for an urban-related increase in NH_4^+ concentration. The constructed wetlands efficiently reduced levels of NH_4^+, suspended solids and organic carbon, while the concentrations of NO_3^- and PO_4^{3-} were slightly enriched from the treatment. Nutrients did not significantly affect the biofilm biomass, however, the abundance of specific algae phyla within the biofilm was influenced by the concentration of PO_4^{3-}. Both biofilm biomass and primary production were influenced by light availability controlled by the concentration of suspended solids and no correlation was identified between nutrient levels and biofilm function.

Discussion and take-home message: The key findings of this study were that the riparian constructed wetlands in the present form can be useful for purification of organic polluted streams heavily influenced by anthropogenic activities. The poor reduction of NO_3^- and PO_4^{3-} was likely due to the limitation of carbon and anoxic conditions. The removal of suspended solids by the constructed wetlands influenced light availability, which was found to be the primary controlling environmental parameter determining for biofilm structure and function.

*josj@bio.au.dk, annekirstine.dybdahl@bio.au.dk, emil@bio.au.dk, carlos.arias@bio.au.dk, tenna.riis@bio.au.dk: Department of Biology, Aarhus University, Ole Worms Alle 1, 8000 Aarhus C, Denmark

**carlos.arias@bio.au.dk, tenna.riis@bio.au.dk : WATEC, Aarhus University, Centre for Water Technology, Vejlsøvej 25, 8600 Silkeborg, Denmark

Posters

Walls in the conference area

Poster presenters	Title of the poster
Anne-Lise Trøst Frisch Funding	PFAS distribution in Danish wastewater treatment plants (WWTP) – Identification of control measures for the distribution between sludge and water
Andrea Mongelli	Investigation of Quaternary Ammonium Compounds (QUATs) Pathways into Surface Waters: Implications for Urban Runoff and Wastewater Treatment
Lone Tang	Effect of organic compounds migrating from PE pipes on drinking water biofilms
Jiexi Zhong	Removal of micropollutants from effluent wastewater using activated biochar made from sewage sludge and wood pellets
Krzysztof Piotr Kowalski	Role of active carbon saturation with chlorinated compounds and operational factors on removal of PFAS and DMS in pump and treat plants
Borja Valverde Pérez	Can water resource recovery facilities participate in the stabilization of the energy system?
Mohammad Mahdi Agha Shirazi	Membrane crystallization for Li recovery from brines
Ramya Veerubhotla	Waste to Watts – Wastewater Powered Sustainable Batteries employing Electroactive Microbes
Emil Jespersen	Pollutant removal in bioswales
Thomas M. Odgaard	Helical Hollow Fiber Membrane Modules for Energy-Efficient Membrane Distillation of Industrial Wastewater

PFAS distribution in Danish wastewater treatment plants (WWTP) – Identification of control measures for the distribution between sludge and water

K. B. Andreasen, **Anne-Lise T.F. Funding****, S. Lindholst***, J. G. Christensen*****

Introduction: In Denmark, there is a growing focus on environmental pollutants in wastewater, and many utilities have already invested both time and money in how to manage PFAS-contaminated sludge. The significant attention, both political and media-wise, on PFAS and an imminent adoption of an urban wastewater directive is expected to affect the management of the effluent and thereby affecting the management of pollutants on the WWTP. Currently, it is unknown how PFAS is distributed between fat, sludge, and the effluent to the recipient. This project aims to provide the necessary knowledge regarding the distribution of PFAS and how flocculants and coagulants affect the distribution. The hypothesis is that the distribution of PFAS between reject water and sludge can be influenced by these chemicals. This is tested with a selection of coagulants/flocculants both in the laboratory using the MCT-Higgins setup at Danish Technological Institute and will be applied in full-scale. The project aims to present a mass balance for PFAS in the four participating WWTPs and to provide insight into the effectiveness of the applied chemistry in controlling the distribution of PFAS between the sludge and water fractions.

Methods and data: Sampling is conducted by flow-proportional sampling and representative grab samples. The most suitable accredited analysis methods are still being investigated. But the entire data processing and all four mass balances are expected to be completed by April 2024. Data and mass balance from one or two WWTPs are expected be available for presentation in January 2024.

Results: Confer “methods and data” above.

Discussion and take-home message: For now, there is no economic rationale for transferring as much PFAS as possible to the sludge. Only when it becomes profitable to treat the sludge in a way that removes PFAS does the method provide the most economical value. The value of transferring as much PFAS as possible to the sludge is currently environmentally by reducing the discharge of PFAS into the aquatic environment. Even if it is possible to influence the distribution at the WWTPs, it should not replace an effort to reduce the discharge into the sewer. Controlling the distribution on the WWTP is merely a temporary method until a more future-proof solution is found.

** kba@thistedvand.dk: Johnsens Allé 6C, 7700 Thisted – Main applicant*
*** atff@teknologisk.dk: Kongsvang Allé, DK-8000 Aarhus, Denmark – Project leader/Presenter*
**** sbl@teknologisk.dk: Kongsvang Allé, DK-8000 Aarhus, Denmark*
***** jguc@teknologisk.dk: Kongsvang Allé, DK-8000 Aarhus, Denmark*

Investigation of Quaternary Ammonium Compounds (QUATs) Pathways into Surface Waters: Implications for Urban Runoff and Wastewater Treatment

Andrea Mongelli[*], Pedro N Carvalho[**], Lena Mutzner[***], Kai Bester[****]

Abstract

Quaternary ammonium compounds (QUATs), including benzalkonium chlorides (BACs), are widely employed in human hygiene, food production, and building protection. While QUATs in human hygiene and food production contribute to wastewater discharges with potential removal in treatment plants, those in runoff from buildings are often released untreated through stormwater sewers into receiving surface waters. This study aimed to identify the primary pathway of QUATs into surface waters.

For this study, four sampling campaigns were conducted under different weather conditions at 8 stations along the Værebro Å (Sæland, DK) between 2021 and 2022. Additionally, effluents from three wastewater treatment plants (WWTPs) were collected during dry weather conditions. Quantitation of QUATs and metoprolol was performed using HPLC-MS/MS. No sample preparation was necessary for the surface water samples, except for the addition of internal standards. For the WWTPs effluent samples, a centrifugation step was introduced to separate the water and solid particles in the method.

In a sampled river stretch (Værebro Å), QUATs concentrations during dry weather remained below 0.1 ng/L, contrasting with concentrations during rainy weather reaching up to 90 ng/L. Tributaries not receiving discharges from wastewater treatment plants exhibited significant loads, suggesting rainwater runoff from roof and terrasse treatments as the predominant source. This conclusion is supported by mass balance assessments using metoprolol as a wastewater marker and a mass balance model, supporting the hypothesis that urban runoff prevails over wastewater treatment plants as the primary QUAT source.

These findings provide insight into the challenges faced in earlier surface water monitoring, where results were inconsistent and not linked to traditional sources. Two key factors driving QUAT inputs into receiving waters were identified: the presence of urban surfaces treated with QUATs combined with rain events washing QUATs from these surfaces into rivers. Consequently, our study underscores the need for appropriate stormwater treatment or additional restrictions on QUAT usage.

* am@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark
** pedro.carvalho@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark
*** Lena.Mutzner@eawag.ch: Eawag, Swiss Federal Institute of Aquatic Science and Technology, 8600 Dübendorf, Switzerland.
**** kb@envs.au.dk: Environmental Science, Aarhus University, Frederiksborgvej 399, 4000 Roskilde, Denmark

Effect of organic compounds migrating from PE pipes on drinking water biofilms

Lone Tang*, DA Søborg and TL Skovhus, VIA University College; CS Vesterlund, NH Hansen, TREFOR Vand A/S; KB Kristensen, Aarhus Vand A/S; S Musovic, Teknologisk Institut; T Høst-Madsen, Nordic Wavin A/S*

Abstract: Polyethylene (PE) pipes are often the chosen material when commissioning new drinking water pipes in Denmark. Previous studies have identified numerous compounds leaching from PE pipes to drinking water. Here, the effect on enrichment cultures of young (8 weeks, FRE) and old (6 years, BUS, TBR) PE pipe biofilms were studied with a) 9 selected compounds known to migrate from PE pipes and b) a natural "PE-cocktail" obtained from crushed PE pipe. The 9 pure compounds had a limited effect on biofilm growth from BUS and TBR, while the growth and activity of FRE biofilm was stimulated. The PE-cocktail stimulated activity of biofilms, and increased biofilm formation in BUS and FRE enrichments. These results highlight potential beneficial effect of biofilms on the distributed drinking water quality.

Introduction: Polyethylene (PE) pipes have been used in drinking water systems since the 1960s and has been the most used pipe material in Denmark since the 1980's. Numerous organic compounds have been identified migrating from plastic pipes into drinking water including additives, e.g. stabilizers, dyes, co-formulants, and degradation products. This study investigates the effects of organics migrating from PE pipes on drinking water biofilms from the drinking water distribution system.

Methods and data: Biofilm were collected from three field locations; a newly commissioned (8 weeks, FRE) PE pipe, a PE pipe with mature (6 years, TBR) biofilm located at a waterworks, and a PE pipe with mature (6 years, BUS) biofilm located close to the consumers. The biofilms were used for testing the effect of 9 selected organic compounds migrating for PE pipes on biofilm growth and activity (final concentrations of 0.5 mg/L and 5 mg/L). Microbial *growth* was quantified by measuring DNA after growth with the organic compounds and microbial *activity* was measured by quantification of ATP after exposure to the selected organic compounds for two hours. Furthermore, a "PE-cocktail" was fabricated by grinding a PE pipe into small pieces and incubating with milli Q water for 72 hours before the water was applied for growth and activity tests.

Results: The pure components had a limited effect on the amount of biofilm formed in enrichments from BUS and TBR irrespectively of whether 0.5 or 5 mg/L was present. In contrast, the FRE biofilm enriched from newly installed PE pipes were significantly stimulated by all the 9 organic compounds irrespectively of whether 0.5 or 5 mg/L was added. The activity of the FRE biofilm were also significantly stimulated by all 9 organic compounds. In contrast, the BUS biofilm was not significantly influenced and TBR biofilm were unaffected by 5 of the organic compounds, while the remaining 4 decreased the activity with 11-19%. This suggests that the biofilm age was more important for biofilm response than the properties of the individual organic compounds. Incubation of a 4 days old biofilm with "PE-cocktail" increased biofilm activity compared to a control with 41, 49 and 57% for BUS, TBR and FRE enrichments, respectively. The stimulatory effect of the PE-cocktail on activity can be contributed to both stress and growth. When enrichments were grown with "PE-cocktail" as the only organic source biofilm growth was stimulated in BUS and FRE with 68 and 34%, respectively, compared to incubation made with only minimal medium. This illustrate that the "PE-cocktail" serve as a nutrient source. The biofilm formation in TBR was reduced when the minimal medium was diluted with "PE-cocktail" (62%) or water (43%) suggesting that the reduction partially was caused by dilution rather than toxicity of the "PE-cocktail".

Discussion and take-home message: The increase in activity observed in a biofilm enriched from newly installed PE pipe may be attributed to the possibility of increased migration of various components from the freshly introduced PE pipes. This observation suggests that biofilm formation within drinking water distribution systems can serve as a protective barrier, thereby conferring advantages to both water quality and consumers.

The introduction of a "PE-cocktail" exhibited a notable stimulatory effect on biofilm activity in biofilm enrichments obtained from all three distinct locations. However, the response of the biofilm communities from these locations diverged when the "PE-cocktail" was provided as a nutrient source. This divergence highlights the importance of establishing and sustaining a pertinent biofilm community within newly installed PE pipes, ultimately contributing to the improvement of water quality and, consequently, benefiting consumers.

**LTAN@via.dk*: *VIA University College, Banegårdsgade 2, 8700 Horsens, Denmark*

Removal of micropollutants from effluent wastewater using activated biochar made from sewage sludge and wood pellets

Jiexi Zhong**, Aarhus University*, Henrik Sønderborg, AquaGreen**, Sara Letholm Skaarup,* Odsherred Forsyning, *Kai Bester, Aarhus University*****

Introduction: Conventional activated sludge processes are reported to be inefficient (0-60%) in removing micropollutants (such as pharmaceuticals). Activated carbon as well as activated biochar produced, e.g., from materials and from circular economy can be used to remove these micropollutants in the effluent without generating any by-products.

Methods and data: Activated biochars were made from sewage sludge and wood pellets in different ratio and were applied to remove the micropollutants in effluent wastewater collected from Hillerød WWTP. The removal over time is monitored to compare the capacity of conventional granular activated carbon (GAC, column A) to these different biochars (column B, C, D, E). The respective materials were packed in glass columns (0.18 L) and loaded with effluent water for 9 months. Concentrations in in- and outflow samples were determined by HPLC-MS/MS.

Results: Among the 30 compounds quantified, column A, B, D and E (i.e., conventional GAC and three different biochars) are effective (90-100% removal) in removing 9 compounds. For 21 compounds, the removal in column B, D and E is reduced to 50% at a lower bed volume (400-1400 bed volumes) compared to those made of GAC (close to 100% removal at 1500 bed volumes), indicating towards decreased capacity of biochar columns in comparison.

In comparison to commercial activated carbon (column A), all the biochar column exhibited a similar sorption behaviour in benzotriazole (~98% removal) and in furosemide (~99%). The removal of oxazepam in columns B, C, D, and E, is reduced to 70% after 1200, 1100, 1500 and 1500 bed volumes, respectively.

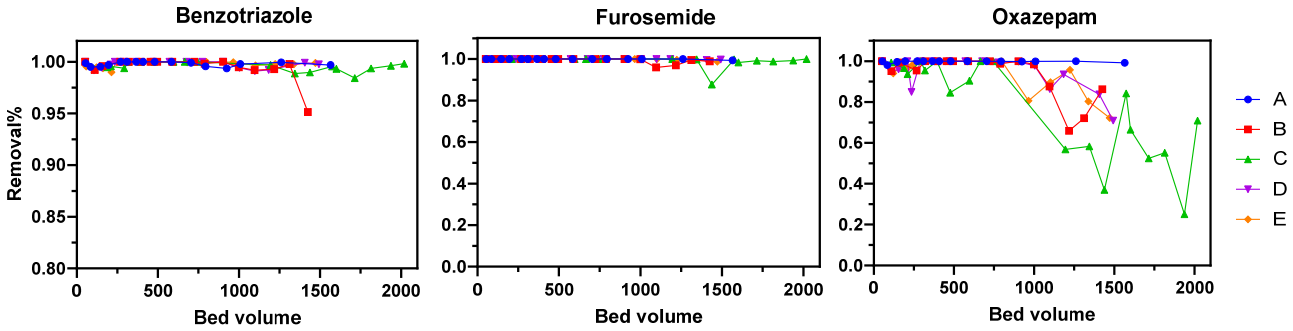


Figure 1: Removal in columns packed with commercial activated carbon (column A) in comparison to activated biochar produced from mixture of sewage sludge and wood. Sludge fraction is 0, 30, 70, and 100% for column B, C, D, and E, respectively.

Discussion and take-home message: 1) Biochar made from sewage sludge can remove micropollutants, its capacity, is however lower than commercial GAC. 2) The removal and capacity of activated biochar is compound dependent whereas commercial GAC is expected to have capacity over 10.000 bed volumes.

*jz@envs.au.dk: Frederiksborgvej 399, 4000 Roskilde
**hrso@aquagreen.dk: 7421, Risø Huse 50, 4000 Roskilde
***sls@odsherredforsyning.dk: Hovedgaden 39, 4571 Grevinge
****kb@envs.au.dk: Frederiksborgvej 399, 4000 Roskilde

Role of active carbon saturation with chlorinated compounds and operational factors on removal of PFAS and DMS in pump and treat plants

***Krzysztof Piotr Kowalski**, Capital Region of Denmark**

Abstract: This study investigates the efficacy of granular activated carbon (GAC) filters in the removal and monitoring of chlorinated solvents across 40 pump and treat plants operated by the Capital Region of Denmark. In 2022, an extensive analysis campaign was conducted to measure dimethyl sulfide (DMS) and per- and polyfluoroalkyl substances (PFAS) concentrations in both inflow and outflow from the treatment plants. The study aims to present data and correlations between the removal efficiency of DMS and PFAS and critical factors such as active carbon saturation, process parameters, and water quality. Preliminary findings showcase that pollutant concentration in outflow increases increase of active carbon saturation, Figure 1 and 2. However, to grasp the complexity of these relationships, advanced statistical methods will be incorporated to consider additional parameters. By analyzing the removal efficiency of PFAS and DMS in relation to active carbon saturation, water quality parameter and operational factors, this study may provide some insights for optimizing treatment strategies in the face of emerging contaminants.

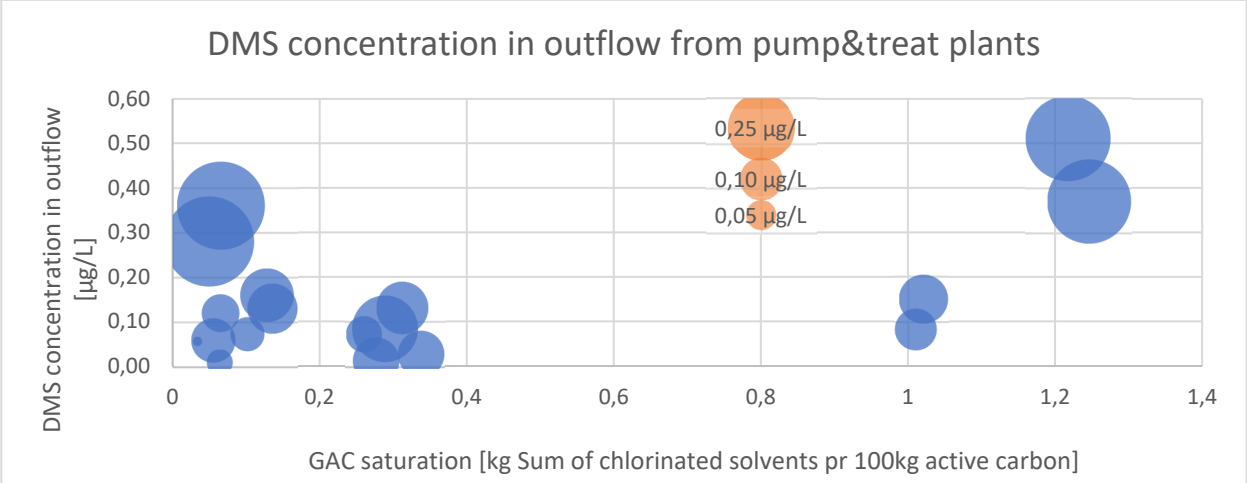


Figure 1 DMS concentration found in outflow of some of the pump and treat plants with GAC filters (bobble size presents concentration in inflow)

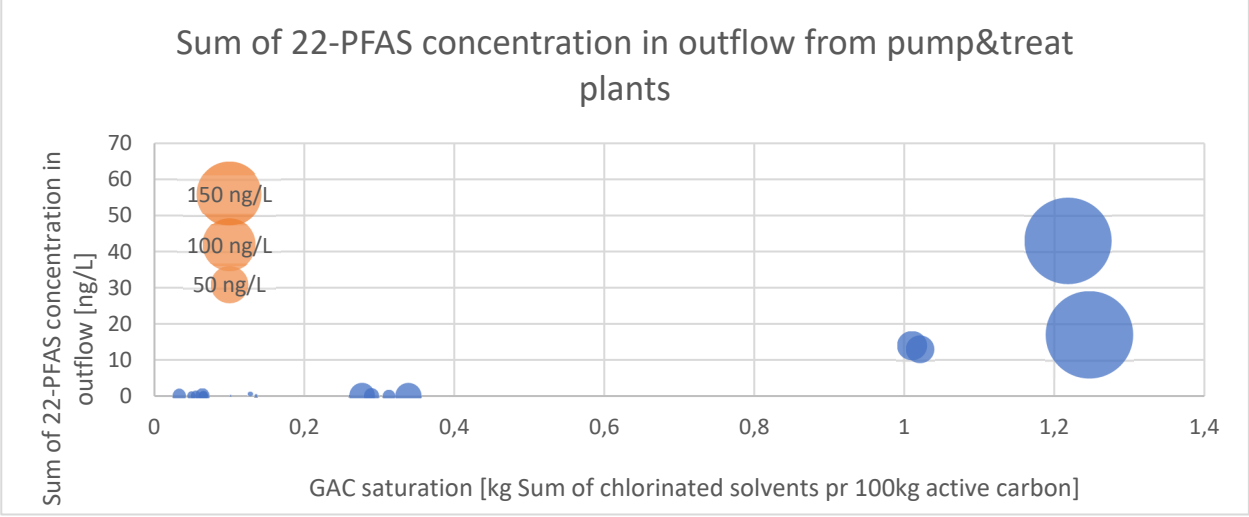


Figure 2 Sum of 22-PFAS concentration found in outflow of some of the pump and treat plants with GAC filters (bobble size presents concentration in inflow)

* krzysztof.piotr.kowalski@regionh.dk

Can water resource recovery facilities participate in the stabilization of the energy system?

Ana Fernández-Guillamón, University Castilla-La Mancha, Antonio Vigueras-Rodríguez, Politécnica de Cartagena**, Luca Vezzaro,* ***Borja Valverde-Pérez*** *(bvape@dtu.dk), DTU Sustain****

Introduction: Grid frequency *f* is an essential parameter in energy systems and must be as close as possible to its nominal value (f_{nom}). However, over recent decades, and because of the transition towards larger share of renewable energies, power systems have been gradually changing. Energy systems relying on diverse energy sources suffer from frequent deviations from f_{nom}. To compensate this, consumers can participate in the energy market by selling capacity (i.e., compromising themselves to increase power demand above their needs) or reducing demand, thereby compensating for the deviations caused by renewable energies during their (de-)activation. In this study we assess the feasibility of using WRRFs to compensate for these deviations by optimizing aeration regimes.

Methods and data: the plant model describes the Kolding WRRF, which is modelled as two alternating aeration tanks for nitrogen removal, following the bio-denitro process. Aeration is responsible for at least 60% of the power consumption of the WRRF. The NDHA model is used to describe carbon and nitrogen removal. The model accounts with ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB). AOB model describes both the nitrifier, nitrification and the denitrifier denitrification pathways for N_2O generation. Heterotrophic denitrification is described as a four steps process. Considering that a WRRF is participating in the grid frequency control, when $f \neq f_{nom}$ during a certain amount of time, such WRRF is committed to modify its energy consumption. The aerators of the WRRF would be switched ON/OFF depending on the grid frequency:

- $f < f_{nom}$ → Turn OFF both aerators → reduce consumption
- $f > f_{nom}$ → Turn ON both aerators → increase consumption

Once that both aerators are simultaneously connected or disconnected, inflow is divided into the reactors. When either the frequency has been restored or the maximum duration has been exceeded, the frequency control by the WRRF is not required anymore and the WRRF recovers traditional rule-based control.

Results: results (fig.1) suggest that WRRFs can participate in the energy system for frequency compensation in most assessed scenarios. When short term control actions are required (approx. <40 min), the WRRF shows better nitrogen removal during the night and early morning. However, long interventions should be avoided during the highly loaded periods, such as midday, when the WRRF is affected by the wastewater discharged to the sewers in the morning. It is also during this period when N_2O emissions reach their highest values (data not shown), compromising the carbon footprint of the WRRF. Carbon removal is improved when the energy demand is increased, while it is poorer when the aerators are switched off and nitrate is completely removed.

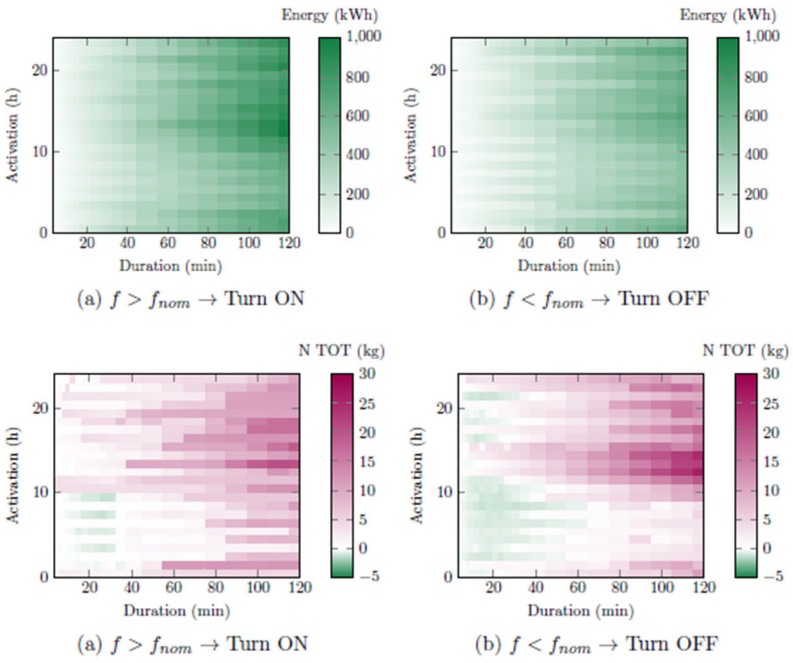


Figure 1. Left: increase on energy demand and impact on nitrogen removal when the WRRF sells capacity at different intervals of control switch (x-axis) and times of the day (y-axis). **Right:** decrease on energy demand and impact on nitrogen removal when the WRRF reduces energy demand.

Membrane crystallization for Li recovery from brines

Mohammad Mahdi A. Shirazi*, AAU BIO, Aamer Ali****, AAU Energy, Cejna Anna Quist-Jensen*****, AAU BIO

Introduction: Membrane Crystallization (MCr) is emerging as a promising technology to improve the extraction of minerals from brine sources that are currently underutilized. The conventional techniques employed for mineral extraction are confronted with a range of difficulties, including limited specificity, reduced productivity, potential harm to the environment, and operating limitations. The MCr technology (Figure 1-a) has the potential to significantly transform this field by integrating many unit operations into a single, compact, modular, and efficient process for recovery of minerals and water from unusual sources, such as highly saline brines. In current study, we explored the potential of MCr for Li from different brine compositions.

Methods and data: The MCr system (Figure 1-b) used in the current study consists of a hollow fiber module with 21 hydrophobic, capillary polypropylene (PP) membranes (pore size of 0.2 µm and porosity of 73%), peristaltic pumps for recirculation of hot (feed) and cold (permeate) streams, feed and permeate containers, analytical tools for monitoring the feed solution and permeate stream, a scale, and a data-collection system. The feed solution was made by dissolving various salts (Li_2CO_3, NaCl, KCl, and LiCl) into distilled water to provide a simulated multicomponent brine solution. The effect of different feed temperatures and flow rates on Li crystallization and vapor flux was explored.

Results: Among various operating parameters, the feed temperature was found the most effective one. This is because MCr is a thermally driven membrane process. This temperature difference between the feed and permeate streams provides the vapor pressure difference, which is the driving force for mass transfer. As could be observed in Figure 1-c, stable, but different permeate fluxes were achieved at various feed temperatures (40, 50, and 60 °C). Moreover, it should be pointed out that the crystallization of different salts can happen at different temperatures. For example, for the Li_2CO_3-water solution, crystals were formed earlier at higher feed temperature. This is due to the reverse effect of temperature on the solubility of Li_2CO_3. However, in the presence of various salts, the crystallization behaviour can be different. For example, the addition of NaCl or KCl into the Li_2CO_3-water solution can delay the formation of Li_2CO_3 crystals. This can be explained by the effect of NaCl and KCl on the solubility of Li_2CO_3 in water due to the salting-in phenomena, also known as uncommon-ion effect.

Discussion and take-home message: MCr is a promising technology for Li extraction from different brines. The process allows controlling the crystal quality and crystallization kinetics through operative variables such as feed temperature. This method has the potential to make Li extraction more sustainable and potentially economically viable when combined with renewable or low-grade energy sources. The pure water in the permeate stream (Figure 1-d) is recovered as a byproduct.

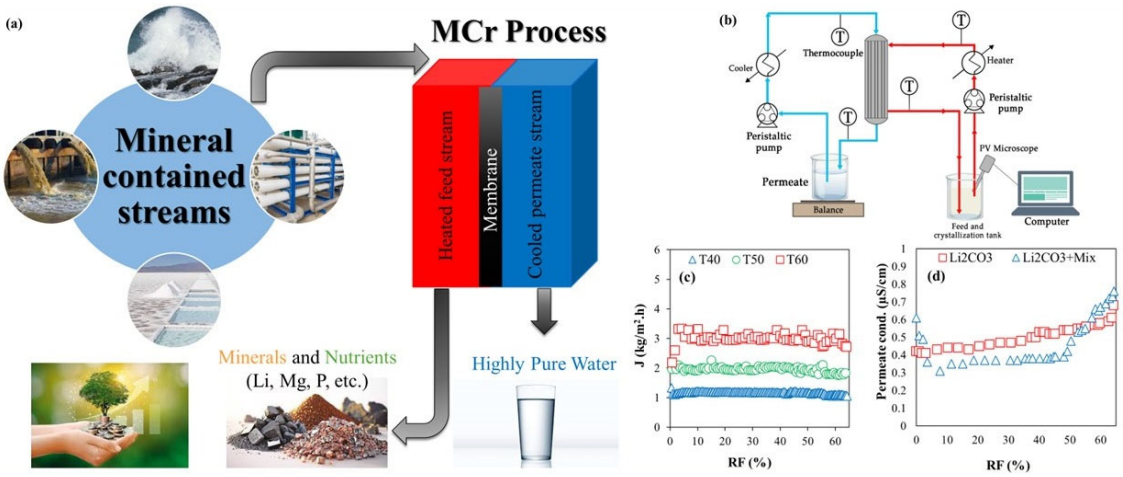


Figure 1: (a) The concept of MCr technology, (b) the typical system for MCr experiments, (c) MCr permeate flux at various temperatures, and (d) the quality of permeate stream by using a multicomponent feed solution at 60 °C.

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

Waste to Watts – Wastewater Powered Sustainable Batteries employing Electroactive Microbes

***Ramya Veerubhotla**, Center for Water Technology (WATEC), Aarhus University, Aarhus C, 8000, Denmark.*

Abstract

Bacteria play a key role in the wastewater treatment process. Typically, energy (in the form of electricity) is required to treat sewage. On the other hand, Microbial Fuel Cells (MFCs) generate bioelectricity employing electroactive microbes to oxidize organic matter and directly convert them to electricity. However, they need expensive membranes, bulky and sophisticated equipment such as pumps to function. My research work involved the development of a novel bacterial biofuel cell made from paper and simple carbon electrodes (costing > 1 DKK per device). To initiate the power, one can simply inject wastewater (0.5 mL) containing bacteria into the device with a syringe. This results in yielding a power output of 10 µW (equivalent to 8.75 W/m^3) converting the wastewater directly into power in an environmentally friendly manner. Further, ten devices are stacked to boost the power output which generated upto 0.1 mW. The energy harvested from bacteria is utilized to power an IoT-based wireless temperature sensor up to 30 s and send the signal wirelessly to a custom-built app on a mobile phone. The integration of wastewater treatment and electricity generation has the potential to revolutionize the way we perceive and manage waste resources.

Introduction: Wastewater treatment is a crucial process for removing pollutants from water before discharge. Microbial fuel cells (MFCs) harness the metabolic activities of microorganisms during wastewater treatment to generate electricity, offering a sustainable and innovative approach to both environmental remediation and energy production.

Methods and data: This study introduces an economical bacterial biofuel cell, employing paper (Whatman Filter paper, handmade paper, and recycled paper) and carbon electrodes (graphite powder). Power activation involves a straightforward injection of 0.5 mL bacteria (*Shewanella putrefaciens* grown in lactate-based synthetic wastewater).

Results: Voltage of 0.5 V and 10 µA can be generated from a single batch operation. Stackable in sets of ten, these devices collectively yield 0.1 mW, powering an IoT temperature sensor for 30 s and wirelessly transmitting data to a mobile app.

Discussion and take-home message: Blending wastewater treatment with power generation is a game-changer, redefining how we handle waste. It's not just eco-friendly; it's a power move, turning waste into a resource for a cleaner and energy-smart future.

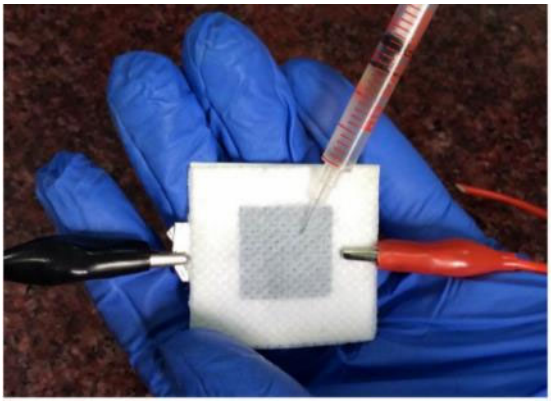


Fig 1. Picture of the Bacterial Biofuel Cell Developed in the Study

Pollutant removal in bioswales

***Emil Jespersen*[1*], *Anne-Kirstine Dybdahl*[1], *Josephine Søborg Jensen*[1], *Anne Laustsen*, *Carlos A. Arias*[1,2]**

Pollutants such as nutrients, heavy metals, and polycyclic aromatic hydrocarbons (PAHs) are transported with runoff during precipitation events. If these pollutants end up in the aquatic environment, they can have detrimental effects on the biota but also on human health. Currently, urban runoff in the older parts of cities is collected in combined sewers where it is mixed with wastewater and then treated at the wastewater treatment plant (WWTP) before being discharged to the aquatic environment. Treatment at the WWTP reduces the load of pollutants discharged to the aquatic environment.

Precipitation events are expected to increase in intensity and frequency due to climate change. This will result in increased events with combined sewer overflow, as the sewers hydraulic capacity can be exceeded during these events. During combined sewer overflow, a mixture of runoff and wastewater is discharged directly to the aquatic environment without treatment, which constitute a serious threat to the aquatic environment. To adopt to the changing climate and to prevent sewer overflow, several countries have started to separate their sewer systems. In the separated sewer system, wastewater is transported in one piping system to the WWTP while runoff is transported in another. In the second piping system, runoff is transported to a retention or detention pond before being discharged to the recipient. Removal in retention and detention ponds are mainly due to sedimentation and flotation, but this is not able to reduce the concentration of dissolved pollutants.

The alternatives to ponds are bioswales. Bioswales are a constructed depression or trench in the landscape where runoff is collected by gravity and then infiltrated through a soil matrix. During infiltration, pollutants are mainly removed by sorption to the soil matrix. However, knowledge on removal rates in bioswales are limited and calls for an assessment. To assess removal rates, water quality is monitored in two bioswales located in the city of Aarhus, Denmark. Water quality is monitored in the in- and outlet of the bioswale combined with samples from two suction lysimeters at different depths in the soil matrix. Removal rates in the bioswales will be compared with removal rates in two retention ponds. We predict that the bioswales will show higher removal rates than the ponds due to sorption in the bioswales compared to sedimentation in the ponds.

[1] [1]Department of Biology, Aarhus University, Ole Worms Alle 1A , 8000 Aarhus C, Denmark

[2] Aarhus University Centre for Water Technology WATEC Aarhus University, Vejlsøvej 25, 8600 Silkeborg, Denmark

[3] Aarhus Vand, Hasselager Allé 29, 8260 Viby J

* emil@bio.au.dk

Helical Hollow Fiber Membrane Modules for Energy-Efficient Membrane Distillation of Industrial Wastewater

Thomas Märcher Odgaard, AAU BIO , Cejna Anna Quist-Jensen**, AAU BIO, Aamer Ali***, AAU Energy*

Abstract

Introduction: Membrane distillation (MD) has emerged as a versatile and prospective separation process with applications in desalination and wastewater reclamation. Despite its advantages, the implementation of MD faces persistent obstacles such as energy consumption and membrane fouling, which diminish its desirability and sustainability in comparison to traditional water separation techniques. State-of-the-art MD hollow fiber modules employ a straight fiber geometry, which, potentially, are suboptimal in terms of energy efficiency. In this study, various fiber geometries, encompassing both straight and helical configurations, are examined with the objective of enhancing the energy efficiency and, consequently, the permeate flux in direct contact MD systems, with a long-term objective of modeling such systems.

Methods and data: For the fabrication of helical MD fibres a MATLAB model capable of modelling the fibres was developed. This allowed to investigate feasible and viable fibre geometries prior to physical module fabrication (Figure 1-a). After selection, the desired geometries filtration modules were made with a fixed fibre length of 100 mm, and varying module length depending on helical pitch. The used fibres are commercially available with a pore size of 0.2 µm, a porosity of 73% along with the internal dimensions of 1.8 mm. The linear capillary membrane fibres were shaped into a helical geometry by winding them around a central metal support rod of a sufficient radius, attaining both the desired pitch and the specified number of turns (Figure 1-b). The membrane modules were tested in a direct contact MD (DCMD) setup.

Results: With the aid of the MATLAB model, it was possible to fabricate helical fibre geometries with relative pitches in the range of 10-15. At the same time initial experimental results show an increased permeate flux of helical fibre designs compared to their straight counterparts. It was also observed that the difference in permeate flux of helical and straight fibres was the minimum at very low and very high Re; thus, the helical fibres showed the best relative performance at intermediate Re ranges. Experiments highlighting the impact of parameters (radius and diameter) of helical geometric are ongoing, with final tests utilizing industrial wastewater from the food sector as feed solution.

Discussion and take-home message: The outcomes of this study demonstrate that alternative helical hollow fiber membrane geometries hold the potential to augment membrane distillation permeate flux and, consequently, enhance energy efficiency. Such geometries also have the potential to reduce concentration and fouling issues in membrane processes. This improvement is presumed to arise from the potential reduction of temperature polarization, mainly on the feed side, and to a lesser extent on the permeate side as well.

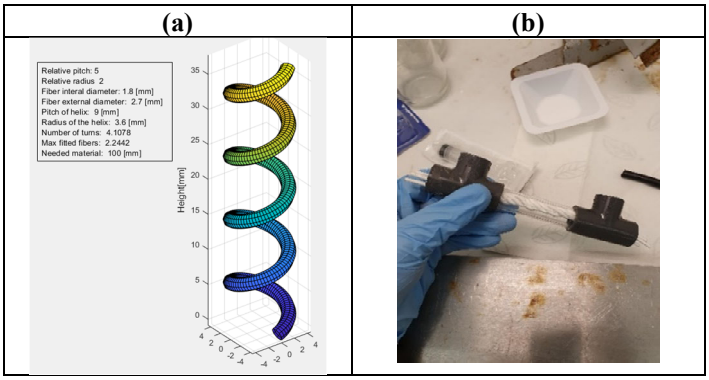


Figure 1: (a) Simulation of the helical fiber geometry, (b) the fabricated helical module.

* todgaa19@student.aau.dk*: Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*

** *cejna@bio.aau.dk: Fredrik Bajers Vej 7K, 9220 Aalborg East, Denmark*

*** *aal@energy.aau.dk : Fredrik Bajers Vej 7H, 9220 Aalborg East, Denmark*