17th DWF WATER RESEARCH CONFERENCE
8th February 2023

Technical Abstracts and timetables
EVENT SPONSOR 2023

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2023

Danish Water Forum
Agern Alle 5, 2970 Hørsholm, Denmark.
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OPENING SESSION,

OPENING SESSION, 8 February 10:00-12:00 (All time slots given in the program are CET)
THEME: PFAS, Fate and Future
EVENT HALL 1.
Moderator and Chair: Peter E. Holm, Vice chairman, Danish Water Forum

10:00 Welcome, by Hans-Martin Friis Møller, Chairman, Danish Water Forum
10:10 Logistics, by Jesper Dannisøe, Director, Danish Water Forum
10:15 Cleaning of "the forever chemical" in water - perspectives and priorities, Rikke Markfoged, TI
10.35 PFAS in the treatment plants, Nikolaj Mikkelsen, Kalundborg Utility
10:55 PFAS: Technology Horizon Scan & Global Best Practices Study, Lauren Former, Isle Utilities
11:15 Health aspects of PFAS, Susanne Hougaard Bennekou, Danish Patient Safety Authorities (ONLINE)
11:35 EU action on PFAS; Joannes Gaard, Danish Ministry of Environment.
11:55 Q&A
12:00 Lunch break

NO ABSTRACTS FOR THIS SESSION

Technical sessions:

Session	Title	Chair and co-chair	Where??
Session 1: 13:00 – 14:30	PFAS, Fate and treatment.	Ida Holm Olesen, Novafos	**EVENT HALL**
Session 2: 15.00 – 16:30	Resource recovery from waste water.	Chair: Ole Mark, Krüger	**EVENT HALL**
Session 3: 13:00-14:30	Removal of organic micropollutants and toxicity	Chair: Peter E. Holm, KU, Vice Chair DWF	**ROOM 1**
Session 4: 15:15-17:15	Groundwater and Evapotranspiration	Chair: Peter Henriksen, WATEC, AU, DWF Board	**EVENT 4**
Session 5 13:00 – 15:00	Drinking water and Floooding.	Chair Hans-Jørgen Albrechtsen, DTU, Inês Breda, Eurowater	**EVENT 4**
Session 6: 15.15 – 17.15	Sulfides + special.	Chair Torben Lund Skovhus, VIA, Christian Schou, Aarhus Vand	**ROOM 1**

After the sessions (approx 16:45), you are invited to drinks, snacks and mingling, followed by the nomination for the NIRAS and Grundfos awards.

Registration fee incl lunch, breaks, snack, drinks (ex. VAT):

- Students: 400 DKK
- Members of DWF: 800 DKK
- Non-members: 1.200 DKK

The conference does NOT offer online access to the sessions.

Session 1: PFAS, Fate and treatment.

Time: 13:00 – 14:30
Chair: Ida Holm Olesen, Novafos, DWF Board
EVENT HALL

Time	Speaker	Topic
SESSION 1: 13.00 – 14:30		
13.00	Jan-Max Arana Juve	Size-selective trapping of PFOA in Fe-modified zeolite framework photocatalysts
13.15	Allyson L. Junker	Photocatalytic Membranes for PFAS Removal
13.30	Junying Wen	Comparison of photo-degradability of legacy and emerging PFAS in water
13.45	Sabine Lindholst	How to effectively reduce PFAS discharge – possibilities and challenges
14.00	Dhruv Sharma	LCA of waste handling technologies for PFAS
14.15	Dorte Harrekilde	Remediation technologies for PFAS in groundwater – an overview
14:30	Coffee break	

Size-selective trapping of PFOA in Fe-modified zeolite framework photocatalysts

Jan-Max Arana Juve*, and Zongsu Wei**

Introduction: Per and polyfluoroalkyl substances (PFAS) are a family of persistent micropollutants found in water and soils all over the world, which lead to catastrophic consequences for human health and the environment. Perfluorooctanoic acid (PFOA) is one of the most widely discharged PFAS pollutants. The main strategy to deal with PFOA at the lab and practical scales are based on adsorption technologies such as activated carbon; however, effective and low-cost PFOA degradation methods are still needed. In this context, we designed an adsorptive photocatalyst with common commercial materials to adsorb large amounts of PFOA and further degrade it under UVA irradiation.

Methods and data: In this work, 5 modified commercial zeolite frameworks are used as adsorbent materials to evaluate the effect of the pore opening. A simple modification process exchanges iron ions with H^+ in the zeolite pore and iron oxide is precipitated on the catalyst surface to initiate degradation of PFOA upon UVA irradiation. Additionally, 5 commercial zeolites with the same framework are used to study the effect of the composition and design an effective catalyst to adsorb and degrade PFAS to operate under realistic conditions. We aim to (I) understand the effect of the framework structure and composition on PFAS removal and degradation; and (II) provide insights to elucidate the adsorption and photodegradation mechanisms.

Results: The BEA zeolite outperforms other tested frameworks due to its similar pore size compared to the reported PFOA molecule (13 x 6.5 x 6.5 Å). The optimal adsorption capacity of BEA zeolites is 70mg PFOA/g catalyst, which is comparable to the performance of granular activated carbon. The iron-doped BEA zeolites are stable photocatalysts that can achieve complete degradation and >60% defluorination of PFOA in 4h optimizing the SiO_2/Al_2O_3 ratio to 150. The complexation of PFOA and the Fe species favored subsequent degradation by superoxide radicals.

Discussion and take-home message:

- Fe-BEA zeolites have excellent PFOA adsorption (70mg PFOA g^{-1}) and degradation (>60% defluorination in 4 hours).
- The modification results in a stable adsorptive photocatalyst with tailored pore size, which fits the PFOA molecules.
- Iron complexation and superoxide radicals lead to a stepwise defluorination under low-energy UVA irradiation.
- An initial adsorption (i.e. in a settling tank) and a second photodegradation step can ensure the practical application of photocatalysts.

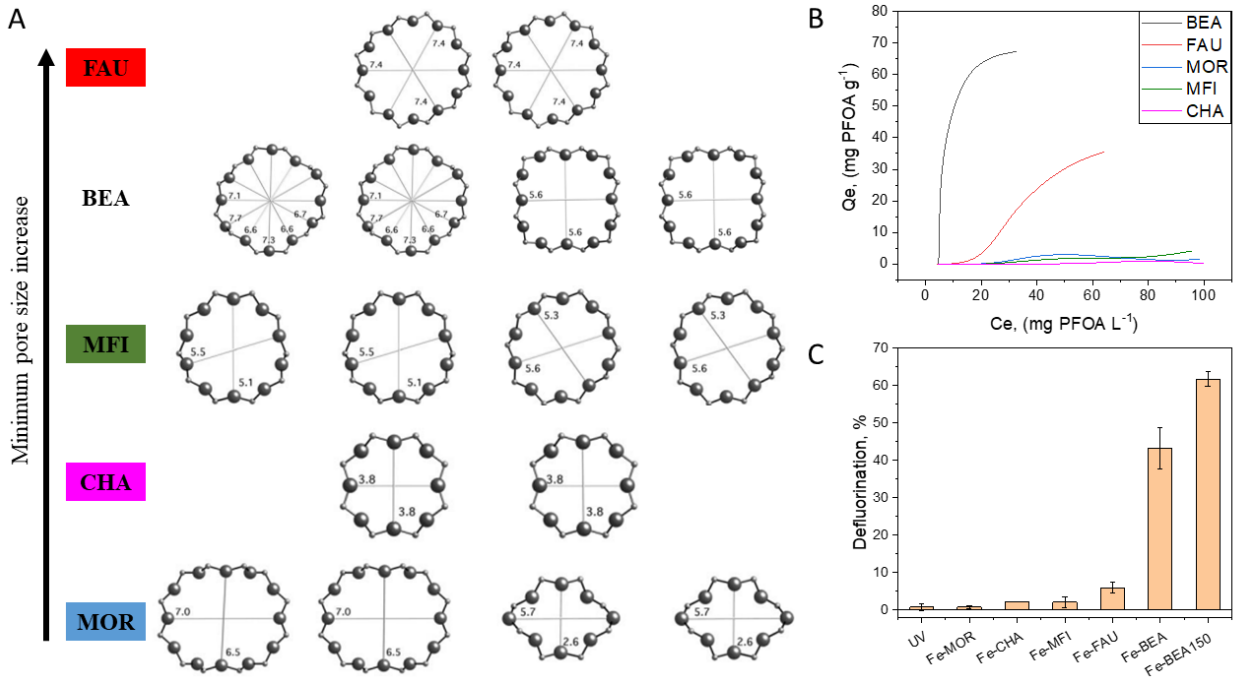

Figure 1: Site-selective Zeolite frameworks (SiO_2/Al_2O_3 ratio 30) a) types of zeolite pore channels and theoretical sizes, b) adsorption isotherms, c) photodegradation of PFOA (365nm, 1 mg L^{-1} PFOA, 1 g L^{-1} catalyst, 4 hours irradiation)

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Photocatalytic Membranes for PFAS Removal

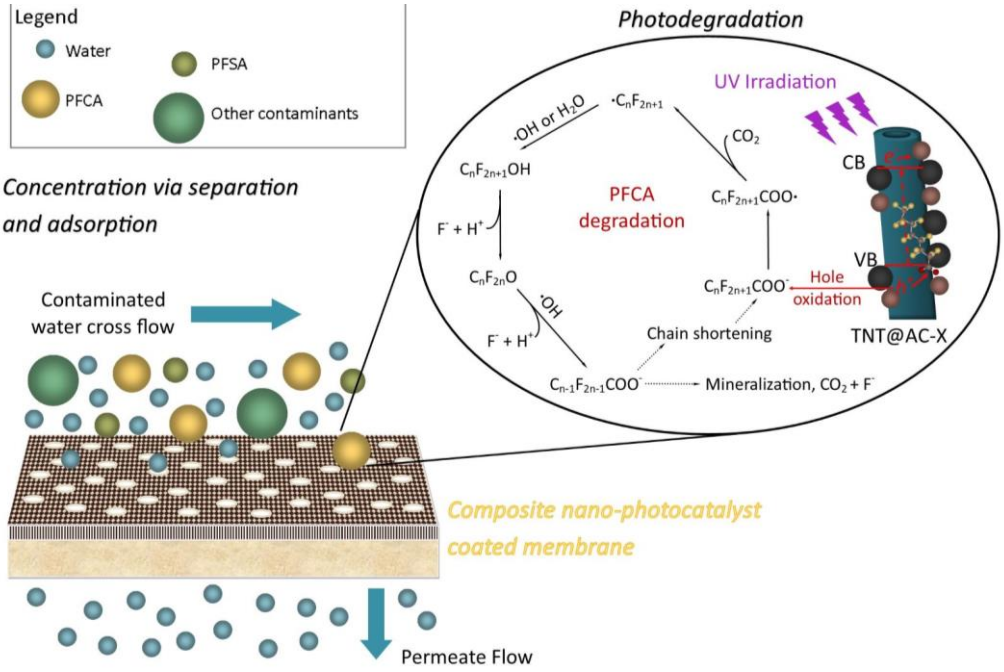
*A. L. Junker & Z. Wei, Department of Biological and Chemical Engineering, Aarhus University**

Introduction: Persistent pollutants, such as per-and polyfluoroalkyl substances (PFAS), endanger society due to their resistance to degradation, mobility in the environment, and long-term exposure risk. While water treatment methods are ineffective, reverse osmosis and activated carbon can remove PFAS from water but generate contaminated waste streams. Advanced oxidation processes and thermolysis treatments show potential to mineralize PFAS into benign compounds; however, these methods are expensive, energy intensive, and difficult to scale up. By contrast, combined membrane separation and adsorptive photocatalysts can efficiently concentrate and destroy PFAS, without harmful waste products and under conditions normally found at WWTPs.

Methods and data: Four adsorptive photocatalysts were synthesized and compared for PFAS degradation in slurry form and immobilized on PES ultrafiltration membranes. Catalyst loadings were tested and compared. PFOA and PFOS spiked samples were treated under UVC irradiation for 4 to 6 hours. After treatment, samples were analysed for fluorine ion content by ion chromatography and for PFAS content by LC-MS. Samples are also being testing for potential leaching of catalyst.

Results: The catalysts were successfully immobilized on the membrane. Short-chain PFAS species and fluorine ion observed during sample analysis are evidence of PFAS degradation. In slurry, the photocatalysts removed 85-95% and degraded 31-58% of PFOA. Comparatively, the membrane tests removed 34-46% of PFOA, though 10 times less catalyst treated the same volume. However, the membrane's removal abilities diminished when reused cyclically.

Discussion and take-home message: The composite catalyst simultaneously removes PFAS and destroys it; doping further improved its effectiveness. Immobilization on membrane surfaces was successful; the polydopamine method was simpler and vacuum deposition achieved the highest catalyst loading. However, the setup needs further optimization to improve cyclical membrane use. In the future, additional coating methods will also be tested on ceramic membranes, and the photocatalytic membranes will be tested under different pressure and flow conditions.



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Comparison of photo-degradability of legacy and emerging PFAS in water

*Junying Wen, WATEC & AU BCE *, Huarui Li, WATEC & AU BCE & YTU **, Zongsu Wei, WATEC & AU BCE ***, Leendert Vergeynst, WATEC & AU BCE *****

Abstract

Introduction: Poly- and perfluoroalkyl substances (PFASs) are of high concern in Denmark. Many studies have been focusing on legacy PFASs such as perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which have in the meantime been banned in Europe and United states. However, limited studies investigated the removal of newly emerging short-chain replacements such as hexafluoroprolylene oxide dimer acid (GenX), which has already been detected in drinking water in many regions (e.g. United States, The Netherlands). In this study, we have compared the potential of photocatalysis to degrade PFOA, PFOS and GenX.

Methods and data: PFOA, PFOS and GenX (10 µM) were exposed to Fe-doped zeolite (1 g/L) under UV radiation for up to 7 hours. PFAS and fluoride were analysed by high-performance liquid chromatography coupled to mass spectrometry and ion chromatography, respectively.

Results: Compared to PFOA (70%) and PFOS (51%), the defluorination of GenX (33%) was the lowest (Fig 1a). The removal of GenX (79%) was also the lowest compared to PFOA (100%) and PFOS (100%) after 7 hours of irradiation (Fig 1b). The first-order degradation rate of GenX (1.23 min-1) is 3 and 1.4 times lower than PFOA (3.92 min-1) and PFOS (1.71 min-1), respectively.

Discussion and take-home message: The slower degradation of GenX is likely due to its lower hydrophobicity, leading to less adsorption on the Fe-zeolite photocatalyst. Based on the identified transformation products, we proposed 2 different pathways of GenX degradation resulting in the formation of ultra-short-chain PFASs with a chain length of 2 and 3 carbon atoms. Degradation of GenX resulted in 2 moles of ultra-short-chain PFAS per mole of GenX, whereas PFOA and PFOS degraded by losing 1 carbon-fluorine bound at the time, resulting in a gradually shortening chain length of 7 to 2 carbon atoms and only 1 mole of degradation products per mole of parent compound. The produced ultra-short-chain PFAS showed to be resistant to photocatalysis, likely due to their low hydrophobicity and thus poor adsorption on the photocatalyst, which explains the overall lower defluorination of GenX. In conclusion, GenX is more challenging to be removed and degraded from water because it produces higher levels of ultra-short-chain transformation products, which are more persistent to photocatalysis.

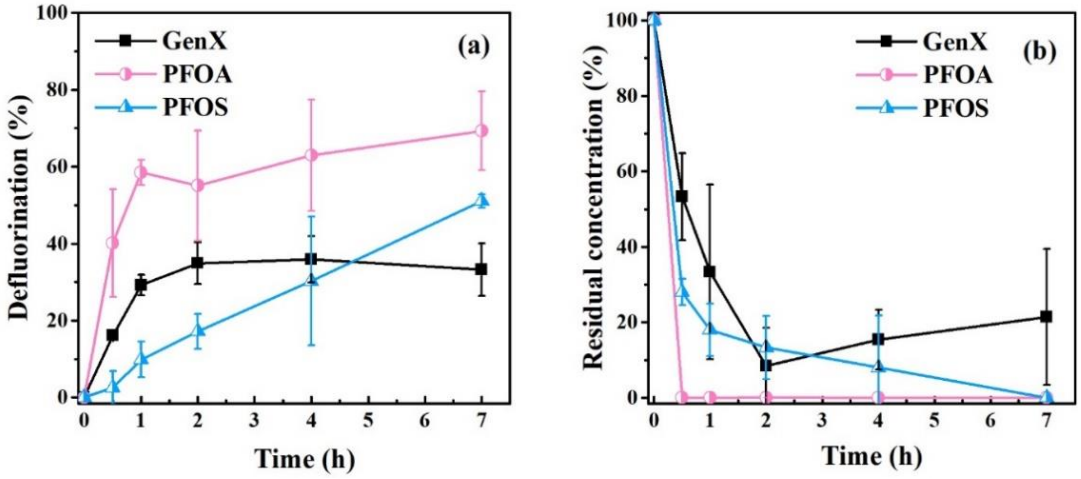

Figure 1. Comparison of the defluorination (a) and degradation (b) of GenX, PFOA and PFOS (n = 3).

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How to effectively reduce PFAS discharge – possibilities and challenges

S. Lindholst, Rikke Markfoged, Danish Technological Institute, Tore Svendsen, Vandrensning.com**, Kamilla Speht Kaarsholm, Henrik R. Andersen, DTU Sustain****

Introduction

PFAS, the forever chemicals with bioaccumulating and often harmful effects have been reported everywhere – in air, water, and soil. Different obvious point sources have been identified, but this is probably only the tip of the iceberg. The project "PFAS-inator" aims for designing a sustainable and cost-effective technology concept for removal of PFAS compounds. Here it is considered in what degree parameters impact removal efficiencies, cost, and energy consumption, and further how these measures are affected by the degree of cleaning.

Methods

For the evaluation of the effect of parameters, the following have been considered:

- effect of other compounds usually present in leachate and run-off water from fire-fighting facilities,
- effect of PFAS-concentration and PFAS-substances, and
- effect of pre-treatment both with regards to improved cleaning-efficiencies and production of PFAS-contaminated waste.

Substances interfering with PFAS-adsorption were evaluated with laboratory and on-site resin columns (Figure 1). Pre-treatment technologies such as flocculation, flotation, filtration, foam fractionation and ozonation were optimized and evaluated for their removal efficiency of interfering compounds and total cost- and energy requirement. Adsorption of various PFAS compounds to ion-exchange resin were determined in both batch experiments, laboratory scale columns and pilot scale setups.

In this evaluation SCWO was considered and optimized for destruction of PFAS concentrate, and the effect of PFAS concentration was considered both from a safety and energy/cost perspective.

Figure 1: Column-setup for adsorption efficiency evaluation of various leachate waters. Left: Laboratory setup 100-mL columns and right: small-scale side-stream field-setup (250mL columns).

Results and discussion

Evaluation of both various water matrices as well as technologies for pre-treatment, adsorption and destruction has provided insight into the important parameters for an effective reduction of PFAS discharge to the environment. Here we present that the concentration of organic matter and presence of specific PFAS-compounds are decisive for the efficiency of concentration by adsorption. The efficiency of pre-treatment technologies is dependent on the specific water and types of organic matter, while the optimal use of pre-treatment technology includes consideration of sludge production. While initial PFAS concentration is less important for the cleaning efficiency, cleaning volume and final target concentration have a large impact on the total cost and energy consumption.

Take-home messages

Organic carbon concentration and presence of short-chained PFAS-compounds complicates PFAS-removal efficiencies.
Optimal pre-treatment technology is dependent on water type.
Destruction of PFAS-contaminated waste should be minimized in volume both for adsorbent material and sludge.

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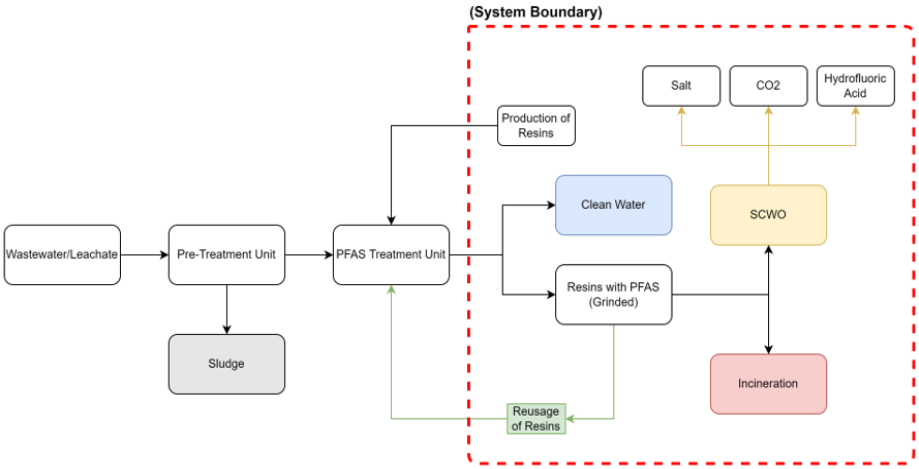
LCA of waste handling technologies for PFAS

R. Markfoged[1], A.Damgaard[2], M. Nymann[3], T. Svendsen[4], D. Sharma[1]

Danish Technological Institute[1], DTU Sustain[2], Aquarden Technologies[3] ,Vandrensning.com[4]

Abstract: Per- and polyfluoroalkyl substances (PFAS) are a group of synthetic, fluorinated chemicals that have been widely used in industrial and consumer products due to their water- and grease-repelling properties. PFAS are highly persistent and bioaccumulate by nature. Because of this, PFAS have been consistently detected within the water, soil, in food products, and even in humans. Due to their high chemical stability, traditional water and wastewater remediation methods have not been sufficient in treating PFAS. Currently, PFAS are removed from water by ion exchange method followed by destruction of either the adsorbent or the concentrated eluent after regeneration. In this study, the environmental impacts from destruction of PFAS soaked ion-exchange resins using two different destruction technologies, namely, Incineration (Waste to Energy Plant) & Super Critical Water Oxidation (SCWO) was quantified. Further investigation was made into if the regeneration of resins would be environmentally viable as compared to resin destruction. This study aims to bridge the gap in the literature by analysing and comparing the environmental life cycle impacts of current PFAS waste handling technologies and identifies the best scenario to eradicate PFAS from the environment.

Methods & Data: The modelling of various scenarios was performed in the software "EASETECH" and follows the guidelines of ISO 14040. The system boundary of the modelling included PFAS-soaked resin to final PFAS destruction, production/reuse of new ion-exchange resin considering production of regeneration solution, and energy-recovery from incineration. The required data for study was provided by various stakeholders (DTI, DTU, Vandrensning.com & Aquarden Technologies) and wherever needed, the libraries from Eco-invent had been used for modelling purposes. The assigned system boundary for the study can be seen below:



Results & Discussion: The emissions in kg-CO2 equivalent for 4 scenarios have been quantified. Incineration (Waste to Energy Plant) with regeneration of resins was, from a climate perspective, shown as the most environmentally friendly scenario to handle PFAS adsorbed resins. However, in the current study, waste to energy plant works as efficiently as it can while the energy recovery from the SCWO plant hasn't been considered and energy production mix taken is not entirely renewable. Moreover, since 58% of the emissions in SCWO plant comes from direct CO2 release, it shows a high potential of improvement by coupling it with carbon capture technology.

As pre-treatment technologies haven't been considered in the current system boundary, the project has been extended as a master's thesis to further investigate the influence of additional treatment steps as well as nutrient recovery from sludge on the obtained conclusions. The limitations encountered in this project will also be addressed and covered in the future work.

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Remediation technologies for PFAS in groundwater – an overview

*Dorte Harrekilde, Ramboll**

Abstract

Introduction: Contamination with PFAS is widespread and there is a growing concern with respect to their presence in groundwater and surface water intended for drinking water. PFAS consist of more than 4.700 compounds with very different physical and chemical properties. Furthermore, quality criteria for PFAS in drinking water are very low in the ng/l range. This makes them very challenging to remove effectively from water. The presentation will give an overview of treatment technologies available to remove PFAS from groundwater.

Methods and data: The presentation on available treatment methods is based on technologies described in the Danish Handbook on investigation and remediation of PFAS-contaminations and on Ramboll's worldwide experience in treating groundwater and surface water intended for drinking water. The technologies are based on adsorption, separation and/or destruction. Effectiveness, availability, developmental status, precursor concerns, cost and sustainability will be discussed for the treatment methods with a focus on methods, that are sufficiently developed to be used in full scale.

Discussion and take-home message: Adsorption of PFAS to granular activated carbon is at present the most widely used treatment method but is not very effective towards short chain PFAS. Ion exchange resins and filtering media are steadily evolving. Removal of short chain PFAS will in many cases require more than one treatment step and frequent replacement of adsorptive or filtering media. New treatment methods are rapidly evolving.

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[No presentation] Removal of PFAS from the drinking water supply of Fanø

A.C. Koch*, S. Duch-Hennings**

Introduction

Per- and poly-fluorinated alkyl substances (PFAS) has been used for a multitude of applications, including firefighting foam, weatherproof clothing, non-stick cookware, and many others, and as a result they are being discovered in more and more locations. The regulatory requirement in Danish drinking water for the sum of PFOA, PFOS, PFNA, and PFHXS is 2 ng/L. At Fanø, the drinking water contains between 3 and 5 ng/L of these substances, and it is therefore a requirement that this level is decreased to meet the requirement.

Methods

To find the best suited treatment technology, filtration through three types of activated carbon (AC) and a special PFAS-selective ion exchange resin was tested, both separately and in combination. The tests were carried out using a setup with two columns as shown in Figure 2, each filled with activated carbon or the selective resin. The test columns were fed with water of drinking water quality (except the elevated PFAS), and they were connected such that they can be used either in parallel or in serial connection.

Results

The results showed that all tested technologies had an effect and removed some PFAS (see Figure 3), but the removal efficiency was significantly better when resin was used compared to AC. The activated carbon type 1 (AC1) showed a removal efficiency fluctuating between 25% and 50%. The activated carbon type 2 (AC2) showed a higher removal initially, but declined steadily to levels below 20%. The activated carbon type 3 (AC3) showed the highest removal of the AC, but also a very fluctuating performance, varying between 40% and 90%. The resin showed much better removal, starting at 100% (outlet PFAS was below the detection limit) and maintaining this level until approximately 75000 bed volumes of water had been treated. At this point, the removal declined slowly, but seems to reach a steady removal of just below 80%, which was maintained at least until 130000 bed volumes had been treated.

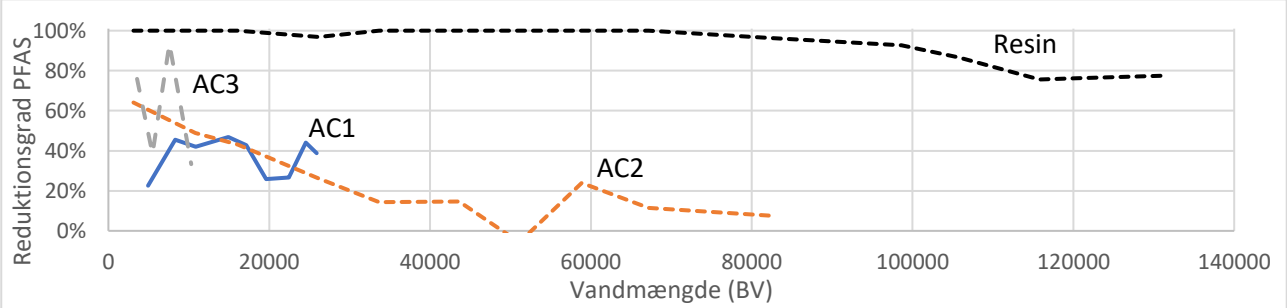

Figure 3

Discussion

Both types of activated carbon showed insufficient removal efficiency to meet the strict Danish requirement of 2 ng/L PFAS. At best, the steady removal efficiency was 50%, meaning that the outlet PFAS level was only reduced to about the same level as the regulatory requirement. The AC3 showed very fluctuating performance, and at the time of writing, more data is required to establish a reliable assessment of the long-term performance. The PFAS-selective resin, on the other hand, showed a removal efficiency of 100% initially and is thus adequate for reaching values in compliance with the regulation.

A possible challenge with the resin can be, that if the water contains high levels of NVOC, the NVOC can cause fouling on the resin. This challenge can be solved by using filtration through AC before the resin filter. The water at Fanø had a level of NVOC of 3-4 mg/L and AC-filtration was used initially as safety, but it proved unnecessary in this case. With other sources of water, the AC-filtration may be required.

Based on the results from this test, a full-scale PFAS removal based on selective resin is now being built.

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Session 2: Resource recovery from wastewater

Time: 15:00 – 16:30
Chair: Ole Mark, Krüger, DWF Board
EVENT HALL

Time	Speaker	Topic
15:00	Rune Dall Harpøth	Development of model for optimizing biogas production and reducing methane emissions
15:15	Brian Rosenkrantz Jensen	Integrated steam-drying and pyrolysis of biosolids
15:30	Dennis Severin Hansen	Experiments on Chinese Cabbage Growth and Soil Conditions by Amendment of Sewage Sludge Produced Biochar at Different Temperatures
15:45	Trine Dalkvist	Digital Twins for Water Resource Recovery Facilities (WRRFs) – Lessons learned from full-scale applications
16:00	Jonathan Guld Christensen	ReUse: Re-utilization of Resources from Industrial Waste Streams
16:15	Tanzila Sharke	Selective recovery of phosphorous using activated carbon material impregnated with iron oxide and (electro)chemical regeneration of sorbent active sites
	End of session	

Development of model for optimizing biogas production and reducing methane emissions

*Martin Rosenørn Eskesen, Christian Holst Fischer og Rune Dall Harpøth, Danish Technological Institute**

Introduction

The project aims to develop a model which can be used as an operational tool for optimizing biogas production in anaerobic digesters treating sludge. The model is based on results from analyses of the biomethane potential of the biomass feedstocks (primary and secondary sludge, industrial waste etc.) from five Danish wastewater treatment plants. Additionally, the residual methane potential of the degassed sludge was analyzed to quantify the methane emissions from the storage tanks, from which gas is often not collected. This is of significant relevance, as it may soon be required by law for the treatment plants to self-regulate their methane emissions. The final goal of the project is to use the data from the laboratory analyses as well as operational data from the full-scale digesters to identify actions to be implemented for optimizing the biogas production.

Methods and data

Samples of biomass feedstocks were collected from the treatment plants three times over a period of about 8 months and was analyzed for dry matter, volatile solids and the biomethane potential was measured in 0,4 L bottles using digestate from the full-scale digesters as inoculum. The results were coupled to sensor data on mass flows and solids content from the treatment plants to calculate the expected methane production in the digester and the potential emissions from the post-digesters. Additionally, the sensor data from the treatment plants was used to obtain relevant operational parameters (organic loading rate, retention time etc.) for comparison between the different plants.

Results

The results show, that by coupling the biomethane potential analysis to sensor data from the biogas plants it was possible to model the theoretical maximum methane production of the digesters. Thus, the model can be used as an indicator for the conversion efficiency of the feedstock at the different biogas plants. The variability in biomethane potential of the sludge from the five plants was up to 18%, while the seasonal variability based on the three samples was up to 17%.

Discussion and take-home message

The results show that there can be notable differences in the biomethane potential of the same type of sludge from different plants, and that the potential also varies during the year. This implies the traditional way of estimating the methane potential from a theoretical value based on a COD measurement is inaccurate, as it does not account for these variations. The model developed in this project can be used as an operational tool for evaluating the operational conditions, based on the conversion efficiency. This allows for optimization of the operational parameters to maximize methane production in the digesters and simultaneously minimize the methane emissions from the storage tanks. Application of the model is not limited to the five treatment plants participating in the project, and thus there is great potential for using this model to improve the biogas production across the whole industry.

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Integrated steam-drying and pyrolysis of biosolids

Brian Rosenkrantz Jensen, Henning Schmidt Petersen

Introduction:

Integrated steam-drying and pyrolysis of biosolids – results and takeaways from the world's first operational full-scale implementation in Denmark

Presentation by a Danish cleantech company of the results from a novel biosolids drying and pyrolysis plant processing biosolids from 50.000 PE (approx. 1.000 tons dry solids per year). Removal of PFAS from polluted biosolids, the positive climate impact via CO_2e capture / storage and fossil fuel savings, nutrients recycling and the ongoing financial savings by using this new technology are all presented.

Municipal and Industrial wastewater sludge management is one of the biggest concerns of water management, as an increasing number of emerging pollutants, such as pharmaceutical residues microplastic, and PFAS, must be controlled. Additionally, many countries are banning spreading biosolids on farmland, with alternative disposal routes being either expensive (such as incineration) or environmentally problematic (landfill).

The technology has the potential to disrupt how to manage biosolids from municipal wastewater around the world. The technology has been developed and patented together with the Technical University of Denmark.

We will present how the pyrolysis process is designed to completely avoid formation of polycyclic aromatic hydrocarbons (PAHs) in the biochar and how it eliminates organic contaminants such as pharmaceuticals and PFAS.

The close integration of the units allows the process to run via the intrinsic energy of the biosolids. The energy for the biosolids drying is largely recovered as hot water, which can be used for e.g. local or district heating. The plant further recovers phosphorus in the 400 tons/year produced biochar.

Methods and data:

The integrated unit is based on thermodynamics and herby the thermal energy is recovered at a very high efficiency.

The data acquired from the first test unit, has been used to upscale and build the commercial unit on Fårevejle and Søndersø wastewater facility.

Results:

Pyrolysis, biosolids management, nutrients recycling, emerging contaminants removal

Discussion and take-home message:

- Phosphorous recovery – Returning a valuable resource to landfill
- PFAS Removal – Removal of organic pollutants
- Carbon sequestration – CO2 reduction

Brian Rosenkrantz Jensen — Sales Manager – AquaGreen

Henning Schmidt Petersen — CEO – AquaGreen

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Experiments on Chinese Cabbage Growth and Soil Conditions by Amendment of Sewage Sludge Produced Biochar at Different Temperatures

Dennis Severin Hansen, Mette Hedegaard Thomsen, AAU Energy,*

*Ariel Turcios, Jutta Papenbrock, Leibniz University Hannover – Institute of Botany **,*
*Anna-Marie Klamt, Kasper Reitzel, SDU – Department of Biology***,*

*Christian Wieth, AquaGreen*****

Abstract

Introduction: The disposal of sewage sludge is governed by market forces, depending on legislation, taxes, and yields. There exist many solutions for pre-treatment and handling sludge at the treatment plant and several solutions for final disposal. Biochar is a novel alternative solution for the final disposal of sewage sludge as a fertilizer or soil improver. Although biochar produced from sewage sludge research is still limited, it has generated a great deal of interest as a soil amendment due to its potential for increased soil fertility and water-holding capacity. The climate change potential for carbon sequestration has often been highlighted as the main argument for producing biochar. However, while such measures are essential when discussing climate change, they do not necessarily benefit the farmers for landfilling biochar on their fields economically. The phosphorus (P)-rich content in sewage sludge produced biochar could potentially achieve two goals at once related to the rising need for P for food production and the rising risks of climate change-induced droughts worldwide. Both topics have been estimated to threaten agricultural production worldwide in the future, where phosphate rock and phosphorous have been included in the European Critical Raw Materials List in 2014 and 2017, respectively. At the same time, the severe drought affecting many regions worldwide has been further expanding and worsening in the last couple of years, which puts stress on water management, especially with the increasing global population growth.

It is important to emphasize that biochar from sewage sludge is still excluded from being accepted as fertilizer products under the EU Regulation 2019/1009, where the primary concern is mainly the lack of techno-scientific evidence. This study has investigated sewage sludge-produced biochar at different production temperatures and executed plant pot experiments to investigate the effect on plant growth.

Methods and data: A plant pot experiment has been executed at Leibniz University Hannover following the DIN standard 16086-1 using Chinese cabbage (*Brassica rapa* subsp. pekinensis) to investigate different biochar-produced conditions influencing plant growth and soil conditions. The sewage sludge was collected from the Danish wastewater treatment plant Fårevejle and pyrolyzed by the company AquaGreen in Denmark. The samples came from the same batch to secure consistency in its property. The sewage sludge was dried at 120°C and then pyrolyzed under controlled pyrolysis conditions on an in-house slow pyrolysis continuous screw reactor at AquaGreen to ensure uniform heating and treatment. Three different highest treatment temperature was chosen to analyze their characterization effect on the plant experiment: 590°C, 665°C, and 765°C, all with the same residence time of 45min.

Results: Even in a controlled environment, the water holding capacity increased by 18-24% based on the biochar concentration compared to the control group. Furthermore, the addition of biochar in the soil resulted in an increase the concentration of potassium (K) and P in the plant tissue. The increase in crop biomass was, however, not significant within the experiments compared to the control group.

Discussion and take-home message: In a controlled environment, the biochar showed to positively affect the water-holding capacity in the soil and increase the P concentration in the plant tissue. The yield did not show any significant effect in the plant pot experiments. However, this may well be an outcome of executing the experiment in a controlled environment in a greenhouse. The study is a start-up project within in biochar topic, financed by the Interreg Denmark-Germany EU fund project: NEPTUN. More long-term plant studies are necessary to determine the effect of adding biochar produced from sewage sludge on farmland for several crop seasons. This includes to what extent biochar can help agriculture water and P fertilizer management in the future.

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Digital Twins for Water Resource Recovery Facilities (WRRFs) – Lessons learned from full-scale applications

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Abstract

Owing to recent advances in digitalization, great opportunities have emerged for online data collection, and processing, as well as modelling and control of water resource recovery facilities (WRRFs). These components are essential to Digital Twins, providing the framework for data-driven process control, operator training, and decision support for optimal operation of WRRFs towards efficiency and sustainability goals.

This abstract presents the implementation of a digital twin at Egå WRRF (120,000 PE; Aarhus, Denmark), which has been made in close collaboration with the managing utility Aarhus Water. The Digital Twin integrates:

I. A process model of Egå WRRF, describing influent dynamics, treatment processes and automatic controllers (aeration, solids handling, recirculation of activated sludge)
II. Acquisition, storage, and validation of online data from sensors, and energy meters, which are used as input to the process model or for model validation
III. A dedicated user interface, where the status and efficiency of the WRRF can be visualized in real-time and in the future through a set of measured and simulated key performance indicators (effluent quality, energy consumption, operational costs, and carbon footprint)

Key results from the Digital Twin operation at Egå WRRF are summarized in Figures 1 and 2. Real-time evaluation of measured and simulated NH4-N, DO and MLSS concentrations in different locations of the WRRF (Figure 1) shows a close match between measurements and simulations results. This close match makes it possible to rely on modelling evaluations for virtual testing and comparison of alternative operational scenarios. Simulated key performance indicators (Figure 3) relating to energy and cost efficiency and the carbon footprint of the WRRF can be monitored dynamically in real-time by means of model-based soft sensors.

The implementation of the Digital Twin at Egå WRRF will be advantageous for the evaluation of alternative operational scenarios, the predictive identification of adequate controller settings in response to wet weather events and/or to minimize carbon footprint, and effluent compliance evaluation during extraordinary maintenance or process failure.

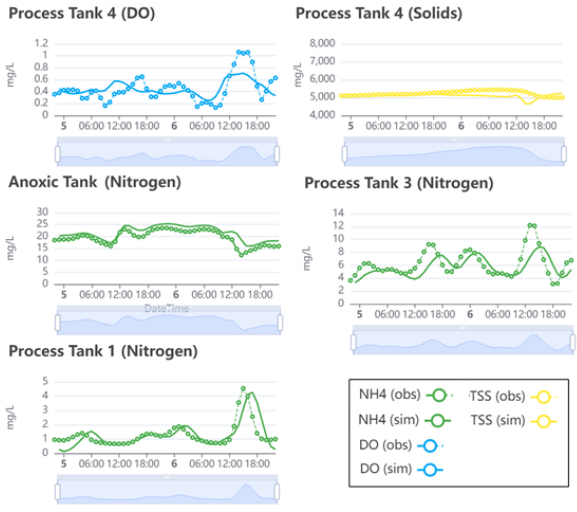

Figure 1. Dissolved oxygen (DO), NH_4-N and mixed liquor SS concentrations from online sensor data and process model simulations at different locations of Egå WRRF. Results are shown for real-time simulations (21:00, 06/04/2022) with hindcast period of 48 h.

Figure 2. Key performance indicators for energy, cost efficiency and carbon footprint at Egå WRRF. Presented trends are based on real-time simulations (21:00, 06/04/2022) with hindcast period of 48 h.

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ReUse: Re-utilization of Resources from Industrial Waste Streams

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Introduction

Substantial amounts of water, energy and other resources are wasted from production facilities when send to the local wastewater treatment plant. Re-utilization of resources, extraction of energy, and reuse of water can reduce the load to wastewater treatment plants, and the environmental footprint. The lighthouse project ReUse aims to implement resource reutilization at three different Danish production facilities - i) production of detergent, ii) paper products from recycled paper, and iii) food ingredients. For each production facility, a thorough initial mapping of the water product streams has pinpointed the most significant re-utilization potential, and pilot scale setup are at the moment verifying the business case before final implementation of a full-scale plant.

Methods and data

Water streams in each production unit was mapped with respect to water flow, water quality and resources - as a rough overview at the total production site and in depth for selected parts of the production. This mapping allowed for a well-considered selection of re-utilization cases, based on valuation, feasibility, and cost. The valuation considered among others, savings on water and CO_2 consumption, savings regarding wastewater handling and chemical consumption, value of extracted resources, and improved manufacturing process and green transition. Feasibility was considered from a holistic perspective, evaluating whether the resources would be valuable at the specific location, and if there is a feasible technology for the extracting and usage of the resource. Finally, calculating the cost for such a new technology included adaption of technology to new market, adjustment of the production unit to provide room for the technology, and CAPEX and OPEX.

A least one case from each production unit was selected for technical evaluation and adaption, including laboratory and pilot testing. The cases are a mixture of proven technologies adapted to new markets, new combinations of technologies as well as new technologies that are developed while testing.

Results

The combined mapping of water, energy and resources has allowed cases to be selected on a thorough basis. Preliminary results have shown the possibility to reduce wastewater production significantly, while extracting resources in the wastewater and reducing energy consumption at all three facilities. The cases, presently being explored in pilot scale, includes minimization of product loss by innovation sensor application and upstream process water treatment, aiming at water reuse and reduced downstream water treatment cost. Results and learnings from the pilot-scale testing will be presented at the conference. Upon completion of the pilot-scale testing and before project completion, full-scale implementation of selected cases is to be initiated at each production facility.

Discussion and take-home messages

The combined mapping of water, energy and resources has allowed for informed decision making for selection of re-utilization cases from both an economic and environmental point of view. Other production facilities can benefit from this methodology. As such, the synergy of considering energy, resources, and water in combination, will support the current political goals regarding energy and environment.

The ReUse project is supported by MUDP under the Danish Ministry of Environment.

Selective recovery of phosphorous using activated carbon material impregnated with iron oxide and (electro)chemical regeneration of sorbent active sites

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Abstract

Eutrophication is the excessive formation of algae as a result of phosphate-enriched water, leading to a growing environmental concern. It is estimated that nearly 70% of the Danish lakes do not meet EU Water Framework Directive (WFD) due to the historical build-up of phosphorus in the lake sediments. Therefore, this work investigates the effectiveness of activated carbon cloth impregnated with iron oxide in phosphorous recovery. Herein, two primary aspects are investigated, 1) selective properties of sorbent material, and 2) (electro)chemical regeneration of sorbent active sites using capacitive deionisation (CDI).

Iron oxide-loaded activated carbon cloth (sorbent) was fabricated. The sorbent material was characterised by X-ray photoelectron spectroscopy (XPS) and X-ray diffraction (XRD). The passive adsorption and electro-active desorption were conducted in batch experiments. A synthetic solution containing 500 ppm concentration of each of the ions $H_2PO_4^-$ and Cl^- was used for passive adsorption. The result showed an adsorption capacity up to 19 - 25 mg $H_2PO_4^-$ per gram of sorbent material, with a 100% selectivity towards $H_2PO_4^-$ over monovalent Cl^- ions. It was also obtained that up to 80% of the adsorbed $H_2PO_4^-$ ions were recovered through the electrochemical system. It was possible to regenerate more than 50% of the sorbent active sites after the 5th cycle of adsorption and desorption experiments. Overall, the iron oxide-loaded activated carbon cloth is a promising material in selective recovery of phosphorous with a good capacity and regeneration ability.

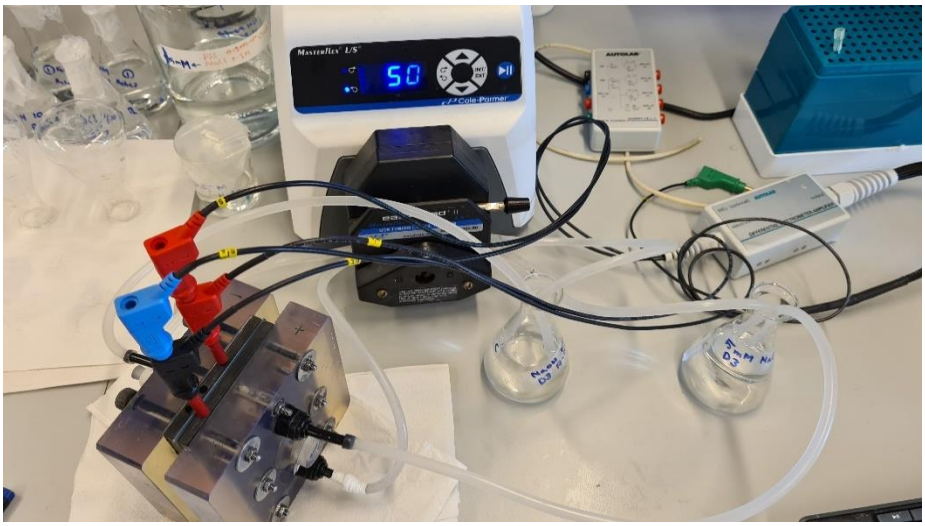


Figure 4: Electrochemical desorption of phosphate and regenerating active sites of the iron oxide-loaded activated carbon cloth in CDI cell

Session 3: Removal of organic micropollutants and toxicity

Time: 13:00 – 14:30
Chair: Peter E. Holm, KU, Vice-chair DWF
<u>Room 1</u>

Time	Speaker	Topic
13:00	Yrsa J. Larsson	Removal of quaternary ammonium biocides in wastewater treatment - biodegradation, metabolites and sorption
13:15	Kamilla Marie Speht Kaarsholm	Design towards a treatment solution for groundwater entering Grindsted Å
13:30	Vaidotas Kisielius	Nature-based solutions and organic micropollutants: emission and control from different water sources
13:45	Nicolaj Damgaard	Extent and causes of inhibition of microbial activity in wastewater treatment systems caused by persistent and generational pollution
14:00	Adam Hambly	Fluorescence as an online water quality tool in recirculating aquaculture systems
14:30	Coffee Break	

Removal of quaternary ammonium biocides in wastewater treatment - biodegradation, metabolites and sorption

A. Mongelli, Y. Larsson**, J. T. Koning***, K. Bester****,*
Environmental Science, Aarhus University

Abstract : Concentrations of Quaternary ammonium compounds (QUATs), i.e., BAC-12, -14, -16 and DDAC were determined in wastewater influent and effluent as well as in sludge. From these removal rates and partitioning were calculated. Additionally, biodegradation was determined quantitatively and metabolites identified.

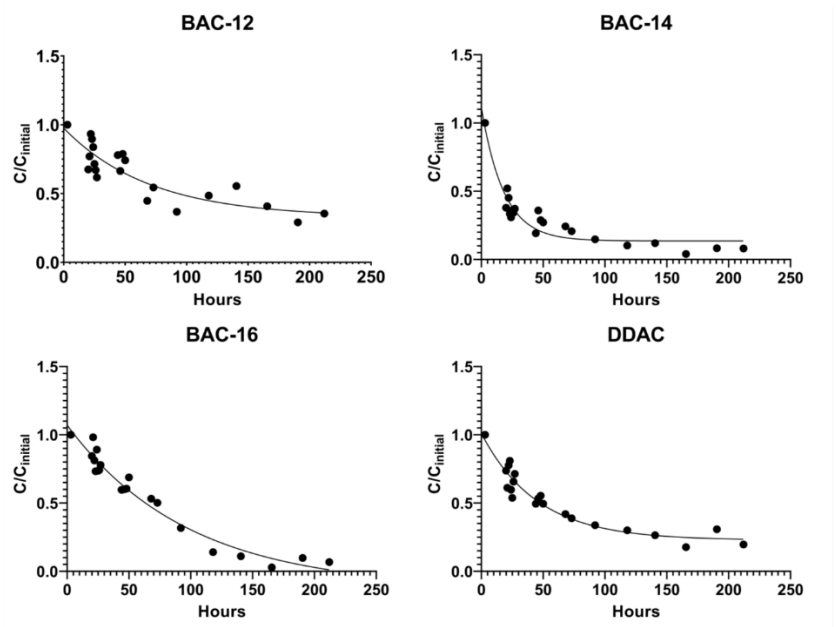
Introduction: QUATs are the most commonly sold biocides in Europe and several thousand tons are marketed every year. However due to their surfactant nature it is not easy to determine basic physico-chemical data and thus predictions for the behaviour in wastewater treatment are difficult to make.

Methods and data: Inflow and effluent concentrations were determined by means of HPLC-MS/MS from 24 h composite samples from three smaller WWTPs on Sjælland.

Results: BAC-12, -14, and -16 as well as DDAC were detected in all WWTPs. The highest influent concentrations in WWTP were measured for DDAC (1000-4900 ng/L) followed by those for BAC-12 (900-2200 ng/L), BAC-16 (88-217 ng/L) and BAC-14 (25-100 ng/L).

Usually, removal in tested WWTPs was high (exceeding 99%). According to the sorption studies, this could completely be due to sorption as sorption alone could result in 99% removal.

Biodegradation rate constants for a large variety of QUATs in sludge were determined in incubation experiments with half-lives ranging from 1.5-60 h. Concerning the congeners found in Danish WWTPs the spread was on average: 13 h (BAC-16) and 14 h (BAC-14), 31 h DDAC 12 and 49 h (BAC-12). Considering the relative rapid biodegradation of BAC-16, it can be assessed, that biodegradation is also contributing to the high removal of BAC-16. Generally, the transfer of QUATs into sludge is high, making the QUATs thus rather a sludge than a recipient water issue.



Biodegradation kinetics for BAC-12, -14, -16 and DDAC in a sludge incubation

Discussion and take-home message: High amounts of QUATs enter WWTPs. In WWTPs high removal occurs. Most of the removal is due to sorption, making QUATs rather a sludge/soil issue than a water/recipient one.

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Design towards a treatment solution for groundwater entering Grindsted Å

K. M. S. Kaarsholm[*,¤], D. F. Sanchez*, R. Martin**, H. R. Andersen**

Abstract: The stream running through Grindsted is polluted with industrial chemicals such as vinyl chloride and other chlorinated ethenes along with sulfonamides, sulfanilic acid and barbiturates due to infiltration of polluted groundwater. A pump-and-treat solution could treat some of the polluted ground water prior entering the stream. However, treating vinyl chloride could be trick as it is very volatile and sorbs poorly on activated carbon. In the MUDP project Treatment Trains, we search for a treatment train which that fits to the complex water pollutions cases by combining efforts and technologies from several SME. In these first results of the project, we were able to reduce the concentration of vinyl chloride by ozonation without creating off-gas. This open the possibility for other companies to add technologies to the treatment train which can address the remaining chemical and degradation products.

Introduction: In Grindsted, the Grindsted Å running through the city is polluted with industrial chemical as polluted groundwater enters the stream. Especially, vinyl chloride cause problems as its concentration in the stream exceeds the national determined water quality criteria. Since the pollution with vinyl chloride mainly occurring in a relative short stretch of the stream, pump-and-treat solution has been suggested to mitigate the pollution. However, treatment of vinyl chloride is tricky as it is very volatile and sorbs poorly on actives carbon. Here we investigated if we could degrade vinyl chloride in an off-gas free ozonation which would allow complementary solutions to be added in later stages of a treatment train, such as activated carbon and biofilm polishing.

Methods and data: We performed batch experiments in the laboratory where ozone was added to samples under controlled conditions without stripping volatile compound such as vinyl chloride. Groundwater samples from different places along Grindsted Å were used. After ozonation, the samples were analysed for chlorinated ethenes, sulphonamides and other compounds related to the pollution at Grindstedværket. The software, GraphPad Prism, was used for data treatment, where the ozone dose needed to obtain 90 % removal was determined.

Results: In our batch experiments, we found the following results:

- Sulfonamides reacts fast with ozone and thus can be considered treated then vinyl chloride is ozonated.
- Sulfanilic acid can be found in high concentration in some locations on the stream (sample 1), and as it reacts fast with ozone, the high and fast ozone consumption by this compound affects the ozonation of other compounds.
- The ozone dose required to remove 90 % of the chlorinated ethenes is ranged vinyl chloride < dichloroethens < trichloroethene < perchloroethene.
- In the main place where the treatment is intended to be placed (Sample 2 and 3) 5 - 15 mg/L ozone removes vinyl chloride and sulfanilic acid leaving only pollutants that are well treated by activated carbon or biodegradation by biofilm.

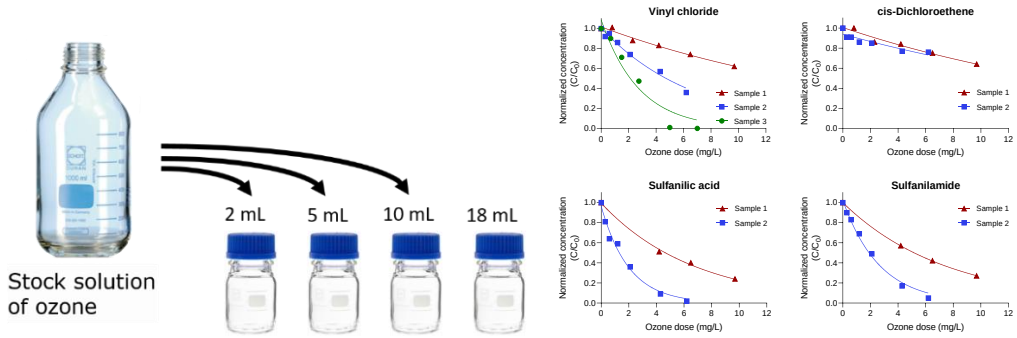

Figure 1. Ozonation of three groundwater samples taken along Grindsted Å. Sample 1 contained high amount of sulfanilic acid (13 mg/L), Sample 2 contained 1.1 mg/L of sulfanilic acid and sample 3 sulfanilic acid not analyzed yet.

Discussion and take-home message: In these first results of the project, we were able to reduce the concentration of vinyl chloride by ozonation without creating off-gas. Based on this, we design a pilot system for continuous ozonation which will be used to investigate other SMEs methods for polishing the water in a biofilm reactor and if and how activated carbon is needed to supplement the treatment in order to remove all chemicals and toxicity measured by bioassays.

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Nature-based solutions and organic micropollutants: emission and control from different water sources

V. Kisielius, L. Zhu*, K. Bester*,**, P.N. Carvalho*,***

** Department of Environmental Science, Aarhus University,** WATEC - Centre for Water Technology, Aarhus University*

Introduction:

Nature-based solutions refer to engineered green infrastructure such as treatment wetlands, green-walls, green-roofs, and others. These systems have shown potential for treating water contaminants, while simultaneously providing other environmental and urbanistic benefits. Since an estimated 80 % of wastewater globally flows to nature untreated with environmental and public health implications, the proposed solutions can potentially significantly decrease this percentage. Micropollutant removal is being increasingly important for the safe water reuse. Therefore, at the Department of Environmental Science (ENVS) of Aarhus University (AU) in Roskilde we further investigate the extent to which nature-based solutions can treat water from micropollutants, and the mechanisms involved in this treatment.

Methods and data: We perform non-target screening, suspect screening and quantification (GC and LC) of organic micropollutants in urban waters, especially wastewater and road runoff. The analytical work supports research developing nature-based solutions for urban water storage, treatment and reuse. We highlight two current projects: NATURE and MULTISOURCE. The project NATURE assesses effectiveness of Danish-based constructed wetlands to reduce aquatic micropollutants with focus on antibiotics and antimicrobial resistance. The project MULTISOURCE monitors seven diverse nature-based pilot installations treating urban water streams in seven countries with the aim to efficiently upscale these installations in urban areas. Installation operators regularly sample influent and effluent waters and perform basic water quality analysis. The team from the AU besides coordinating the pilot activities, measures organic micropollutants and characterizes the pilot performance in terms of the micropollutant removal efficiency.

Results: For comprehensive monitoring AU has developed the MULTISOURCE suspect list comprising 300 organic compounds of relevance (e.g., Water Framework Directive, Watch Lists, Review Publications) for which we validate their presence or absence in different waters and regions. For quantitation of the organic micropollutants, methods with two major target lists for wastewater and urban runoff were designed and verified, covering 90 and 60 compounds respectively. First results demonstrate promising micropollutant removal. For instance, pilots monitored by the project NATURE show 63–92% removal of different antibiotics. A phytoparking pilot in Belgium monitored by the project MULTISOURCE treating separately grey and black water streams demonstrates 96 and higher percentage removal of antidepressants (venlafaxine), insecticides (DEET) and commonly applied disinfectants (didecyl-dimethyl-ammonium chloride (DDAC)).

Take-home message: Nature-based solutions show high potential to control micropollutant emission for the purpose of environmental protection and safe water reuse. They can be applied as stand-alone systems or for polishing a pre-treated wastewater. We will outline the important findings and their potential in the 17th Annual DWF Conference.

Figure 1. Treatment wetland in Denmark (project NATURE, left) and green-wall in Spain (project MULTISOURCE, right), designed to treat combined sewer of the area and greywater of the building, respectively

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Extent and causes of inhibition of microbial activity in wastewater treatment systems caused by persistent and generational pollution.

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

Introduction: In Denmark many sites and sources of water pollution have been identified. Among the most conspicuous are 10 sites identified as 'generational pollution'. The complex and extensive pollution at these sites will remain a problem for generations to come if nothing is done now. Beyond the generational pollutions many pollutions are persistent and hard to treat, such as landfill deposits, industrial production etc. To remediate the pollution, water is pumped into specialized or municipal wastewater treatment plants (WWTPs). WWTPs rely heavily on microbial activity to remove unwanted compounds from the water. This master's project will explore and quantify factors that inhibit microbial metabolism in these plants when polluted water is treated there.

Methods and data: Water was retrieved from two polluted plots of land and from one landfill. the extent of inhibition of microbial activity by the polluted water was determined by standardized 'oxygen uptake rate' experiments complemented with measurement of ammonia and nitrate concentrations to quantify nitrification and heterotrophic activity. The oxygen uptake rate experiments were performed with either non-adapted sludge from a municipal WWTP or adapted activated sludge retrieved from a specialized industrial WWTP treating polluted water. Planned and ongoing work include testing different physicochemical pretreatments of the polluted water such as ozonation or adsorption by activated carbon to evaluate if and how much this can alleviate inhibition of microbial activity and thus facilitate biological treatment.

The potential of microbial adaption to polluted water conditions was further explored in a lab-scale moving bed biofilm reactor (MBBR) with plastic carriers as support for biofilms. The water used for this was landfill leachate, characterized by very high concentrations of inorganic chemicals (ammonium, sulphate, phosphate etc.) and organic xenobiotics (PAHs, PFAS etc.).

Results: Preliminary results show 30% inhibition of heterotrophic oxygen uptake in the polluted water compared to a nonpolluted water control. In the MBBR setup a stable biofilm grew on plastic carriers in landfill leachate in less than one month. Measurements of ammonium and nitrate show active nitrification and denitrification in the reactors. The experiments with adapted activated sludge and physical and chemical pretreatment of the polluted water are currently ongoing. More results will therefore be presented at the conference.

Discussion and take-home message: Microbial solutions for wastewater treatment are often cheaper than other physical or chemical solutions, but as it has already been shown in this project, microbial communities are susceptible to inhibition. This is seemingly unavoidable with everchanging and complex pollution. However, microbial solutions could potentially be utilized as a step in specialized and adaptable treatment processes if an adapted biofilm can be grown and/or if appropriate physical or chemical pretreatment is employed that can remove factors that inhibit the microorganisms. Present microbial, physical, and chemical treatment options alone will not solve all pollution. However, combining such treatments could enable more efficient wastewater treatment, especially by creating a stepwise solution that can be adapted to remediate pollution from different sources.

Fluorescence as an online water quality tool in recirculating aquaculture systems

A.C. Hambly, M. Büki*, K. M. S. Kaarsholm*, H. R. Andersen**

Abstract: Organic matter in aquaculture water can be characterised by fluorescence. We investigated natural fluorescence in Danish fish farms with time and water treatment equipment variations in order to determine which fluorescence transitions are most characteristic for the water quality with the goal to produce single wavelength fluorescence detectors for the most significant fluorescence transitions as prototypes for new online sensors.

Introduction: In recent years, recirculating aquaculture systems (RAS) have emerged as the state-of-the-art towards sustainable fish farming. These land-based systems offer reduced water usage, and potential control over water quality and discharge, amongst other advantages. However, accumulated dissolved organic matter (DOM) from fish feed residue and faecal waste, toxins and pathogens in the recycled water can lead to sub-optimal water quality and thus pose serious threats to fish health. Some DOM such as proteins, humic and fulvic acids, exhibit very different chemical- and bio- availabilities, as well as being highly fluorescent, and thus we are investigating the possibility of using fluorescence spectroscopy as a monitoring and process performance tool for RAS water. For instance, ozone treatment can decrease DOM concentrations, but at the same time can react with bromide to form hypobromous acid in saltwater systems. Ozone and hypobromous acid are both highly toxic for the fish, so both treatment firewalls and online monitoring tools need to be in place to prevent serious operational problems. In this work we investigated the change in natural fluorescence in Danish fish farms with time and treatment variation in order to determine which transitions are most characteristic for the water quality. In the continuation of the project single wavelength fluorescence detectors will be manufactures as prototypes for new online sensors.

Methods and data: Samples were collected from various points within different Danish fish farms to monitor organic matter changes throughout the treatment train. Additionally, batch scale ozonation studies were conducted in the laboratory to assess the relationships between fluorescence, organic matter, ozone dose, and hypobromous acid formation. Ozone doses of 1, 2, 5, and 10 mg/L were investigated, and samples were analysed by Fluorescence EEM spectroscopy combined with parallel factor (PARAFAC) analysis, along with TOC, ozone and hypobromous acid.

Results: A significant difference could be seen between sampling points pre- and post-ozonation over a 5 month sampling period. DOM concentration and character was also observed to vary week to week. In the batch ozonation experiments, formation of hypobromous acid was detected in all samples dosed with 5 and 10 mg/L of ozone, whereas no or very low concentrations were detected in samples dosed with 1 and 2 mg/L of ozone. Furthermore, all 4 fluorescence components decreased with increasing ozone dose, however component 4 decreased significantly faster than the other 3 components (fig. 1).

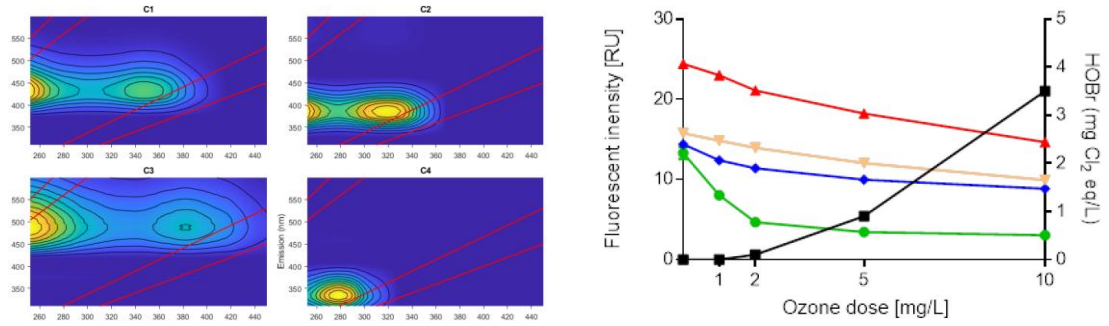

Figure 1. Fluorescence EEM PARAFAC model developed from the fish farm and ozonation samples (left) and the effect of ozone dose on the 4 components (right) where components are C1 (red), C2 (orange), C3 (blue), and C4 (green), and HOBr (black).

Discussion and take-home message: Reduction of a specific low wavelength UV fluorescence component correlated with the beginning of significant hypobromous acid formation in RAS. This component is often described as representing highly bio-available protein-like organic matter, and has been linked to microbial activity in many different types of aquatic systems. Organic matter concentration and character varied week to week within full-scale RAS, and as the ozone dose was essentially fixed, the effective ozonation treatment performance also varied week to week within this system. As the organic matter concentration and character is not static within a RAS, ozonation treatment performance could be improved with the help of online process monitoring. Fluorescence spectroscopy therefore shows potential for an online monitoring and process performance tool for land-based fish farms.

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Session 4: Groundwater and Evapotranspiration

Time: 13:00 – 14:30
Chair: Peter Henriksen, WATEC, AU, DWF Board
EVENT 4

Time	Speaker	Topic
13:00	Krzysztof Piotr Kowalski	Opportunities and challenges for analysis of data collected in relation to operation of pump & treat plants
13:15	Seyyed Reza Mashhadi	First borehole nuclear magnetic resonance (BNMR) results from peatlands in Denmark
13:30	Kiril Manevski	Potential of Sentinel 2 + 3 data to estimate evapotranspiration partitions with Two-Source Energy Balance model
13:45	Vita Antoniuk	Water Deficit Index to assess crop drought stress, evapotranspiration, and irrigation recommendations
14:00	Cécile M. M. Kittel	Evapotranspiration and soil moisture modelling at field scale using Copernicus data
14:30	Coffee break	

Opportunities and challenges for analysis of data collected in relation to operation of pump & treat plants

*Krzysztof Piotr Kowalski, Capital Region of Denmark**

Abstract

Capital Region of Denmark put an effort in more than 70 locations, to minimize risk associated with pollution that threatens water aquifers, human health or surface waters. Among those locations around 40 sites are aimed to remediate groundwater with help of active carbon filtration, that have been incorporated into pump & treat plants, where necessary pre-treatment and controllers are applied to ensure that process runs automatically.

Though operations of the plants require monitoring of processed water quality, obtained results of analyses are saved in GIS supported database and process parameters, which can be achieved with help of regular analyses and remote supervision with help of SCADA, respectively.

As a result of operational tasks, a substantial amount of data is collected. Among the main sources of data entries, one may find each year:

- Analysis results from 570 samples collected from 200 points within the treatment processes, where around a half is associated with active carbon filtration,
- Record of process parameters, like flow and pressure, gathered with time span of 5 second,
- Around 400 entries about plants maintenance (f.e. replacement of pump, active carbon media),
- Electric energy consumption data (form supplier).

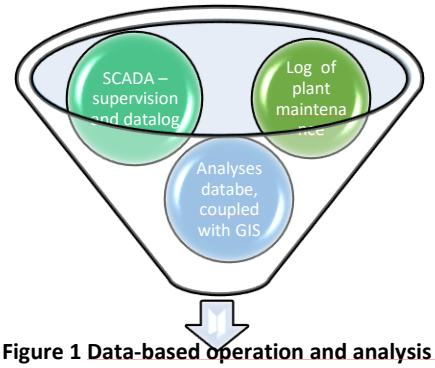
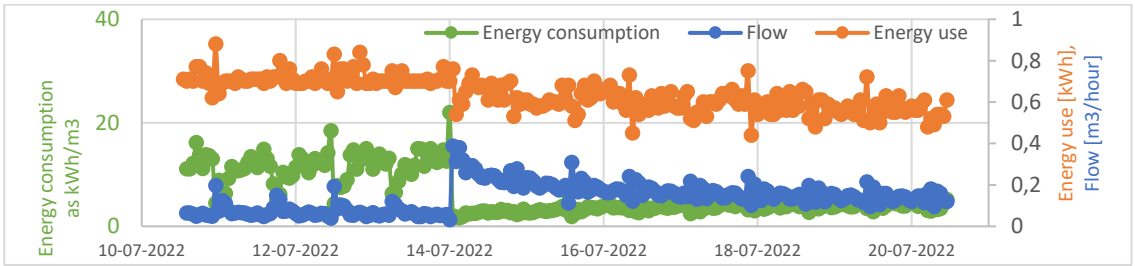


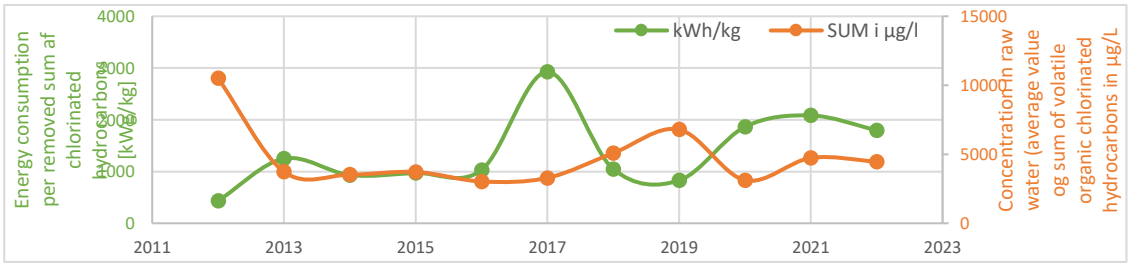
Figure 1 Data-based operation and analysis of Pump&Treat plants

Collected data gives an unusual opportunity for in-depth analysis of treatment processes from different perspectives. For example, for the same pump&treat plant:

- Combining flow, electric energy consumption with maintenance log shows changes in energy consumption, as kWh/m3 before and after changing one of the groundwater pumps, Figure 2,
- With use of yearly volumes of treated water, electric energy consumption and analysis results of volatile organic chlorinated hydrocarbons it is possible to track energy consumption per removed contaminant, Figure 3.

Developing proper data collection and processing methodology may help in evaluation of cost and effectiveness of the remediation and serve as benchmark in developing and evaluation of new, more sustainable methods for remediation for current and future contaminants.





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First borehole nuclear magnetic resonance (BNMR) results from peatlands in Denmark

S.R. Mashhadi [1], D. Grombacher [2], J. B. Pedersen [3], M.A. Kass [4], A.V. Christiansen [5], D.H. Zak [6], C.C., Hoffmann [7], H.E. Andersen [8], J. Audet [9], P.E. Lærke [10], and R.J. Petersen [10]

Abstract

Borehole Nuclear Magnetic Resonance (BNMR) is a non-invasive in-situ geophysical technique that investigates hydrogen-bearing fluids within the pore spaces of rock and soil. The method is based on the same underlying physics as an MR scanner, where in this case a logging tool is lowered down a borehole in order to sample in-situ properties of the rock or soil volume surrounding it. The BNMR method provides a reliable measure of total water content, and insights into the pore size distribution of the soil. Thus, it is possible to determine the water partitioning in the soil (i.e., clay-bound, versus capillary-bound, versus mobile water), which offers valuable inputs to hydrogeological, geotechnical, and environmental studies. Here, we have focused on the use of BNMR data for the study of peatlands, where porosity and water partitioning fractions are crucial factors controlling hydrology and biogeochemical processes within the peat soils. Consequently, for the first time, an effort was made to investigate a few peatland sites in Denmark. The utilized BNMR system is the "DART" instrument, a cylindrically shaped tool with the length and diameter of 172 and 4.4 cm, respectively. It is a dual frequency system with two distinct sensitive zones that are about 1mm thick, located at 5 and 7.5 cm away from the borehole center. Measurements can be made each 23 cm, resulting in a depth profile with 23 cm resolution. The data acquisition or logging speed is approximately 9 meters per hour. The below figure illustrates an example of the BNMR results in a borehole at the Vejrumbro peat site, in Viborg, Denmark. The data match with available geological information and reflect the variations of porosity and hydraulic conductivity (K) well. Peat and gyttja (fluvial sediment) can easily be recognized from the bottom sand layer due to different total porosity or total water content. Although both peat and gyttja have almost the same ranges of total porosity, they can be distinguished by the T2 distribution or water partitioning data. The peat has a higher percentage of free water with respect to gyttja because the pore size distribution shifts towards lower pore sizes by increasing the degree of decomposition (e.g., more decomposed peat or gyttja). Although the K values are calculated based on three different methods, they follow the same general trends in the borehole. However, the suitable site-specific constant values in the formulas should be recalibrated based on local coincident NMR/K measurements. Overall, BNMR data from the investigated peatlands highlights the effectiveness of BNMR technique in providing detailed information about porosity and water partitioning in the soil. BNMR shows great potential to contribute to clarify wide-ranging near-surface issues related to porosity, water partitioning fractions, and permeability information.

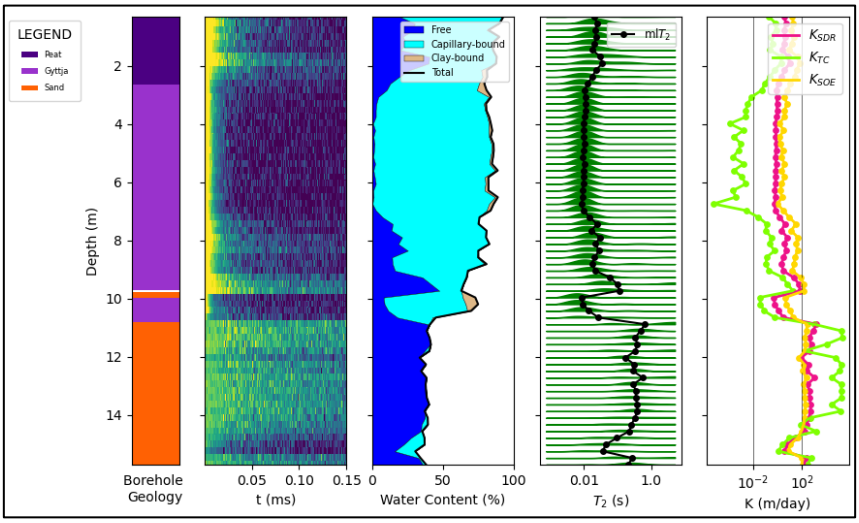

Figure 1. The results of BNMR data measurements in the VB-V03 borehole in Vejrumbro peat site.

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Potential of Sentinel 2 + 3 data to estimate evapotranspiration partitions with Two-Source Energy Balance model

Junxiang Peng, Swedish Agricultural University, Mathias N. Andersen, **Kiril Manevski**, Aarhus University***

Abstract.

Energy balance assumes total radiation over land surface equals sum of sensible, latent and soil heat flux. The immeasurable latent flux - evapotranspiration (*ET*) – comprises two sources from soil evaporation (*Es*) and crop transpiration (*Tr*). Decades of research is still accompanied by high uncertainty in *Tr* estimates necessary to manage drought and multisectoral water use. We studied the added value of Sentinel 2 (S2, multispectral, 10/20 m) and S3 (thermal, daily, 1 km) satellite data for calculating *ET* and *Tr* based on the Two-Source Energy Balance (TSEB) concept.

We collected *Tr* data (sap sensors) from potato plants grown in experimental fields with full and little irrigation on sandy soils in Denmark during 2018 (drought) and 2019 (normal). We downloaded S3 land surface temperature (LST) data and sharpened to 10 m following Guzinski & Nieto (2019) in a three-steps procedure: 1) aggregate with bilinear function the 10- and 20 m S2 data (9 bands) to 1 km to match S3 data at pixel level, 2) use random forest regression between the resampled S2 and S3LST data and 3) apply the random forest model to the original S2 data all at 10 m to produce 10 m S3LST. We parameterized TSEB with the sharpened S3LST, in addition to leaf area index calculated from S2 data and canopy cover calculated from Normalized Difference Vegetation Index, observed plant height and weather data, to obtain outputs of *ET* and *Tr* and compare to sap flow measurement.

The results showed that, compared to the analysis conducted with drone LST data, *Tr* from S3LST correlated poorly with the measured sap flows and was overestimated, especially at the low *Tr* rates (Fig. 1). Hence, the model showed lower drought effects and needs improvements.

Drone data are still expensive (both the flight campaigns and the thermal camera), limited to small-scale applications and the thermal camera is prone to poor data quality due to temperature drifts and random errors. S3LST data have good potential for estimating *Tr*, but care is still required due to uncertainties, including 1) quality of the sharpening (clouds and edge effects), 2) correlation between S2 and S3 data, 3) estimated *LAI* and *fc* and 4) process uncertainties in TSEB. Some solutions include sharpening to 20 m, including Landsat 7+8 data and run the toolbox of Sentinel Application Platform (SNAP) operated by European Space Agency to test for improved estimates of *LAI* and *fc*.

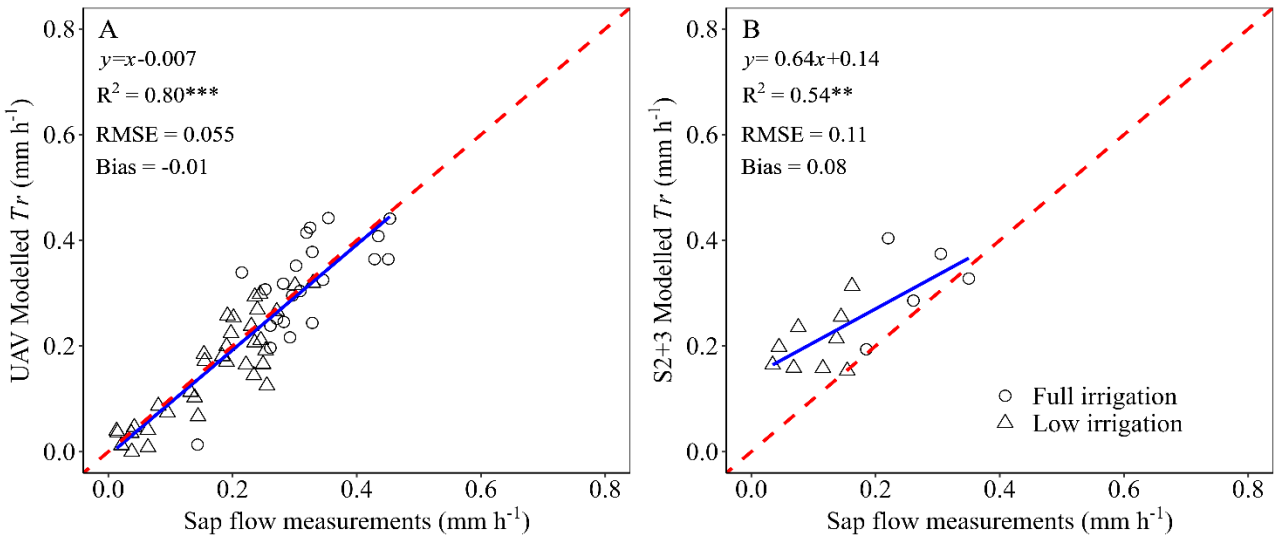

Fig. 1. Fit between transpiration rate (Tr) observed by sap sensors and either modelled with land surface temperature data from Unmanned Aerial Vehicle (UAV, A) or from Sentinel satellite (S2+3, B). R2 and RMSE depict the correlation coefficient and root mean squared error, respectively, and dashed line shows the perfect 1:1 fit. Number of data differs between the plots as UAV involved diurnal flights, whereas S2+3 is daily.

Acknowledgements. Parts of this work was funded by the Innovation Fund Denmark through the ERA-NET Co-fund Waterworks 2015 project 'POTENTIAL' - Variable rate irrigation and nitrogen fertilization in potato; Engage the spatial variation. Special thanks are given to the extracurricular effort of the first author aside their regular employment.

Water Deficit Index to assess crop drought stress, evapotranspiration, and irrigation recommendations

Vita Antoniuk, Kiril Manevski, Mathias Neumann Andersen*

Abstract

Canopy temperature is impacted by the water status. If sufficient water supply is available, the canopy will be cooler due to transpiration comparing to the areas with unavailable or limited water supply. Such difference in the surface temperature can be detected by the means of thermal infrared measurements. By using unmanned aerial systems (UAS), it is possible to acquire thermal image of the whole field that will show spatial variability within it. This information can be used to determine water status. However, as the field may have difference in canopy structure, there is an advantage to take into account fraction of vegetation cover as soil can have significant impact on the surface temperatures. Water deficit index (WDI) uses vegetation index/temperature (VIT) trapezoid space in order to determine water status of an area with regards to canopy cover. Based on the study in 2018-2019 in central Denmark with winter wheat (Triticum aestivum L) as a test crop, UAS equipped with thermal and multispectral cameras were used to derive WDI. The calculations of the VIT trapezoid for the WDI calculations from meteorological data were improved by using partitioning of soil and canopy radiation fluxes and aerodynamic resistances. The canopy-soil dual approach of WDI was combined with dual-crop coefficient ET_a derivation method to create maps of evapotranspiration (ET). WDI and ET maps were derived for both for the season and diurnally (during the day) in order to investigate water dynamics in the field on the different timescales. WDI was highly correlated to winter wheat stomatal conductance and leaf water potential (with R2 up to 0.73 and 0.56). WDI had strong relationship to the fraction of transpirable soil water (FTSW) in the root zone (with R^2=0.74) which allows derivation of soil water deficit from WDI. UAS WDI approach allows to cover whole field in one flight in and thereby study subtle spatial differences in the canopy temperature for the instantaneous estimation of distributed crop water needs for irrigation purposes.

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Evapotranspiration and soil moisture modelling at field scale using Copernicus data

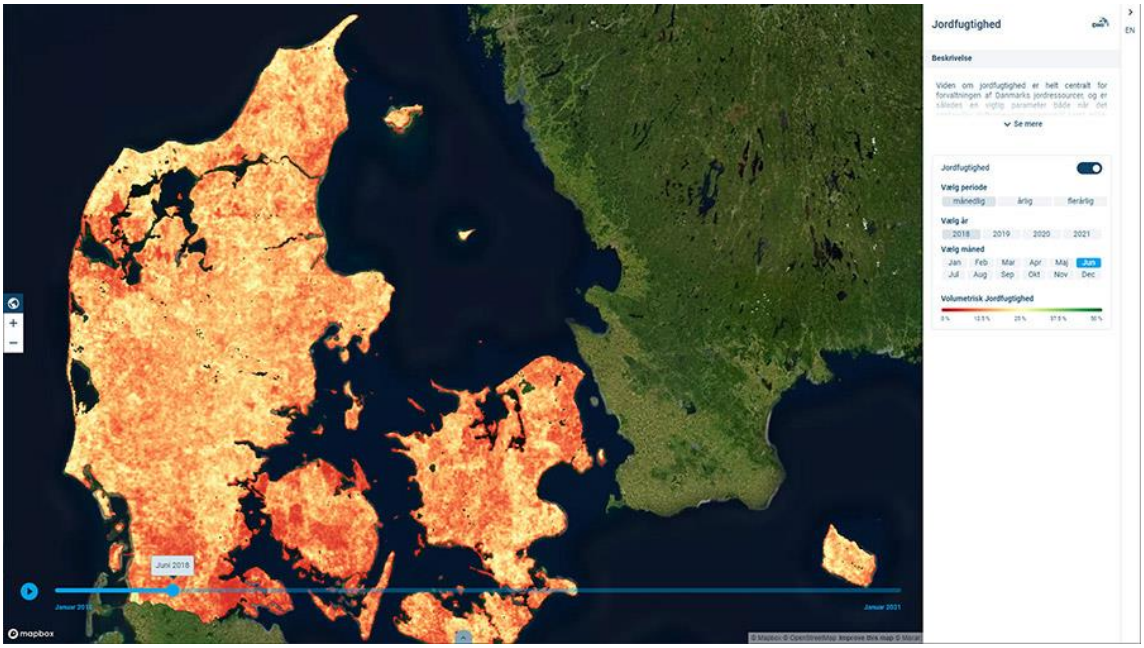
R. Guzinski, DHI, C. Kittel, DHI***

Abstract

Evapotranspiration and soil moisture are key elements of the water cycle and hold a central position in the interactions between land and climate. At field scale, they provide useful information on water use and dynamics, crop water stress and may serve as a proxy for irrigation detection. In this study, we present a modelling approach to estimate evapotranspiration and soil moisture at field scale using Copernicus data.

We use Copernicus observations from optical and thermal-infrared sensors (Sentinel-2 and -3 respectively) in combination with meteorology from Copernicus Climate Data Store and the Copernicus Land Monitoring Service CORINE Land Cover to estimate Evapotranspiration using a Two Source Energy Balance (TSEB) model. By fusing higher resolution optical data from Sentinel-2 with the coarser thermal observations from Sentinel-3, field-scale ET can be obtained at 20 m resolution. By combining ET with a water balance model for the soil column, we estimate soil moisture. For soil moisture, a resolution as low as 50 m can be obtained.

The methods answer two of the main challenges in using remote sensing for ET and soil moisture estimates: data-fusion improves the thermal data resolution and thus the resolution of the end products. Furthermore, the soil moisture estimates are representative of the root zone depth and not limited to the top few centimetres as for conventional satellite-based products. The datasets can be used in irrigation planning and forecasting, monitoring of water use and rights; and the method has been applied for all agricultural areas of Denmark as part of a screening tool for prioritising efforts to take cultivated lowland and carbon rich soils out of production to reduce climate impact.



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Session 5: Drinking water and Flooding

Time: 15:00 – 16.30
Chair: Chair Hans-Jørgen Albrechtsen, DTU, Inês Breda, Eurowater
EVENT 4

Time	Speaker	Topic
15:00	Lisa Vogel	Rotor induced sand filtration – a novel technology for drinking water production at waterworks
15:15	Julie Bruun Jensen	Identification of most efficient filtration materials for removal of problematic pesticides in drinking water
15:30	Pia Jacobsen	Water Living Lab – a large scale test-facility and partnership for innovation
15:45	Lars Skov Andersen	25 years "Danish" water policy dialogue with China
16:00	Pennan Chinnasamy (ONLINE)	Building bottom-up real time decision support system for effective flood and drought forecasting
16:15	Martina Vit	Non-tangible benefits of Nature-based Solutions for hydro-meteorological risk reduction
16:30	End of session	

Rotor induced sand filtration
a novel technology for drinking water production at waterworks

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

Abstract

A widespread challenge when producing drinking water from groundwater containing natural iron is the precipitation of iron hydroxides upon the aeration process. Iron precipitation in the top of sand filters leads to clogging of filters. The traditional method to remove iron precipitates from the filters is frequent 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 ammonium removal of the sand filters due to loss of sand filter native microbes responsible for nitrification. The project aims to develop and verify a novel technology dealing with the issue of iron precipitates at the top of the sand filter without impacting the deeper part of the filter and at the same time reducing water consumption compared to traditional backflushing. A water-driven and motor-driven rotor were tested for their potential to lift the iron precipitates, without impacting the native microbes in the sand filter.

Two different rotor types and concepts were investigated at laboratory scale. A customised 3D-printed water-driven rotor and a commercially available motor-driven rotor were tested over the course of four weeks each on two columns containing sand from two different Danish waterworks. Iron sludge was spiked to the columns twice a week to mimic the on-site precipitation. The aerated inlet water was spiked with ammonium to support growth of ammonia oxidizing bacteria. Once a week the rotor was run and ammonium concentration in the water along with microbial DNA in sand were measured both one hour before and after the rotor runs. Turbidity was measured at different sampling points (inlet, surface- and outlet water) and time periods, including one hour before and after the rotor run. Turbidity measurements in water on top of the filter column were used to compare between water- and motor-driven rotor and as an indicator to evaluate their capability to lift the iron sludge into the water phase, where it subsequently was drained out the column above the filter.

Turbidity measurements showed that both rotor concepts could efficiently lift the iron precipitates on the top of sand filters without compromising quality of outlet water from columns, reflected in the turbidity and ammonium measurements before and after rotor runs. For the water-driven solution shorter distance between rotor and top of sand filter was necessary to be effective. No changes in ammonium removal in the columns was observed after the rotor run regardless of rotor type. Total bacteria amount was only slightly reduced (2-fold) over time with both rotor types, which could be the consequence of lower availability of nutrients and different trace elements in the incoming water compared to the levels in groundwater under real-life conditions at the water works.

Lower water consumption together with turbidity measurements strongly advocate for the motor-driven solution, as the more appropriate solution to continue with in the upcoming pilot scale trials.

Results indicate that both tested rotor concepts (water-driven 3D printed rotor and commercially available motor-driven rotor) had the capability to lift the iron precipitates from the top off the sand filter into water phase and could be drained out of the columns. It could thereby reduce the need for frequent traditional backflushing and related water demands. Impacts of the rotor technology on the sand filter and microbial communities was similar for both concepts tested, however the motor-driven solution is expected to be more effective while at the same reducing the water demand much more. The current observations will be verified in the upcoming pilot scale trials under more realistic on-site conditions.

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Identification of most efficient filtration materials for removal of problematic pesticides in drinking water

J. B. Jensen[1] and S. Musovic[2], Danish Technological Institute[1,2]

Danish waterworks are reporting of an increasing abundance of problematic pesticides in the groundwater, used for drinking water production. One of the often found pesticide is N,N-dimethylsulfamid (DMS), which is found in approx. 36 % of the groundwater wells (GEUS 2022). The presence of pesticides often leads to a closing of the affected groundwater wells and the search for new locations for establishment of new water wells can be difficult and expensive. Due to these challenges, the current project aims to identify the most effective and sustainable materials for removal of pesticides from drinking water at waterworks, to prevent closing of water wells and ensure clean drinking water for the consumers.

The current project was mainly focused on pilot scale trials since the majority of the laboratory tests had been executed in a previous project and those results were then applied for these pilot scale trials. The initial laboratory tests on 10 materials revealed that the activated carbon types Filtrasorb-400, Aquasorb and Silcarbon, were the best at adsorbing DMS, and therefore these were chosen for pilot scale trials.

The pilot scale trials were set up at waterworks at Frederiksberg and in Hjørring, and run for 50 and 65 days, respectively. Eight columns were set up at each waterwork. At Frederiksberg columns were set up with Filtrasorb-400, Silcarbon, Aquasorb or dualmedia (Filtrasorb-400 and Silcarbon), while at Hjørring, coloums contained Filtrasorb-400, Silcarbon or dualmedia (Filtrasorb-400 and Silcarbon). Furthermore, the effect of water-softening prior to filtration was tested in Hjørring. The mentioned waterworks were selected due to existing issues with DMS in groundwater. The flow in columns ensured water residence time to 16 min, which mimic an average residence time in sand filters at the waterworks.

The results indicate that softening of the water prior filtration did not have a significant effect on DMS-adsorption. Filtration with dualmedia did not improve the adsorption either. Interesting, both water-softening and dualmedia setup resulted in a faster breakthrough of DMS, compared to the columns with solo Filtrasorb-400, Aquasorb and Silcarbon. For both Hjørring and Frederiksberg waterworks, all columns containing solo activated carbons revealed breakthrough at day 27, even though the concentration of DMS in the inlet waters at Frederiksberg and Hjørring was four-fold different. Both Silcarbon, Filtrasorb-400 and Aquasorb activated carbons performed almost equally good at each of the tested waterworks, although their adsorption capacity varied between waterworks due to difference in DMS concentration in the inlet water. The observation may strongly indicate that the native groundwater compositions can influence DMS adsorption capacity of activated carbons.

The project will proceed at Frederiksberg waterwork with a semi-full scale trial in 2023.

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Water Living Lab – a large scale test-facility and partnership for innovation

Pia Jacobsen, Water Valley Denmark, Christian Schou, Aarhus Vand***

Introduction: A partnership of 14 organizations is establishing a Water Living Lab focusing on drinking water distribution as a first exploring area. The ambition for the Water Living Lab is to include a digital platform and a physical infrastructure covering an area of 500 km pipe system and 17,000 water meters. The Water Living Lab will serve as facilities, where Danish knowledge institutions, industrial partners, SME's and utilities cooperate in a positive innovation culture to gain new knowledge, develop or improve, test and demonstrate needed solutions.

Water Living Lab one of the projects in Lighthouse Water Tech (Erhvervsfyrtårn for Vandteknologi) which is developing the concept & governance and the digital core facilities – a digital twin and the data sharing method – in parallel with 4 innovation initiatives starting up.

It's a complex set-up, but we find it valuable to have a creative development process and embrace the need from different stakeholders. We hope to open new and better ways to innovate and collaborate.

Methods and data: Dialog, visualization, and storytelling

Results: We will share our first learnings from the complex starting process

Discussion and take-home message: Why is open innovation important and what value do we expect of a Water Living Lab

Speakers: Christian Schou, Aarhus Vand & Pia Jacobsen, Water Valley Denmark

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25 years “Danish” water policy dialogue with China

Lars Skov Andersen, China Resources Management

Abstract

The principal themes of the water policy dialogue with China have been water resources and water supply demand management, and environmental protection. The main activities were 4 strategic knowledge exchanges and 4 policy dialogue seminars at provincial, river basin and national levels. The outcomes and results include mitigation of eutrophication and flood protection of the Three Gorges Reservoir and Dam, reversals of groundwater overdraft in the Minqin Oasis and on the North China Plain, introduction of water resources fees and not least bringing 250,000 rural families out of poverty. The outcomes and results to be presented are the aggregate of 4 major World Bank, British and European Union support and cooperation with projects with China, but with Danish experts, and hence Danish approaches, knowledge, and experiences as underlying themes.

The Sichuan and Chongqing Water and Wastewater Resources Management Strategy (1996-98) was the first major environmental project in the China Go West Strategy. The purpose was a water and environment strategy for 15 major cities upstream of the Three Gorges Dam, the hidden strategy to ensure that the 600 km long reservoir upstream of the Three Gorges Dam would not suffer heavy eutrophication like many Chinese water bodies, thus generating further international criticism in addition to the condemnation of the relocation of several million people along the Yangtze River to be flooded by the 600 km long Three Gorges Reservoir.

In 2002 China revised its 1988 Water Law with assistance from Britain developed the Water Resources Demand Management Assistance Program (2003-2011) testing 6 aspects of the Law in Gansu and Liaoning Provinces of northern China. One pilot was the Minqin Oasis in the Gobi Desert where desertification was threatening urban and agricultural development.

The EU - China River Basin Management Program (2006-12) aimed at marketing and testing approaches of the EU Water Framework Directive and the Groundwater Directive within the Yellow and Yangtze River Basins. The project included 3 strategic knowledge exchanges addressing the Water Supply, Ecological and Flood Management Securities.

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The first activity under the China Europe Water Platform (2013 – onwards) supported by the EU Technical Assistance and Information Exchange Facility was a Chinese request to arrange a seminar on Groundwater Policy, Legislation and Standards, which resulted in 36 recommendations to China.

The groundwater legislation seminar laid the foundation for 3 groundwater policy dialogue seminars under the Rural Water and Food Security Project supported by the EU Partnership Instrument (2018-2023) on i) Water Saving by Groundwater Quantity Managements, ii) Groundwater Quality Management and c) Sustainable Groundwater Management and Use, which in total delivered 24 groundwater policy recommendations.

Take home lesson: Even a small country can inspire the largest country in the world.

Acknowledgements: The presentation builds on 25 years cooperation and contributions by highly skilled colleagues, especially from COWI, DHI and GEUS, but also from government agencies, sector institutes, universities and technology companies in China and most EU Member States.

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Building bottom-up real time decision support system for effective flood and drought forecasting

Pennan Chinnasamy, Pravin Kolhe**, Marie Louise Møllebæk Pollmann-Larsen****

Abstract

Climate change extremes are impacting development and causing huge losses, especially in developing economies such as India. There has been an introduction of extensive monitoring and modelling exercises to predict climate change extremes for adaptation and mitigation activities. On the same note, a Real Time Decision Support System (RTDSS) has been developed by Water Resources Department Government of Maharashtra under Hydrology Project and provide guidance to officials and concerned staff of Water Resources Department for taking decisions for flood/drought mitigation and adaptation management plans. The Government of Maharashtra initiated project on 'Real Time Decision Support System (RTDSS) for Krishna Bhima Basin' and project was commissioned in 2014. The main components of RTDSS are Real Time Data Acquisition System (RTDAS) & Real Time Stream Flow Forecasting and Reservoir Operation System (RTSF & ROS). The RTSF & ROS for Krishna Bhima Sub-Basins is developed for basin having area of 69,967 sqkm.

Introduction: Krishna Basin:

The Krishna river Basin, of which Bhima is a major tributary, covers an area of 69967 sq km in Maharashtra state. This area experience highly variable rainfall both in space and time ranging from 6000 mm in upper Hilly area to 400 mm in lower plain areas. There are 46 major multipurpose reservoirs (apart from other medium and minor reservoirs) constructed for purpose of hydropower, irrigation, domestic and industrial uses. These reservoirs are not specifically provided with flood cushion, they have to moderate flood peaks by proper reservoir operations. Reservoirs are operated with rigid schedules as single entities based on the historical hydro-meteorological data and experience gained. In addition, manual data observation and transmission results in a considerable time lag, between data observed in field and its communication to decision making level which sometime leaves little time, for flood forecasts.

The Krishna Bhīma sub basin area experienced flashy floods in year 2005 and 2006 which caused heavy damages to the lives and properties in the basins. Therefore, under World Bank Aided Hydrology Project (HP-II) Government of Maharashtra developed RealTime Stream flow Forecasting (RTSF) and Reservoir Operation System (ROS) with Real Time Data Acquisition System (RTDAS).Objective of the system are:-

1. To equip Water resources department with a web-based real time stream- flow forecasting (RTSF) and reservoir operation system (ROS) for Krishna & Bhima basin.
2. System should be used to optimize releases from reservoirs for multiple uses throughout the year.
3. Provide a system to better manage floods.
4. Develop a system to optimize coordinated and integrated reservoir operations.
5. To build upon existing HIS on a RTDAS telemetry network.

For development purpose, system is principally divided in to two components i.e.RealTime Stream flow Forecasting (RTSF) and Reservoir Operation System (ROS), and Real Time Data Acquisition System (RTDAS).

Issues: The model efficiency is limited due to data issues that drive the model across the basin. In addition, certain models used in this framework were developed for foreign regions and forced on to the sub-continent. So there is a need to update the current system and to create more representative models with locally source data that can drive such models. A Bottom up data approach is proposed in this current research. In the current research, such an approach is used with recent suit of DHI models to capture flood and drought forecasting.

Methods and data: To collaborate for conducting discussions which can aid to resolve issues related to Real Time Decision Support System (RTDSS) developed by Water Resources Department Government of Maharashtra under Hydrology Project and provide guidance to officials and concerned staff of Water Resources Department for taking decisions regarding upgrading the system (including software / hardware / cloud / sensor / IoT / Communication system / Data visualizations / mobile apps upgrade etc.).

Ground level data are collected from local stakeholders, farmers, NGOs and government agencies and assigned different weights based on the data accuracies and correlations with flood/drought phenomenon. Preliminary results show promising and more representative visualization of the hydrological conditions of the basin.

Results: Development of Real Time Decision Support System (RTDSS) using Bottom-up approach

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Non-tangible benefits of Nature-based Solutions for hydro-meteorological risk reduction: an assessment focusing on interconnectivity and replicability

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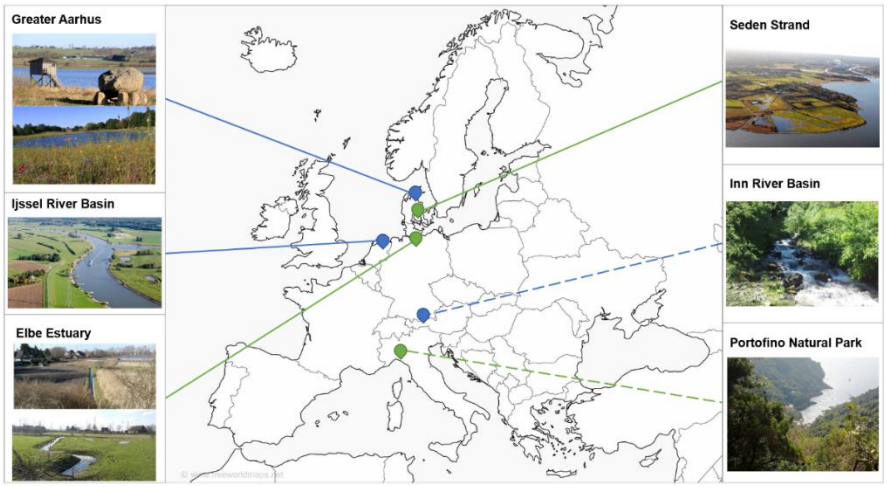
Introduction: Despite the growing popularity of Nature-Based Solutions (NBS) as strategies for, among others, the reduction of hydro-meteorological risks, their uptake is slow. Uncertainties regarding the valuation and consequent economic feasibility of NBS are deemed to be a substantial barrier to their uptake. The monetary valuation of non-tangible benefits of NBS (e.g., increased recreation and enhanced biodiversity) is seen as a plausible strategy to get closer to a holistic assessment. However, the quantification of non-tangible benefits is often not integrated into the assessment of NBS. This situation may risk leading to an inconsistent and biased valuation, which can, in turn, negatively influence the prioritization of these strategies, both directly and indirectly (i.e., through the impossibility of conducting value transfers). To avoid this, more data and base evidence to better quantify the benefits of NBS are needed. Thus, our study aims at collecting holistic data on the non-tangible benefits of NBS across different study sites and determining if there are any patterns in how the different types and contexts of NBS influence people's valuation.



Methods and data: We applied a Contingent Valuation (CV) survey to six different large-scale NBS study sites for the reduction of hydro-meteorological risks, all part of the EU Horizon 2020 project RECONECT (see the mapto the right). The basic structure of the survey was kept the same across sites, but some of the questions were tailored each case study through collaboration with stakeholders of the individual cases. The target of the survey was the general public, and we used willingness-to-pay (WTP) questions to quantify the value given by the respondents to the NBS. Multiple linear regression models were used to determine which of the collected variables have the greatest influence on the value attributed to the NBS.

Results: The survey was successfully adapted and distributed across the six study sites. The data analyses are still ongoing, but some of the preliminary results are: i) For the respondents who accepted to state a WTP, their bids significantly increased when the improvement of nature and biodiversity was mentioned in the valuation scenario; ii)

Personal preferences appear to be the most significant variables linked to a higher WTP in the Danish sites, but for the other sites, the influence of socio-economics and previous flooding experiences appear to be predominant;

iii) Both personal preferences and socio-economic variables significantly influenced the probability of stating a protest vote, i.e., rejecting the valuation scenario altogether, in the Danish sites.

Discussion and take-home message: 1) People appear to value the multiple benefits of NBS, and positively react to implementations improving nature. 2) Similar variables seem to influence the value attributed to NBS across sites, with personal preferences ranking highly among them. However, the degree of significance of these variables changes according to the different contexts.

We believe that our assessment across study sites can be the starting point for a broader initiative to analyze and quantify the non-tangible benefits of NBS across more contexts. This data could then be the basis upon which to build solid and holistic knowledge of these solutions, which would contribute to supporting their prioritization and uptake.

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Session 6: Sulfides plus specials

Time: 15:00 -16:30:
Chair: Torben Lund Skovhus, VIA University College, DWF Board and Christian Schou, Aarhus Vand
<u>Room 1</u>

Time	Speaker	Topic
15:00	Morten Lykkegaard Christensen	Lab and pilot scale evaluation of hydrogen sulfide control by electrochemical generation of dissolved ferrous iron
15:15	Fabian Steininger	Microsensor for Direct Detection of Total Dissolved Sulfide (TDS) in Natural and Technical Environments
15:30	Alaa Khalil	Recovery of H2S scavenger chemicals from offshore wastewater using thin-film composite membranes
15:45	Antonio Vigueras Rodriguez	Empirical characterization of an axial hydrokinetic turbine-based on SG6043 airfoil designed through BEM theory
16:30	End of Session	

Lab and pilot scale evaluation of hydrogen sulfide control by electrochemical generation of dissolved ferrous iron.

A.H. Nielsen, M.L. Christensen, M.K. Jørgensen, AAU, S. Lindholst, Teknologisk**, R.R. Andreasen, Silkeborg Forsyning***, K.P. Karlson, SulfiLogger****, L.M. Hansen, AL2-Teknik*****.*

Introduction: Hydrogen sulfide related odor and corrosion in sewers are among the most challenging problems affecting collection system operation and maintenance [1]. The sulfide originates primarily from anaerobic degradation of wastewater organic matter by sulfate reducing bacteria (SRB). Due to the extent of the problems, several management strategies for sulfide control have been developed. These typically rely on the use of chemical dosing for either precipitating the dissolved sulfide or preventing its formation by suppressing the metabolic activity of the SRB (e.g., [2]). In general, the methods have proven effective, but also rather expensive and involves handling of hash chemicals. A recent laboratory study by Lin et al. [3] has demonstrated the potential for using electrochemical oxidation of solid iron electrodes as a method for *in-situ* precipitant generation. The method has several advantages over traditional addition of acidic iron sulfate or chloride solutions; including no handling of chemicals, increased efficiency of the reaction and reduced influence on wastewater pH level. In the present study, a similar approach has been adapted and tested.

Methods and data: Electrochemical precipitant (Fe^{2+}) release for sulfide control was tested in a pilot scale experimental setup. In the experiments, sulfide was generated in a 400 m long experimental pipe coil and the wastewater treated at end-of-pipe (Figure 1a). The electrochemical cell consisted of five electrodes in a bipolar-series (BP-S) configuration and was operated in Alternating Pulsed Current (APC) mode.

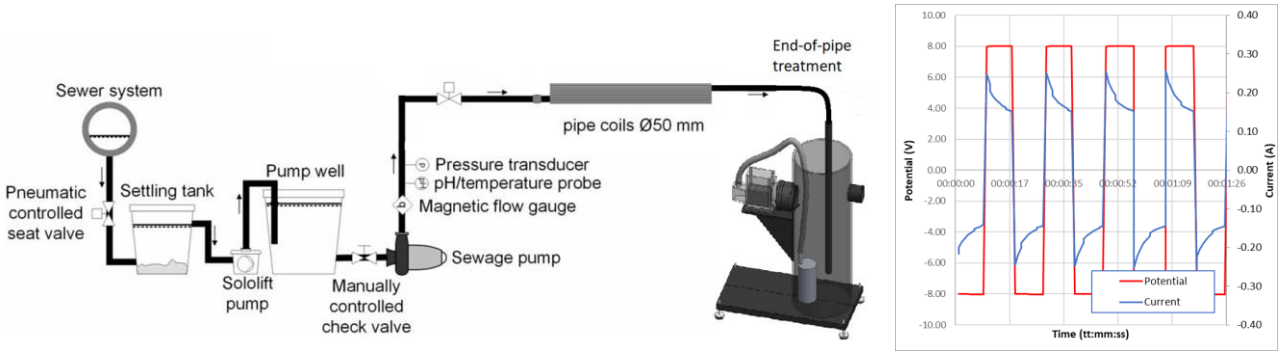

Figure 1. a) illustration of the experimental setup and b) cell potential and current density during an experiment.

Results: Both the pilot scale experiments, and previous lab testing, demonstrated the efficiency of the process. Long term testing is currently being conducted to establish the durability of the electrochemical cell as well as the optimal cell design. Example of cell potential and current density data during an experiment is shown in Figure 1b.

Discussion and take-home message: *In-situ* Fe^{2+} generation was demonstrated in both lab and pilot scale experiments. The process was found to generate mainly Fe^{2+}, which can precipitate directly with dissolved hydrogen sulfide with high efficiency. Current investigations are focusing on cell-passivation by formation of oxide layers on the cathode(s) observed to increase cell resistance and thereby reducing current density (@ constant cell potential). This can negatively affect the release of Fe^{2+} for sulfide precipitation thereby decreasing the overall performance.

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Microsensor for Direct Detection of Total Dissolved Sulfide (TDS) in Natural and Technical Environments

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Introduction: Dissolved sulfide (H_2S, HS^-, and S^{2-}, depending on pH) is an important participant in many industrial and biogeochemical processes. It is produced by breakdown of organic matter and by heterotrophic bacterial reduction of sulfate under anoxic conditions. Sulfide is highly toxic for most higher organisms, and its presence in sewers for example constitutes a serious hazard for workers. Natural waters or fish farms may also turn sulfidic leading to severe fish mortality. In sewers, hydrogen sulfide is oxidized to sulfuric acid on sewer pipe walls, causing severe corrosion and breakdown of such infrastructure. Control and removal of dissolved sulfides is especially crucial in effluents with high sulfide concentrations as found in the tannery and petroleum industry.

Consequently, precise monitoring of sulfide in natural as well as industrial and urban environments is of great importance. While conventional methods to determine TDS are usually performed *ex-situ*, state-of-the-art methods for continuous monitoring are based on electrochemical sensors for either H_2S or S^{2-}. Since the fraction of either H_2S or S^{2-} is dependent on the sample pH, knowledge about the exact pH at the point of measurement is essential for the calculation of TDS concentration and thus simultaneous pH measurements are required.

This, however, not only induces the propagation of the intrinsic error of each sensor (noise, drift, etc.), but is particularly critical at high and low pH intervals, for the H_2S and S^{2-} sensor, respectively. Here the fraction of the calculated concentration largely exceeds the one of the measured analyte, thereby approaching the limit of detection (LOD) of the respective methods (e.g., LOD of the sulfide selective electrode at pH 7-8 is approx. 10 µM). This will cause the amplification of eventual measurement errors or could, in the most extreme cases, generate false zero readings.

Methods and data: To overcome these problems, we have equipped Clark-type H_2S microsensors with an acidic outer chamber mediating the *in-situ* conversion of ionic sulfides (HS^- and S^{2-}) to H_2S, which is in turn oxidized at the transducer electrode (Figure 1). This technique facilitates measurement of TDS at high spatial and temporal resolution even at pH values where most analyte is in the ionic form. The sensor performance and long-term stability was tested and the viability and potential of this novel approach to measure TDS was demonstrated by resolving microgradients in fresh-water and marine sediment.

Results: A typical sensor had a tip opening of 10 µm, a response time of 60 s and linear range of 0-350 µM, with a calculated detection limit of 60 nM. The sensor performance can be largely tuned by altering the geometry of the chamber (sensors can be tuned to measure higher concentrations up to 0-8 mM). Sample pH variations barely resulted in a change of signal and resulted only in a minor error (0.5-1 % per pH unit). Sensors of different sensitivity (0.04 – 2.93 pA/µM) showed no noticeable change in zero current and sensitivity during continuous polarization over 7 weeks. Microprofiles obtained by the novel method showed reduced variability and avoidance of artefacts generated by the pH correction of the standard method.

Discussion and take-home message: We envision this new sensor to be particularly relevant for monitoring TDS not only in biological but also in industrial systems, where sulfides represent a corrosion and health hazard and broad variations of pH limit current monitoring methods. Currently, most mitigation strategies are only based on sulfide levels at discharge and typical sewage flow patterns, which often results in overdosing or poor sulfide control. Sewers are very dynamic systems where pH changes happen frequently (daily pH variations can be up to 1.5-2 pH units), thus monitoring TDS with this novel sensor would allow for correct, cost-effective dosing of sulfide mitigation chemicals at all times. Thus, we recently partnered a water utility company (Aarhus Vand) to implement the novel TDS for monitoring urban sewers, with the final goal to improve the dosing (reducing the cost) of sulfide mitigation strategies.

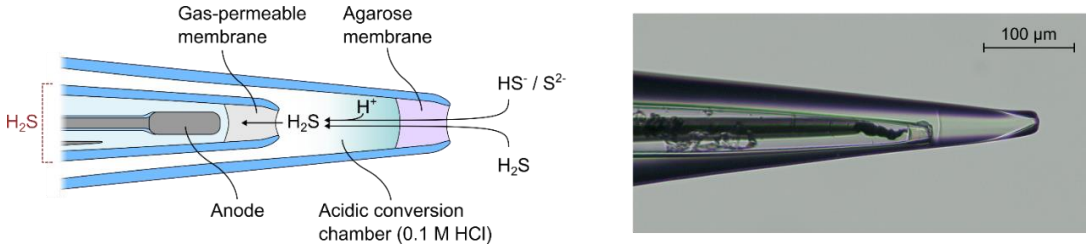

Figure 5. Schematic representation and working principle of TDS microsensor (left) and photograph of the tip region (right).

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Recovery of H_2S scavenger chemicals from offshore wastewater using thin-film composite membranes

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Abstract

Hydrogen sulfide (H_2S) is a highly toxic and corrosive species, produced during offshore oil and gas operation which poses serious operational, health, safety, and environmental issues. H_2S is removed from the natural gas stream by injecting H_2S scavengers (MEA-triazine) into the gas stream at offshore platforms, which converts H_2S into far less hazardous and corrosive species (MEA and DTZ). In addition, MEA-triazine is generally utilized in large stoichiometric excess to increase the rate of H_2S removal, which is expensive and represents > 50% of the total cost of production chemicals. The main idea of this project is the synthesis of tailormade thin film composite (TFC) nanofiltration membranes for the separation of unspent (MEA-triazine) and spent (DTZ) H_2S scavengers obtained from oil and gas wastewater from an offshore installation in the North Sea. Polyamine thin film composite (TFC) membranes are prepared by interfacial polymerization. Modifying the membrane thickness showed an effect on the separation of HET and MEA from the DTZ scavenging reaction product. The TFC membranes had a pure water permeability of (20 L m^{-2} h^{-2} bar^{-1}) compared to the commercial NF270 membrane (10 L m^{-2} h^{-2} bar^{-1}) attributed to their improved surface hydrophilicity and altered structural properties. The TOC of SUS wastewater was reduced by 48% and 37% for the synthetized TFC and NF270 membrane, respectively. At 50% permeate recovery, the rejections for MEA-triazine and monoethanolamine are 62% and 82%, respectively, with zero rejection for DTZ.

The results indicate that the synthetized TFC membrane is a promising strategy for recovering MEA-triazine, thus reducing costs for offshore oil and gas operators while reducing the environmental impact associated to the discharge of this wastewater.

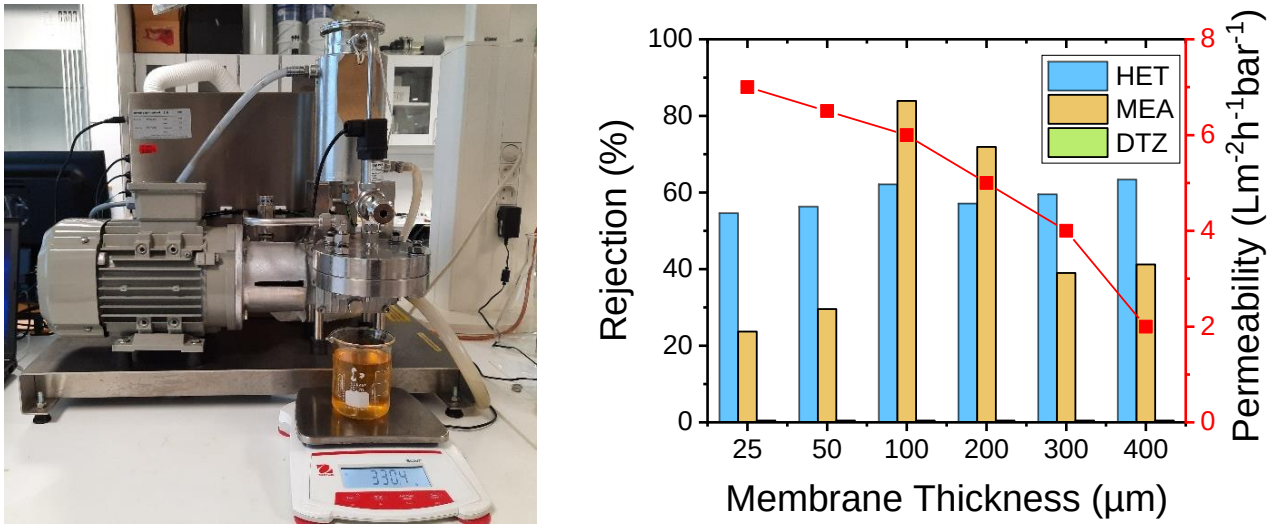

Figure 1. Cross-flow filtration system, Left. Effect of membrane thickness on the rejection of HET, MEA and DTZ and permeability of the synthesized membrane (measured at permeate recovery of 50%), Right.

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Empirical characterisation of an axial hydrokinetic turbine based on SG6043 airfoil designed through BEM theory

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Abstract

There is a potential for small and microhydropower in which hydrokinetic turbines may play a relevant role [1], for instance, in irrigation channels, in-stream hydropower, tidal power or recovery of other residual energies. In this work, a 3-blade AHT has been designed parting from a SG6043 airfoil, optimising its chord and twist angle by classic BEM theory together with Prandtl tip and root loss corrections. This has been done by using the free software Qblade v.0.96 [2]. A 120 mm diameter was chosen, according to the open flow channel conditions available in the laboratory, so that an empirical assessment of its behaviour was possible.

The turbine has then been 3-D printed and assembled together with a mechanical transmission into a Prony brake in order to measure its performance. Measurements have been carried out with different water depth and flow rate conditions, in which several turbine rotational speeds have been assessed by changing the braking torque.

Power coefficient (Cp) has been estimated from the measurements and is plotted in figure 1 against Tip Speed Ratio (TSR). Plot shows better results than the theoretical ones. That is in agreement with other authors [3] and caused by a blockage effect that is not accounted by the hypothesis of the previously used model when using this kind of turbines in a small section, in contrast to their use, for instance, in open see where wake expansion is not limited.

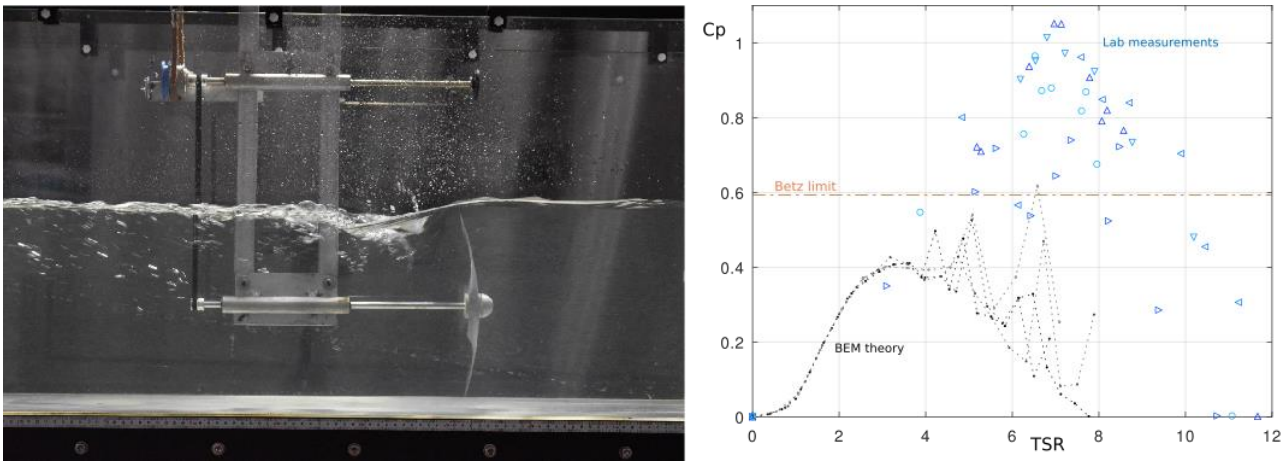

Figure 1: Picture of the measurements as well as comparison of Cp and TSR calculated through the upstream velocity, under different flow conditions.

Conclusions: A simple and low-cost procedure to design and construct hydrokinetic turbines have been shown. Power results can be better than expected when the turbine is used in constrained section such as small rivers or water channels. Blockage effects should be better addressed by analysing results under different blockage ratios together with recent empirical methods, so that simple design procedures could also be improved.

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