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Wetsus 2020 research program

combining scientific excellence with commercial relevance

Wetsus, European Centre of Excellence for Sustainable Water Technology

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Wetsus

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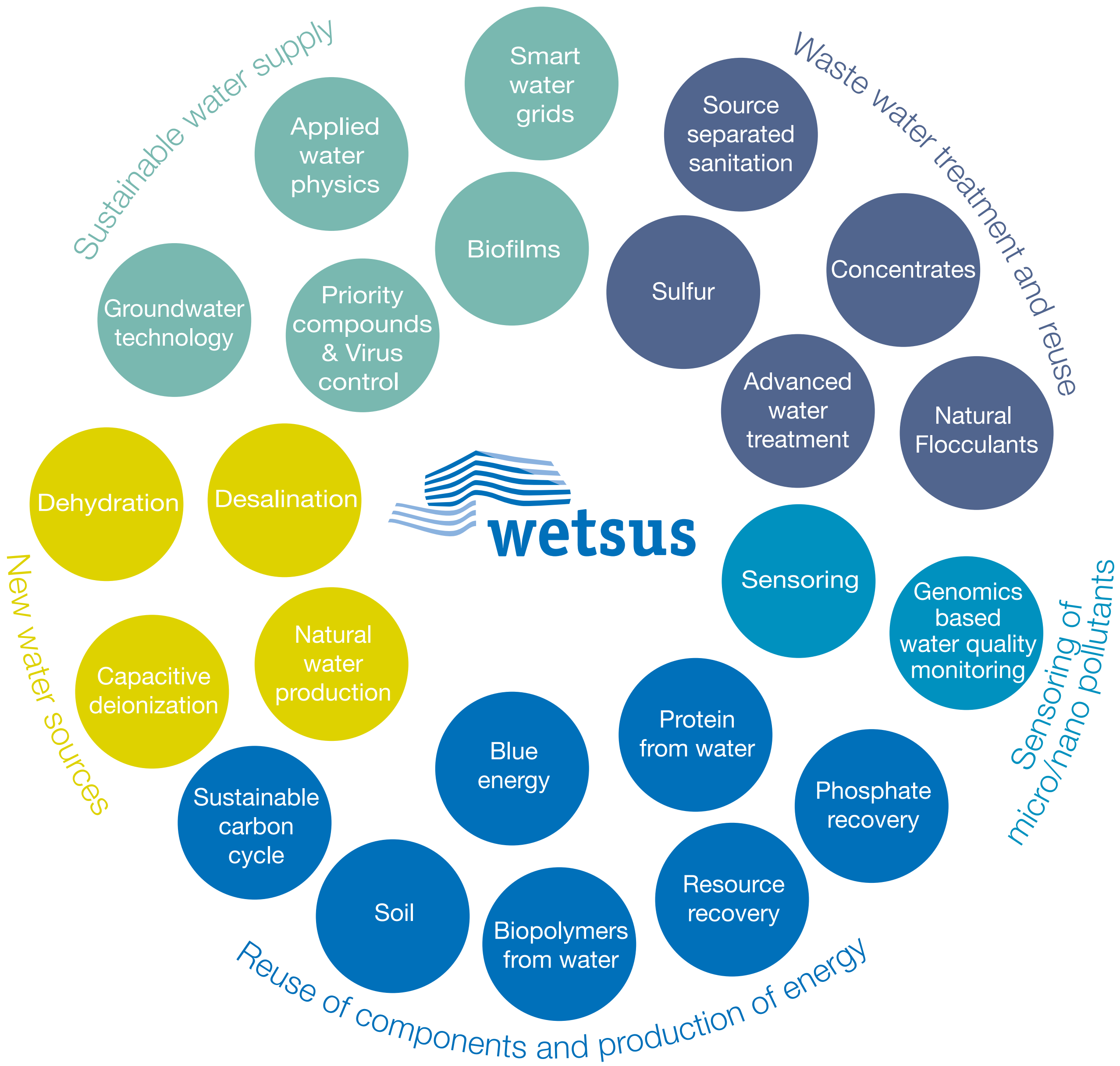
- Northern Netherlands Provinces (REP-SNN)
- the City of Leeuwarden, the Province of Fryslân
- The Netherlands Organisation for Scientific Research

Contents

Wetsus research program

Wetsus' research program is divided into 5 research areas and 23 research themes, which have been assessed in close consultation with the industrial participants. Within these themes, research topics have been defined, which are being addressed in the form of PhD projects. In the following sections, you will find descriptions of the themes and summaries of the current PhD projects.



Applied water physics

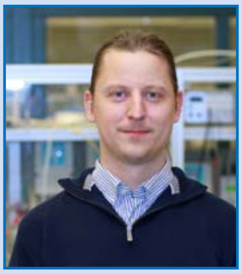
Water is undoubtedly the most important chemical substance of this world. Despite this, and in spite of the fact that it is practically ubiquitous, it still represents one of the best explored and yet least understood substances. When looking deeper into the field, it turns out that there is much special but little general knowledge. For example, there are many theories for each of the various anomalies of water - but rarely one theory that explains more than a few anomalies.

The emphasis of the Applied Water Physics Theme lies in the exploration of these basic properties of water, especially its interactions with electric, magnetic and electromagnetic fields and the effect of such interactions on living organisms like bacteria. Based upon deeper insights into the fundamentals of water, the Theme furthermore focuses on screening commercially available water treatment concepts based upon such interaction. Thereby break-through discoveries through fundamental research and pioneering screening experiments with physical, chemical and biological model systems are combined to pave the way for the development of seminal, epoch making water treatment technologies.

THEME MANAGER

Ruud van Nieuwenhuijze
(Brabant Water)

THEME COORDINATOR



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Research projects

- **Maarten van de Griend**, University of Natural Resources and Applied Life Science
  Vortex treatment of water in a hyperbolic geometry
- **Xiaoxia Liu**, University of Natural Resources and Applied Life Science
  Extended biostability of potable water through sustainable non-chemical treatment
- **Nigel Dyer**
  Harvesting energy from dielectric breakdown
- **Talie Zarei**, University of Twente
  Characterisation and Tuning of DOLLOPs in Potable Waters **NEW**

Industrial partners

brabant Water
wln
GRANDER Belebtes Wasser
IPF Implosions Photonenfeld Forschung
Schauberger Natur Technik
H2motion clear water through motion
INTEGRO
Coherent Water Systems
Bright Spark

Academic partners

TU Graz
BOKU Universität für Bodenkultur Wien University of Natural Resources and Life Sciences, Vienna
TU Delft Delft University of Technology
UNIVERSITY OF TWENTE.

applied water physics

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Vortex treatment of water in a hyperbolic geometry

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Motivation

Over recent years, the ideas of the Austrian forester and bionics pioneer Viktor Schauberger about water and vortices have gained renewed attention. Many individuals and companies are building devices for various purposes and making claims regarding water quality, gas intake and alike. Scientifically, the vortex is still an poorly understand phenomenon. Solving Navier-Stokes equations directly only works for the simplest of geometries, like the flow in a rotating cylindrical container [1].
In a hyperbolic funnel the gas-liquid interface is of special interest. The interface can extend all the way to the outlet resembling a helix or standing wave pattern (fig. 1). In addition a hyperbolic vortex can be created using special rotors in otherwise stagnant water. In both cases the combination of rapid mixing and large interface may indeed make this type of vortex suitable as an efficient aeration device. Currently, 50-70% of the energy of wastewater treatment plants is used for this purpose. Vortices may also be used for particle separation purposes, as heavy particles move to the center, where they can be removed.

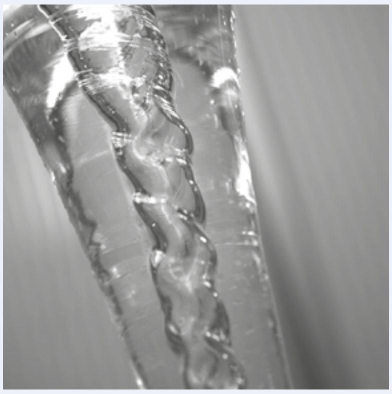

Fig 1. High speed camera image of air-water interface in hyperbolic funnel

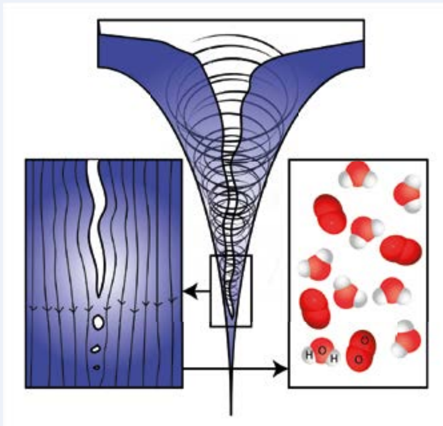

Fig 2. Air bubbles may get detached from the central column and are efficiently dissolved in the water

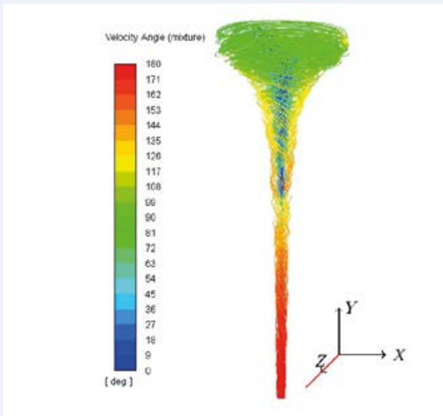

Fig 3. ANSYS Simulation result for velocity angle in degrees between flowlines and y-axis.

Technological challenge

PIV measurements will be performed to study the flow structure of a vortex in a hyperbolic funnel. The existence of an Ekman boundary layer will be determined and the tangential velocity is compared to viscous theoretical models.
Furthermore, we want to study the effects of viscous heating and the time evolution of quantities like pH, conductivity, evaporation and gas intake. We are interested in the possibilities for vortex cavitation and its effects on the water.
Parallel to these measurements, numerical simulations will be performed on these geometries using the ANSYS software (fig. 3). This may help us understand the link between theory and observation.

Research goals

- Create, measure, calculate and simulate the flow pattern in a hyperbolic vortex
- Investigate influence of the vortex on physical and chemical properties of water
- Investigate the applicability of hyperbolic vortexing as aeration mechanism
- Understand the importance of the hyperbolic geometry (if any)

[1] A. Andersen et al., Phys. Rev. Letters (2003)

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Extended biostability of potable water through sustainable non-chemical treatment

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Motivation

Magnetic water treatment (MWT) has been employed to improve water quality and fouling prevention in the past years [1]. However, since the specific mechanism remains unclear, the application is controversial. Recently, a mechanism proposed by Coey [2], the enhanced formation of dynamically ordered liquid like oxyanion polymers (DOLLOPs) in water after MWT with strong magnetic gradients was experimentally verified (Fig.1). It brought a breakthrough in the understanding of MWT from the perspective of water physics [3]. Because microbial activities have been shown to intensively participate in the fouling process of drinking water distribution systems (Fig.2), the microbiological effect of magnetic water treatment can be further explored. Since widely applied chemical disinfection processes cause problems such as recontamination, antibiotic resistance development etc., microbial resource management by MWT may provide possibilities for a sustainable alternative of current drinking water treatment methods. Therefore, the aim of this study is to investigate the effect of MWT on microbial communities and its role in affecting water quality.

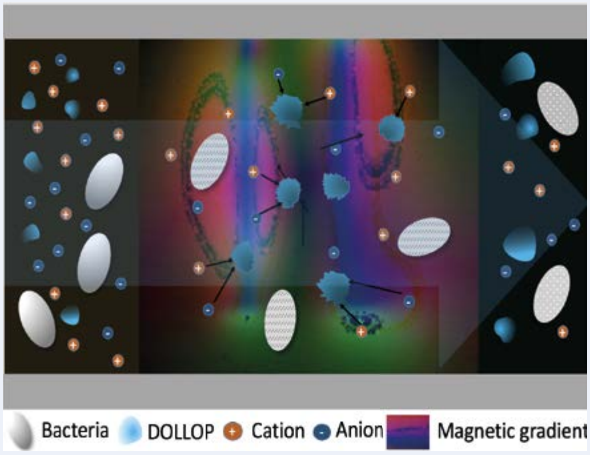

Fig.1 Illustration of the effect of a strong magnetic gradient on DOLLOP formation and microorganisms. A magnetic gradient can dephase the protons spins on the surface layer of DOLLOPs (dynamically ordered liquid like oxyanion polymers), therefore allowing additional ions to join the DOLLOP structures more easily. As a result, the chemical equilibrium is shifted to the colloidal (DOLLOP) phase, and the chemical environment of the microbes is changed by the magnetic field gradient, which in turn influences the microbial behavior.

Technological challenge

Despite many difficulties in studying the effect of a magnetic field, a good understanding of the mechanism is essential for a better application of magnetic water treatment systems. As microorganisms play an important role in water quality management and interact intensively with calcium in drinking water distribution systems, the effect of magnetic fields on the microbial community as well as their interaction with calcium precipitation needs to be better understood. Therefore, the main goal of the project is to understand the mechanism of magnetic field effects on microbial communities and use the knowledge achieved to regulate microbial communities and calcium precipitation in drinking water system.

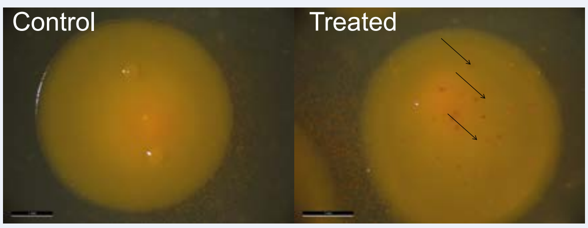

Fig.2 Microbial colonies isolated from tap water exhibit different behavior in microbial induced calcium precipitation before and after the magnetic treatment.

Research Goals

- Establish a methodology in the laboratory to scientifically examine the effect of magnetic fields on microorganisms.
- Investigate the specific physiological response of microorganisms to the magnetic treatment.
- Provide a better understanding on the proposed anti-fouling effect of magnetic water treatment from the perspective of microbiology.
- Develop a microbial management strategy based on the magnetic water treatment effect to improve water quality.

Reference

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Biofilms

Biofilms basically consist of cells embedded in a polymeric extracellular matrix, mostly produced by the organisms themselves — known as extracellular polymeric substances (EPS) — that forms the scaffold for a three-dimensional architecture which is protecting the microbial community from environmental and shear stresses.
The importance and attractiveness of biofilm systems is widely accepted. Biofilms are found in several environments, and play both beneficial and detrimental roles depending on whether their formation is controlled, or it occurs naturally.
In drinking water distribution systems, biofilms are the predominant mode of microbial growth, and their formation poses a significant problem to the drinking water distribution network conditions in buildings as a potential source of bacterial contamination, and also affecting the taste and odor of drinking water and promoting the corrosion of pipes. Additionally, biofilms are predominantly associated with fouling processes in membrane filtration, resulting in a series of operational problems as well as an issue for product quality.
On the other hand, biofilms can have a positive impact, as shown by their extensive use in the field of environmental biotechnology, i.e. self-purification of water, wastewater treatment, bioremediation, etc. Indeed, biofilms can be considered as a natural way of immobilized (whole cell) biocatalysts.
Biofilm formation is a multi-stage process resulting from the balance of several physical, chemical and biological factors. At Wetsus, our strategy is to use a multi-level research approach to examine all these factors, as well as the various technologies to characterize and monitor and, ultimately, to control the biofilms growth. In this way, we aim to gain new knowledge towards finding practical solutions for industries, and a better understanding of both beneficial and detrimental forms of biofilms. In particular, elucidation of biofilm structure is a prerequisite to understand and to model the mass transfer and growth of cells within the sheltering extracellular matrix.

THEME MANAGER

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Research projects

- **Olga Sojka**, University Medical Center Groningen
  Preventing biofilm formation by developing a novel coating on pipe materials in drinking water distribution systems
- **Sara Pinela**, Wageningen University
  Fouling prevention through biological activated carbon and ultrafiltration **NEW**

Industrial partners

Vitens, WLN, Pentair X-Flow, Aquacare Europe & Service, +GF+

Academic partners

Wageningen University & Research, TU Delft, UMCG

Preventing biofilm formation by developing a novel coating on pipe materials in drinking water distribution systems

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Motivation

The purpose of the drinking water treatment facilities is to produce and to deliver high quality drinking water to the consumer. Water leaving the purification plant generally fulfils all the requirements for potable water, but it is often the case that during the distribution, its quality significantly deteriorates. One of the main causes is biofilm's growth on the pipe walls of drinking water distribution systems' (DWDS). The biofilms' presence significantly influences not only drinking water safety and aesthetics but also, by increasing the flow resistance, the distribution process itself [1]. A number of environmental and engineering parameters have been found to affect biofilm formation. Especially interesting in terms of modification possibilities, is the pipe material that significantly influences the process. Until now, all the materials utilized in DWDS construction have been found to harbour biofilm to a greater or lesser extent (Fig. 1) and no effective preventive strategy has yet been provided.

This project proposes the approach in which a novel anti-adhesive hydrogel coating for materials commonly applied in the DWDS will be developed and tested.

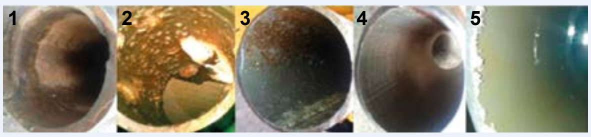
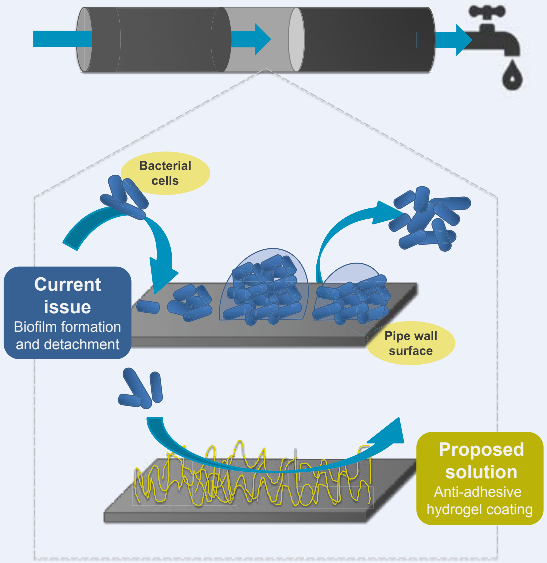


Figure 1: Biofilm growth on different pipe materials, 1 – ductile cast iron pipe, 2 – gray cast iron pipe, 3 – galvanized steel pipe, 4 – stainless steel clad pipe, 5 – polyvinyl chloride (adapted from [1])

Technological challenge

A number of polymer coatings with anti-adhesive properties has been studied in the medical field, where biomaterial associated infection caused by application of surgical implants and in-body devices limits the effectiveness of the treatment [2]. The challenge of this project is the translation of these anti-adhesive strategies from biomedical to DWDS application, considering not only the differences in the operational conditions, but also the robustness and cost-efficiency of such a solution.
To address those challenges, a simple method based on photo-initiated free radical polymerization (Fig. 2) will be used to coat the surfaces of commonly applied materials for DWDS piping, such as PVC and PE. A dedicated lab-scale setup will simulate DWDS conditions, especially targeting physio-chemical parameters of hotspots, where most biofilm growth has been observed (longer stagnant periods, higher temperatures, etc.). Microbial biofilms developed in time will be monitored to evaluate the efficiency of the selected strategy.



Research goals

This research project aims to:

- unravel the mechanisms of initial bacterial adhesion, biofilm formation and detachment on commonly applied DWDS pipe materials, such as PVC and PE,
- develop a novel non-adhesive coating applicable in real DWDS, especially on selected *hotspots*.

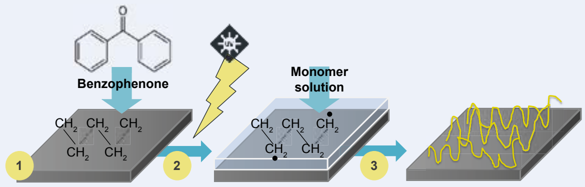


Figure 2: Anti-adhesive hydrogel coating formation on a polymer surface; 1 – surface infusion with benzophenone, 2 – surface free radicals formation through UV irradiation, 3 – coating formation in the presence of monomer (method adapted from [3])

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The research received funding from Netherlands Organization for Scientific Research (NWO) in the framework of the collaboration programme of NWO with Wetsus on Sustainable Water Technology.

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Fouling prevention through biological activated carbon and ultrafiltration

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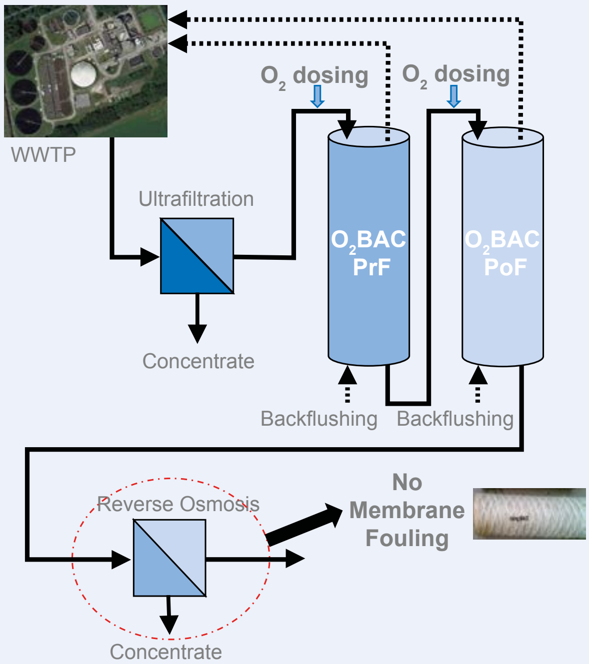
Motivation

Biological Activated Carbon (BAC) is a water purification process that combines physical adsorption onto granular activated carbon (AC) and biodegradation to remove pollutants (Fig 1). The technology is eco-friendly and cost-effective, since the biodegradation helps to prevent the saturation and replacement of the AC. BAC is an established process in drinking water treatment[1], however, BAC also has potential for wastewater reclamation[2,3]. At the Puurwaterfabriek (Emmen, the Netherlands), ultrafiltration (UF), BAC Pre-filter (O_2BAC PrF) and BAC Polishing Filter (O_2BAC PoF), and Reserve Osmosis (RO) are subsequently applied to produce ultrapure water from the effluent of a wastewater treatment plant[5]. This ultrapure water plant has been in operation for over 9 years without the need to replace the AC and RO membranes, although in literature, BAC is associated with downstream fouling[4]. This research aims to understand how UF and BAC can prevent downstream fouling.



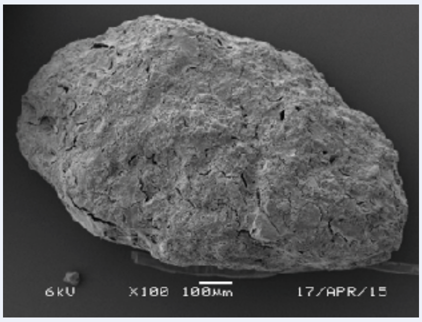
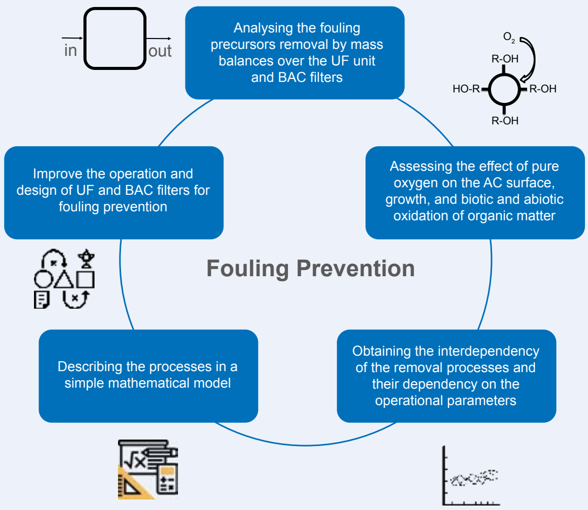


Fig 1. Activated carbon granule covered by a microbial biofilm[6].

Technological challenge

The BAC filters at the Puurwaterfabriek are unique as they are oxygenated and periodically back-flushed. The challenge is to investigate possible synergy between the biotic and abiotic processes contributing to the removal of fouling precursors, and to establish how these processes depend on the BAC operation and design.

Research goals



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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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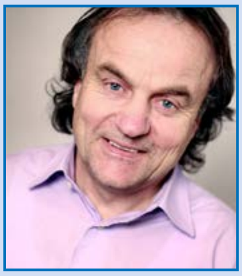
Groundwater technology

In the Netherlands, approximately two-thirds of the drinking water is produced from groundwater. Due to the filtering capacity of the underground, the quality of groundwater is high compared to surface water. However, the water quality is threatened by current and historic emissions of water-soluble micro-pollutants such as pesticides and pharmaceuticals. In addition, fresh water aquifers near the coast are under pressure of advancing brackish water. Furthermore, the operation of abstraction and infiltration wells can be hampered by well clogging and insufficient understanding of the local groundwater flow.

The Groundwater technology theme develops tools for the monitoring and control of aquifers and wells to cope with the issues described above. These tools are not only applicable for drinking water production from groundwater, but also for Aquifer Thermal Energy Storage (ATES) systems and remediation sites. These tools include distributed sensors, e.g. to measure groundwater flow, and methods to remove or immobilise pollutants.

THEME MANAGER



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Research projects

- **Wiecher Bakx**, Deltares
  Smart sensoring of groundwater flow for the management of subsurface assets
- **Sandra Drusová**, University of Twente
  Development of an optical fiber-based groundwater flow sensor
- **Rita Branco**, Wageningen University
  Dissolved organic matter dosing to enhance in situ *pesticides biodegradation in drinking water aquifers*

Industrial partners

Vitens
BIO SOIL Europe
wln water · onderzoek · advies

Academic partners

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Deltares
WAGENINGEN UNIVERSITY & RESEARCH

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Smart sensoring of groundwater flow for the management of subsurface assets

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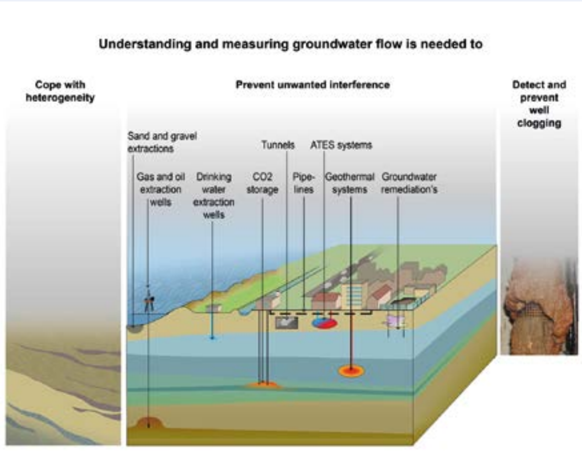
Motivation

For adequate management of groundwater extraction wells, ATES systems, remediation sites, dykes and other subsurface infrastructures, there is a need to improve knowledge of groundwater flow (magnitude and direction) on both regional and local scale. Understanding groundwater flow helps to prevent unwanted subsurface interference as a result of the increase of subsurface use, to detect well clogging and to cope with sediment heterogeneity especially in fluvial deposited sediments.

This can be achieved by measuring groundwater flow in detail and in real-time, e.g. by high accuracy measurement using Active Distributed Temperature Sensing (A-DTS) by insertion of optical fiber cables in de subsurface.



Technological challenges

Measuring groundwater flow in detail and in real-time lead to several technological challenges that will be addressed in this research:

- Inserting of fiber optical A-DTS/FBG cables without disturbing subsurface structures
- Translating temperature data (A-DTS, FBG) to groundwater velocity information, separating flow and sediment influence on the cooling of the DTS/FBG cable
- Combining measurement techniques for a spatial and temporal view of groundwater flow including real-time measurements

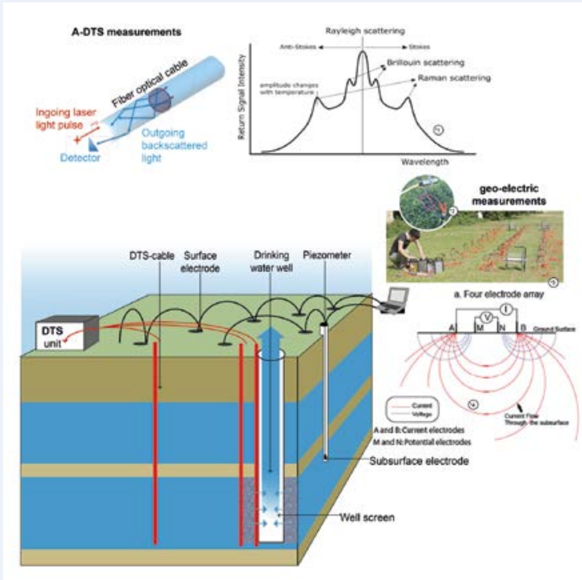
Research goals

- To select sensing techniques for the measurement of groundwater flow in unconsolidated sediments
- To pilot a selection of these techniques in a field situation
- To use these measurements for understanding the influence of subsurface heterogeneity which is essential to improve groundwater modeling
- To build a synthetic/generic predictive groundwater model for subsurface asset management that uses measured data on groundwater flow gathered by the applied sensing techniques

Pilot study

The following groundwater flow sensing techniques will be combined at a drinking water extraction well:

- Active Distributed Temperature Sensing (A-DTS) and Fiber Bragg Grating (FBG) optical fiber cables
- Geo-electrical measurements
- Direct current resistivity
- Self potential (SP)
- Optional: tracer measurements and point-location measurements (using piezometers)



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Note: With special thanks to Wilfried Jansen of Lorkeers (Arcadis) for his help in the graphical design

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Development of an optical fiber-based groundwater flow sensor

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Motivation

Groundwater is the largest and most reliable reserve of drinking water in the world. Understanding groundwater flow patterns is essential for sustainable management of available resources and preventing groundwater-related problems, e.g. well clogging, salt water intrusion and pollution. Due to complexity of subsurface, these problems can not be sufficiently predicted using existing monitoring tools. A promising solution are optical fibers with **F**iber **B**ragg **G**ratings (FBGs).

Optical fibers are harmless to the environment and suffer low losses over great distances which opens the possibility for large area distributed network sensing. Fibers with FBGs will be placed in the ground for real-time and long-term monitoring of local groundwater flow.

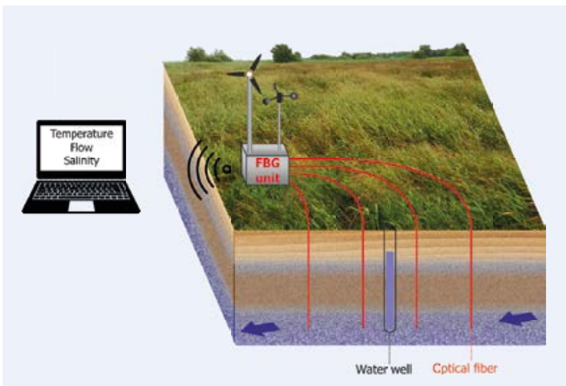

Fig. 1: FBG sensors gathering information about subsurface flow, temperature and salinity in order to identify source and quality of drinking water

Research goals

- Design a flow sensor capable of measuring slow flows (meters/day)
- Place FBG fibers without considerable disturbance of subsurface environment
- Design an autonomous sensing unit operational under field conditions
- Develop a combined sensing platform capable of detecting groundwater flow, temperature and salinity
- Assess long-term survivability of optical fiber sensors in the subterannean environment

References

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Concept

An FBG is a periodic variation of refractive index within the fiber core which acts like a wavelength-specific mirror. The wavelength of reflected light - Bragg wavelength, is sensitive to temperature of the environment and strain applied to the fiber.

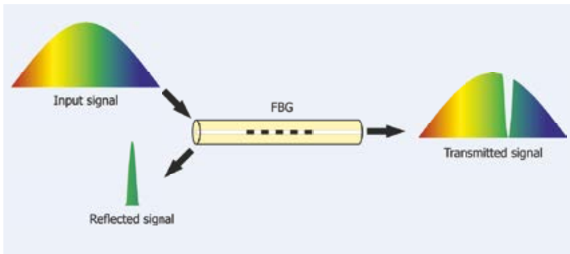

Fig. 2: Fiber Bragg grating reflecting narrow part of input spectrum

The proposed sensor will be capable of simultaneous flow and temperature measurements. The idea is to use heat as a tracer of flow since it does not affect the quality of drinking water. The sensor consists of a central heating element surrounded by multiple sensing fibers with FBGs (Fig. 3). A matrix of FBG temperature sensors creates a 3D map of heat distribution. When water flows through the sensor, heat convection will disturb the symmetry of heat field. Therefore, spatial temperature differences detected by the FBGs can be further translated into a 3D flow vector.

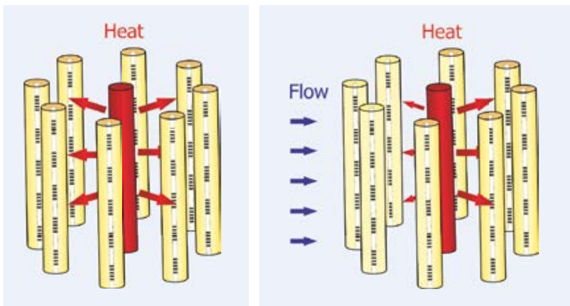

Fig. 3: Principle of FBG flow sensor. Without the presence of flow, all fibers should detect the same temperature if placed at the same distance from the heating fiber. Introducing flow from the left side will make the temperature on the left lower than on the right.

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OS Optical Sciences
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Dissolved organic matter dosing to enhance *in situ* micropollutants biodegradation in drinking water aquifers

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Motivation

In the Netherlands, approximately 65% of the drinking water is produced from groundwater [1]. A recent study reported that about 25% of 200 Dutch groundwater abstractions contain pesticides, and in 13% of the cases above the permitted limit (0.1 µg/L for a single pesticide) [2]. Pharmaceuticals and other micropollutants are also often detected in groundwater above this level. Due to the distributed nature of the source (e.g. agricultural land) and the costs associated to the removal after abstraction, an *in situ* technology for micropollutant removal is needed.

Under adequate environmental conditions, biodegradation of micropollutants can occur naturally in the environment [3]. However, in groundwater the rate of natural attenuation is impaired by the low concentration and recalcitrance of dissolved organic matter (DOM) (Fig. 1A). Previous research indicates that amendment with labile DOM can enhance the biodegradation of micropollutants.

Technological challenge

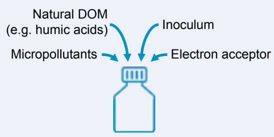
When developing the *in situ* micropollutants bioremediation technology (Fig. 1B) some challenges need to be overcome:

- Low concentrations (µg/L or lower) and heterogeinity of micropollutants
- Groundwater unfavorable environment conditions
  - Low microorganism density
  - Anaerobic environment
  - Oligotrophic conditions
  - Low temperature (≈ 10 °C)
- The in situ treatment cannot negatively affect groundwater safety and aquifer function

Research goals

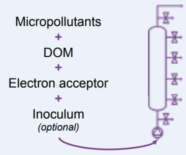
This project aims to develop an in situ bioremediation technology based on DOM amendment to treat micropollutants in groundwater systems. The research approach is divided in 4 phases:

1 Screening



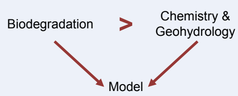
Select most promising combinations of inoculum, DOM source and redox conditions

2 Kinetics & Mechanism



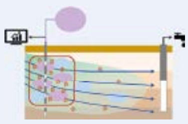
Elucidate process in columns simulating aquifer

3 Reactive transport modelling



Create model to design field experiment

4 Pilot Experiment



First step towards implementing a bioremediation-based strategy

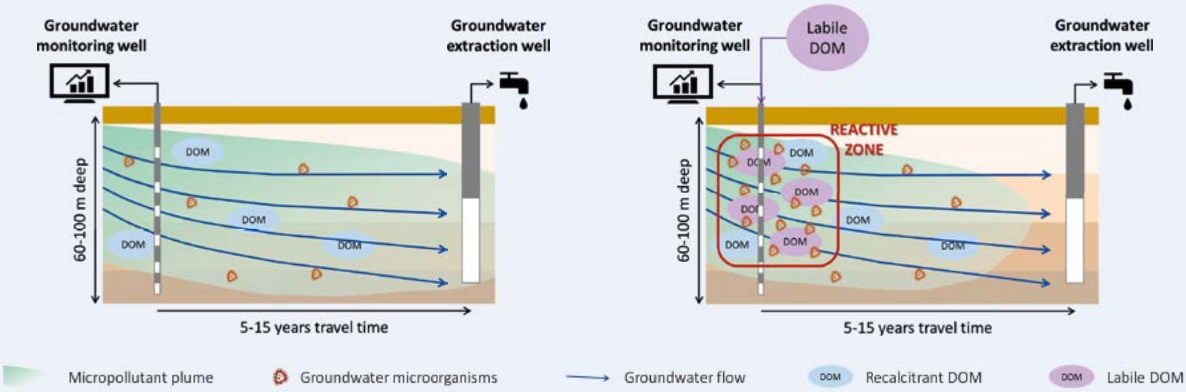


Fig 1. Micropollutant attenuation in groundwater: A – Natural attenuation; B – DOM amended attenuation

[1] Vewin, Dutch Drinking Water Statistics 2017 (2017).
[2] RIVM, Bestrijdingsmiddelen in grondwater bij drinkwaterwinningen (2016).
[3] Helbling, D. E., Curr Opin Biotechnol 33 (2015) 142-148.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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WAGENINGEN UNIVERSITY & RESEARCH

Priority compounds & Virus control

Chemical-free and non-specific degradation and inactivation of human-originated trace contaminants into harmless products is the main focus of this theme.

The goal of this theme is twofold. Firstly, to develop effective and efficient chemical-free UV-based advanced oxidation technologies to produce safe drinking water from impaired water sources. As part of a treatment train, these technologies should be effective in preventing acute exposures to pathogens (viruses) and long-term chronic exposures to chemical contaminants (priority compounds). Technologies and applications will not only be evaluated on their removal performances, but also on potential (geno)toxicological effects of degradation products. Secondly, the goal is to develop instruments and methods for fast and simple process validation on log removal and log inactivation values. Lack of sensitivity of operational monitoring may otherwise reduce the log credits that can be claimed.

Research projects

- **Nimmy Kovoor George**, Fundació Istitut Calalà de Recerca de l'Aigua (ICRA)
  Photochemistry and scale-up of chemical-free AOP by VUV light for water treatment
- **Shuyana Heredia**, University of Twente
  Integrated UV photocatalytic active membrane water purification
- **Swarupa Chatterjee**, University of Twente
  Fluorescence spectroscopy for fast and simple detection and counting of viruses in water

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Academic partners

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Photochemistry and scale-up of chemical-free AOP by VUV light for water treatment

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Motivation

Organic micropollutants (OMP) are increasingly found in sources of drinking water. In our daily life we contribute to multiple sources for OMPs entering our water bodies (eg., from the medicines we consume to the shower gel we lavish). They can be persistent and difficult to degrade leading to possible negative effects on human health and aquatic life, which may e.g. be of mutagenic, genotoxic, or endocrine disrupting nature. For instance feminization of fish has been observed in several rivers globally. Advanced Oxidation Processes (AOPs) can convert OMPs to less harmful coumpounds. AOPs are the oxidation processes that use hydroxyl radical (·OH) for degradation of the OMPs via oxidation. Conventional AOPs have been optimized to an extent that the application is economically feasible (for eg., H_2O_2 /UV or O_3/UV). However, a number of alternative AOPs are promising on lab scale like the vacuum UV-185nm (VUV) based AOP, which produces ·OH radicals in-situ without the addition of chemicals like H_2O_2 or O_3 [1]. However, scale-up and optimized reactor concepts have not been developed yet for applications of the VUV process such OMP reduction in drinking water or biologically treated wastewater.

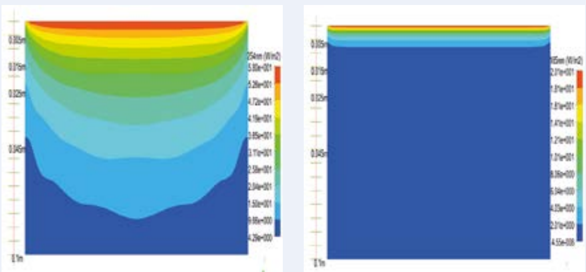
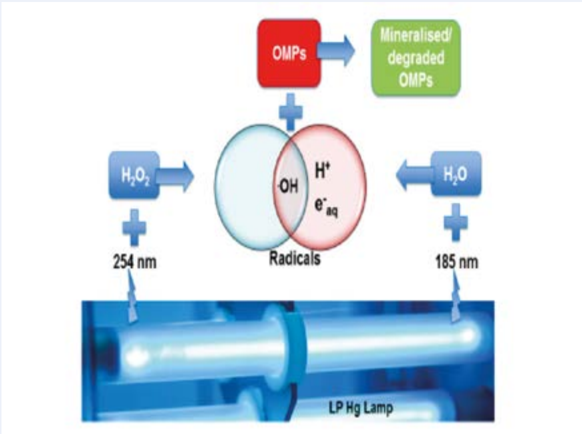


Fig. 1 CFD simulations showing the inhomogenity in irradiated volume of water irradiated at 254nm and 185nm. The higher absorbance of water at 185nm (1.8cm⁻¹) compared to absorbance at 254 nm (<0.01cm⁻¹) resulting in 90% of 185nm photons absorbed within approximately 5mm of water layer.

Technological Challenge

- A reactor design optimization is necessary to realize VUV AOP on large scale.
- High molar absorption coefficient of water at 185nm results in optical pathlengths in orders of millimeters inducing heterogeneous radical concentration in the reactor.
- Major solutes (i.e., chloride, sulphate, etc.) in water also (photo) chemically generate less reactive and long lived radical species.
- The undesired radical species formed from the aforementioned pathway may form harmful byproducts from dissolved (in)organic matter.



H_2O_2/UV	• $H_2O_2 + h\vartheta(254nm) \rightarrow 2{\cdot}OH$	Φ (+·OH)=0.5
VUV/UV	• $H_2O + h\vartheta(185nm) \rightarrow {\cdot}OH + H{\cdot}$ • $H_2O + h\vartheta(185nm) \rightarrow {\cdot}OH + H^+ + e^-_{aq}$ • $H_2O_2(\text{in-situ}) + h\vartheta(185nm) \rightarrow 2{\cdot}OH$	Φ (+·OH)=0.33 Φ (+e_{aq})=0.045 Φ (+·OH)=0.5

Research Goals

Related to Photochemistry:

- Understand matrix dependent micropollutant degradation
- Analyse formation of disinfection byproducts
- Understand the synergistic effects of 185nm and 254nm irradiation on micropullutant degradation
- Analyze the reactive species (radicals, solvated electrons) and their effects on the degradation kinetics of OMPs

Related to Hydrodynamics:

- Develop reactor models using computational fluid dynamics that effectively overcome the issues caused by inhomogeneous illumination of the reactor system due to the high absorption coefficient of water at 185nm
- Understand the effect of addition of H_2O_2 in the system
- Construct and experimentally evaluate a scaled up photoreactor with a minimum flow of 0.5 m^3/h

Reference: [1] Kristin Zoschke et al (2014) Water Research 52 (2014), 131-145

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Integrated UV photocatalytic active membrane water purification

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Motivation

One of the improvements regarding water purification is to treat the water more effectively and economically, avoiding the production of secondary waste pollutants and ensuring safe water supply.

Advanced oxidation techniques and membrane filtration have attracted increasing attention to treat and purify water. Among these methods photocatalytic oxidation with titanium dioxide (TiO_2) is widely studied as this treatment avoids the solid waste [1], and membranes have gained an important place in chemical technology and are used in a broad range of applications [2].

This research seeks to provide a novel water treatment method, based on the synergy between photocatalytic oxidation and membrane separation within a single material to remove micropollutants and inactivate microorganisms. Unique metal membranes in combination with UV light will be used to provide new safe drinking water solutions.

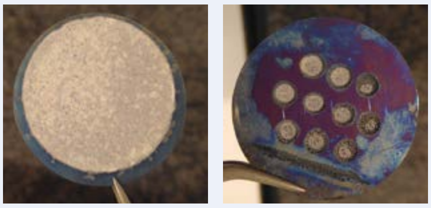

Fig 1. Pictures of both sides of the metal membrane. Highly porous ceramic layer (left) and metal layer connected with the ceramic layer through the openings (rigth).

Technological challenge

The main challenge is to design a reactor that ensures efficient irradiation of the photocatalytic membrane and filtration, avoiding the fouling of the membrane. This requires fundamental understanding of the materials, photochemistry and transport processes.

Membrane filtration results in accumulation of retained species at the membrane surface, known as concentration polarization (CP). Reduction of CP directly results in improved flux, or production, of purified water. A reactive membrane is expected to reduce the CP and biofouling layers via the chemical conversion of reactants, which is conceptually innovative, see comparison in Fig.2. Furthermore, photocatalytic degradation of contaminants in water is considered as a viable method to remove micropollutants and inactivate microorganisms.

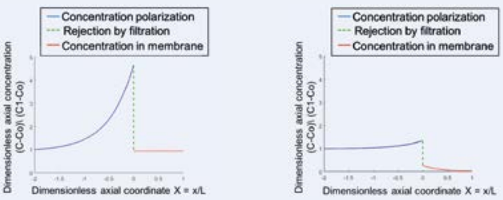

Fig 2. Model predictions for concentration profile with only membrane filtration (left) and with reaction and filtration (right).

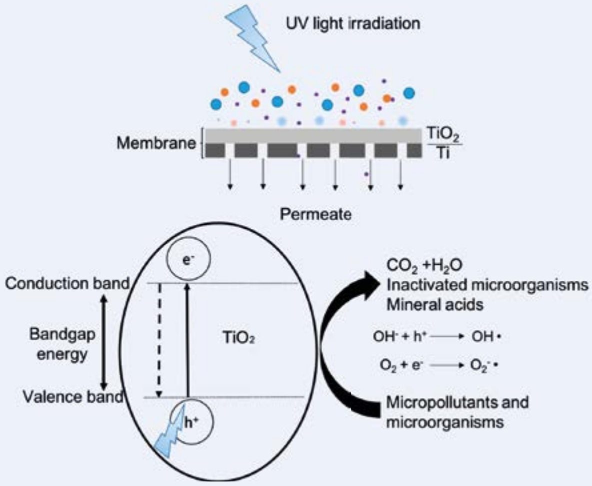

Fig 3. Graphical abstract of the project. Schematic view of the process in the membrane (top) and diagram of the photocatalytic degradation taking place (bottom).

Research goals

- Provide a novel water treatment method combining membrane separation and photocatalytic oxidation. The process will be characterized by size (and/or charge) selective filtration that retains contaminants from the aqueous feed, assisted by photocatalytic oxidation of bacteria, viruses and organic contaminants in contact with the same membrane surface.
- Elucidate and optimize the synergy between membrane rejection and photocatalytic conversion.
- Study the transport and distribution of the UV light and its interplay with the chemical oxidation process. First, using methylene blue as a model compound and later on with bacteriophage MS2, a commonly used surrogate for waterborne pathogenic viruses
- Obtain a transport model that contains the membrane function (rejection) and the photocatalytic degradation (reaction) including light distribution.

[1] Leong, S. et al., Journal of Membrane Science 472 (2014) 167-184.
[2] Baker, R. W., Membrane Technology and Applications (2012).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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MST Membrane Science & Technology

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Fluorescence Spectroscopy for Fast and Simple Detection and Counting of Viruses in Water

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Motivation

Globally, more than 2 million deaths and 4 billion waterborne disease cases annually can be attributed to the use of microbial contaminated water sources [1]. Household water treatment and safe storage (HWTSS) systems have shown to improve the microbial water quality but are less effective in the removal of waterborne viruses. Viruses are very small particles (e.g. 20-100 nm), the infective dose can be very low (~10-100 particles), they are transmitted via the fecal-oral route and are persistent in aquatic environments for extended periods of time.
For the removal of pathogens from drinking water, membrane filtration is a promising technique. Membranes are able to retain very small particles, which may aid in producing microbial safe drinking water. To test, develop and optimize such membrane filters in a limited time, a fast and simple method to quantify virus reduction is mandatory. Combining our knowledge of virology and fluorescence spectroscopy and microscopy are used to develop in quick and easy method to quantify viruses for the development of membranes.

Technological challenge

Currently applied methods to test the efficiency of membrane filters for reduction of waterborne viruses are mostly based on cell culture methods. The proposed fluorescence based assay will be able to detect and count the viruses with high sensitivity. It will be able to quantify the virus retention and inactivation efficiency of membrane filters within few seconds.
The bio-assays [2,4] are accepted as the gold standard [3], however, these assays require specialized laboratory facilities, are complex and rely on a high degree of expertise. The complexity and time required for these assays make them not well suited for membrane development, optimization and installations purposes, which require fast, simple and robust tests for virus retention.

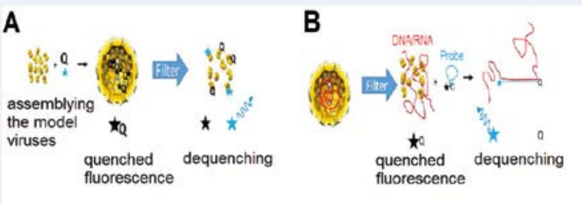

Fig 1. (A) Capsid disassembly as a readout for virus inactivation,
(B) RNA/DNA release as readout for virus inactivation and identification

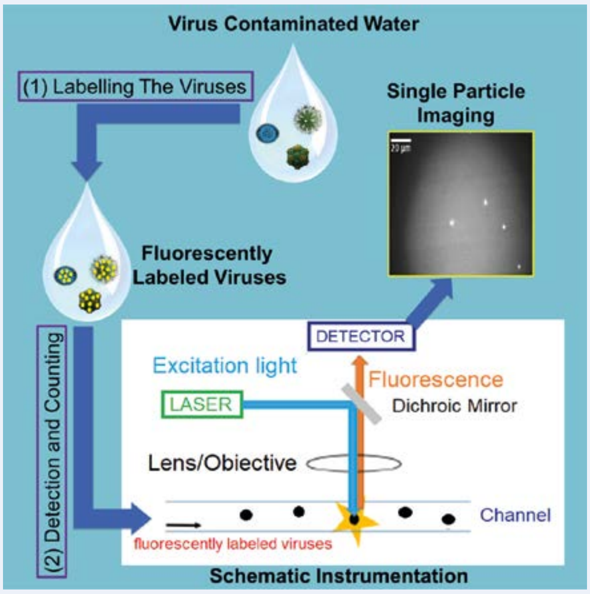

Fig 2. Flow-cycle of Detection and Counting of Fluorescently Labeled Viruses in Water

Research goals

- ❖ Develop an instrument that can detect the necessary low numbers of labeled viruses using fluorescence spectroscopy and microfluidics (Fig. 2)
- ❖ Use fluorescently labeled viruses to study retention of membrane filters and benchmarking the proposed fluorescent assay against the existing virus detection methods
- ❖ Discriminate between mixtures of different labeled viruses
- ❖ Study the mechanism of virus inactivation due to virus capsid disruption or disassembly (Fig. 1A)
- ❖ Identify native viruses in the filtrate based on DNA / RNA identification (Fig. 1B)

References

[1] *World Health Organisation, Drinking-water fact sheets, July 2017*
[2] Huang, H. O.; Young, T. A.; Schwab, K. J.; Jacangelo, J. G. *Journal of Membrane Science* **2012**, *409*, 1.
[3] Husman, A.; Lodder, W. J.; Rutjes, S. A.; Schijven, J. F.; Teunis, P. F. M. *Applied and Environmental Microbiology* **2009**, *75*, 1050.
[4] Haldar, J.; An, D. Q.; de Cienfuegos, L. A.; Chen, J. Z.; Klibanov, A. M. *Proceedings of the National Academy of Sciences of the United States of America* **2006**, *103*, 17667

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Smart water grids

The Dutch water supply network is continuously providing very high quality drinking water, and all of this needs to be transported in the water mains. These mains vary in age between being laid today and a century ago, with many different materials and laying methods used. The replacement value of the whole network is estimated to be more than €10 billion, so it is key to carefully replace end-of life parts. As indicated, there is much variety in the quality and operational state of the network: one specific section of the network could be leaking while another section, a metre further up, could be in perfect condition. There is much uncertainty about the quality of these mains, because it is hard to gauge.
Accurate information is vital to be able to predict end-of life parts and to replace then in time, to prevent downtime, keeping the quality of the water high, efficiently deploying materials and effort and assure good operation of the network. New technologies are needed, such as better inspection methods and measurement systems, combining data streams and a bright future look to anticipate for changes, because of the long term investments associated with water mains. The ambition for this theme is to develop methods for the in-line and on-line inspection of water mains, and the ability to make well-founded decisions about the possible replacement of pipelines.
The research in the Wetsus Smart Water Grids theme has delivered good understanding of PVC push fit joint placement in relation to lifetime, the development of a method to characterize PVC material and concrete. Now, new ultrasonic inspection techniques are developed, allowing the condition of pipelines and appendages of concrete and plastics to be determined. The theme initiated the idea of an autonomous inspection robot, with the development of a prototype, this leaded to a commercial initiative. Data processing research delivers now unprecedented insights from existing data streams and future projects are aimed on better understanding of sensor placement, remotely sensing and predicting the state of the mains.
The close cooperation with the theme members ensures both scientifically relevant and applicable results, leading to notable innovations in the drinking water chain.

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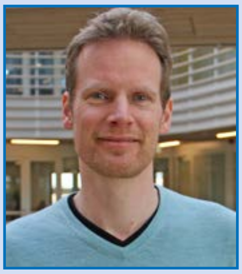
THEME COORDINATOR



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Research projects

- **Caspar Geelen**, Wageningen University
  Smart detection and real-time learning in water distribution: an integrated data-model approach
- **Nandini Chidambaram**, University of Twente
  Non-collinear wave mixing with Phased Array transducers
- **Cao Vinh**, University of Twente
  Smart-pipes, monitoring assets for efficient maintenance

Industrial partners

Vitens · Acquaint B.V. · Brabant Water · PWN · Wavin · Evides waterbedrijf

Academic partners

Wageningen University & Research · University of Twente.

Smart Detection and Real-time Learning in Water Distribution: an Integrated Data-Model Approach

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Motivation

Although Dutch drinking water is of high quality and only 5% of clean drinking water is lost per year [1], the actual behavior of flows within the distribution network and **current state** of the pipes remain largely unknown. Due to the unknown state and continuous degradation of pipes, water companies yearly spend millions in investigating the state of water mains, without a detailed strategy to target most likely degraded pipes.

Although increased water sensor placement in water mains yields **big & fast data streams**, analysis of this data is currently limited to a **reactive** approach of real-time leak detection [2].

However, in order to guarantee robust performance and avoid leakages, a more **proactive** approach is required. Since sensor placement and pipe inspection are costly, the abundance of currently collected sensor data can be further analyzed to facilitate cost-effective monitoring and management of the water supply grid.

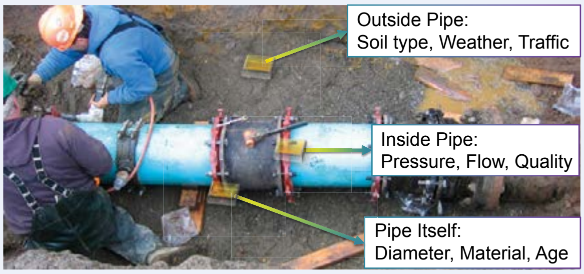

Fig 1. Available data sources influencing pipe condition

Technological challenges

1. **Integration** of multiple data streams with the aim to discover more information than currently possible with separated sensor data processing.
2. **Reconciliation** of flow dynamics from prior (physical) knowledge of the drinking water distribution process and data streams.
3. **Development** of innovative decision support that allow the integration of (noisy/perturbed) data and (incomplete) prior systems knowledge for real-time learning and early warning systems (EWS).

Research goals

- Obtain real-time insight in the state of the assets in the drinking water distribution grid.
- Realize decision support for cost-effective monitoring and management of the water distribution network.

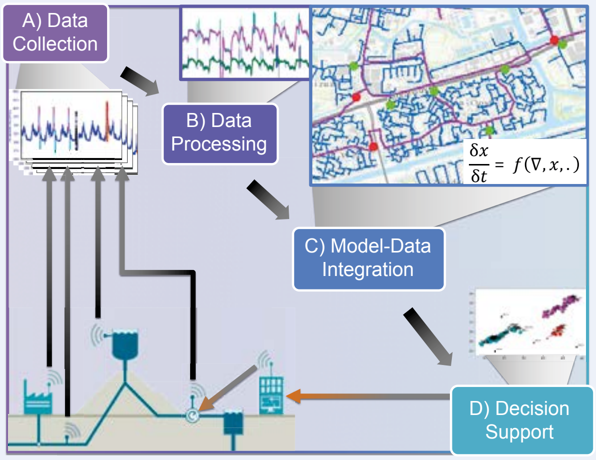

Fig 2. Research approach

Approach

With the help of Dutch drinking water companies, current available data streams (Fig. 1) are collected & investigated (Fig. 2A) and integrated using data science (Fig. 2B). The resulting developed software sensors will allow discovery of new unexpected physical relationships within the water grid. These software programs are combined with GIS maps and mathematical MATLAB models of the water distribution grids in order to reconcile flow dynamics with discovered data relationships (Fig 2C). These insight in the state of the network assets are used to develop real-time decision support (Fig 2D).

Expected Outcome

1. **Early stage** faults and failures detection with corresponding probabilities
2. **Software sensors** for accurate information of network segment conditions in and around the pipes
3. Optimal (mobile) **sensor locations**
4. **Fault detection & isolation** (FDI) for accurate information of the conditions inside the distribution grid

1 [1] "Drinking Water Fact Sheet 2016." VEWIN (2016).
2 [2] Gelazanskas, Linas, and Kelum AA Gamage. "Demand side management in smart grid: A review and proposals for future direction." *Sustainable Cities and Society* 11 (2014): 22-30.

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WAGENINGEN UNIVERSITY & RESEARCH

Non-collinear wave mixing with Phased Array transducers

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Motivation

Drinking water supply mains are degrading over time and the current state of a particular piece of pipeline is mostly unknown. Often, assets in good condition are replaced prematurely, resulting in increased cost and material usage whereas other assets fail before expectation time. Inspection of drinking water supply mains is important in order to determine the current state of the assets for its effective replacement or maintenance.

Non-destructive testing (NDT) is a common method of inspection of water mains. However, there is much more to improve. Polymers like PVC are very difficult to assess using current NDT methods, however, a new technique has been developed in the Wetsus Smart Water Grids research project *Development of Inline Water Mains Inspection Technology*, which makes this possible. This technique of non-collinear wave mixing has been verified with single element transducers as seen in Figure 1. However, extensive mechanical alignment is needed to obtain promising results [1-4]. The use of actuator and receiver arrays enables steering and focusing of the beam at desired angles and directions, which eliminates the need for its mechanical alignment since this can now be done with signal processing. In this way, the method can be applied in water mains with varying diameter and composition.

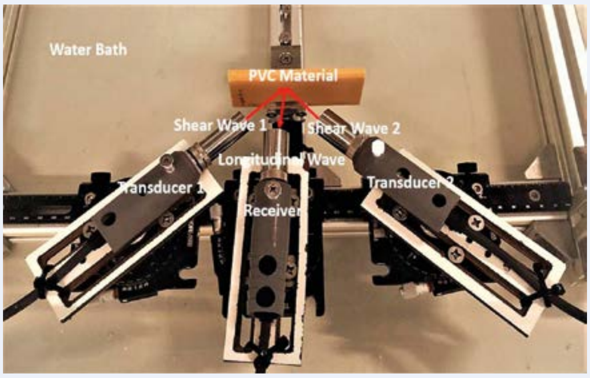

Figure.1 Non-collinear wave mixing configuration where two broadband transducers transmit shear pump waves into a PVC material, in which they interact to generate a longitudinal wave which is recorded by a receiver.

Technological and Scientific Challenges

The challenge lies in 1) investigation of array techniques which are able to generate a well-defined acoustic intensity at a definite area in the material to be investigated, 2) proper alignment of the phased array sensors with respect to the surface of the material, 3) effective detection of the resulting mixed signals 4) storage and handling of a large amount of data, 5) visualization of recorded data and 6) determination of the relative material state from the recorded mixed signal.

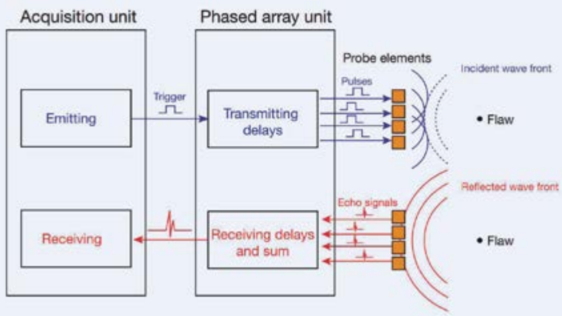

Figure.2 Multiple piezocomposite elements are pulsed at slightly different times to generate a beam. Precise control of the delays between the elements generate beams with various angles, focal distances and focal spot sizes. The echo from the desired focal point hits the elements with a computable time shift. The signals received at each element are time-shifted before being summed up. The resulting sum represents the response from the desired focal point [5].

Research Goals

The possible array transducer configurations must be studied, keeping in mind their specific application in water mains. This will be done by acoustic wave propagation modelling, phased array modelling, testing the model with a lab scale set up, field verification of the model, excitation mimicking multiple number of transducers, reception of the resulting signal with the same transducer array and analyzing the received signal to determine material properties.

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Smartpipes, Monitoring Assets for Efficient Maintenance

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Motivation

Replacement activities of drinking water mains are not only costly but also inconvenient for water distribution companies as well as customer, especially in dense areas (Figure 1). Moreover, pipes that are either in good or defected condition are often entirely replaced if they failed more times a year, resulting in increased cost. Asset managers of drinking water companies want to have a continuously detailed picture of the state of assets to efficiently manage and schedule the replacement activities of the degraded pipes with other groundworks. Consequently, we propose Smart-Pipes, which are polyvinylchloride (PVC) pipes that comprise of multi kind of distributed sensors to collect the required information and communicate together to send data to the data center (Figure 2).

Despite there is a variety of sensors and methods for monitoring and inspecting water mains, deploying and combining them into Smart-Pipes in practical is still challenging in both technological and financial aspects [1-3]. It requires researches for the optimization in selection, placement and installation of sensors, the relationship between information and benefit, the signal processing for multiple sensors data into useful information.

Figure 1: Water mains replacement

Technological challenge

Smart-pipes may consist of a huge number of “Fit and Forget” nodes with different kinds of sensors which are buried underground or place inside the pipes, and they must operate for many decades. Therefore, the challenges are:

1. Identifying the required information and its benefit in getting the insight into the PVC pipes.
2. Determining the optimization of the amount, type and location of sensors in a network or subnetwork.
3. Determining the signal processing methods corresponding to the information.
4. Building an efficient underground / in-pipe communication network in both energy-efficient and reliable aspects.

Research goal

- Developing insight into the PVC water mains by utilizing a multitude of sensors.
- Understanding what requirements are needed for getting the optimal information of the water mains
- Development of a communication method for the sensors network.
- Developing insight into the energy supply of the system

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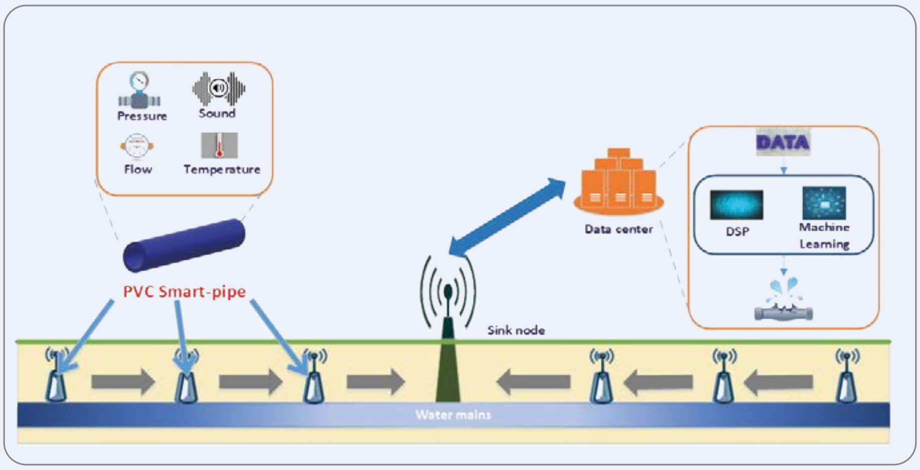

Figure 2: The operation of Smart-Pipes

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Advanced water treatment

The emphasis in this theme is on new sustainable water purification technologies to remove salt, priority compounds, biological material and other contaminants, as stated in the Water Framework Directive. New water treatment technologies are investigated based on physical, electrical and electrochemical principles. These principles can include molecular transport in electrical fields, magnetic, photonic and acoustic driving forces, or driven by pressure. Technologies presently studied are UV-LED reactors, in-situ formed membranes, and reverse osmosis.

Research projects

- **Olga Bernadet**, University of Groningen
  Control of metabolic active biofilms on activated carbon for efficient in situ regeneration
- **Sam Rutten**, University of Twente
  Nanofiltration of greywater for micropollutant removal **NEW**

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Oasen · Vitens · Dunea duin & water · Desah · NX Filtration

Academic partners

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Diverse and metabolic active biofilms on activated carbon for efficient *in situ* regeneration

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Motivation

Activated carbon (AC) is a porous carbonaceous material with high sorption capacity (Figure 1). Many drinking water and wastewater treatment facilities use either powdered AC (PAC) or granulated AC (GAC) for the removal of large and small organic pollutants in minute quantities. Removal of these compounds is crucial for the improvement of the biological stability of water and prevention of any possible adverse effect of the pollutants to humans and the environment [1-3].

As the operation continue, the adsorption sites of the AC will be saturated with organic compounds and can be either discarded or regenerated. Regeneration of saturated AC is aimed for prolonging AC service life and can be achieved by means of biological process. In the biological activated carbon (BAC) system, microorganisms will colonize the surface of the GAC particles, utilizing the adsorbed organics for growth and biofilm formation. The active biofilm surrounding the GAC particles will regenerate the carbon surface through a combination of adsorption/desorption and biodegradation of the organics adsorbed [1, 3]. BAC process has been widely applied, including in the ultrapure water (UPW) plant in Emmen, but a comprehensive study about the underlying physical and biological mechanisms involved has yet to be done. Such information is crucial to improve the overall BAC process efficiency.

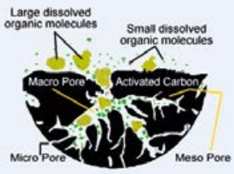

Figure 1 Activated carbon pore structure and adsorption sites [4].

Challenges

Achieving a consistent process performance in BAC system is challenging due to various reasons. Stimulation and regulation of the right biofilm population and metabolic activity are expected to be essential to achieve a successful organic compounds removal and bio-regeneration of BAC particles. Thus, a clear role for the GAC, the biofilm, their interactions, and their influences on the removal of organic pollutants should be characterized in detail (Figure 2 and 3). The results will identify the impact of various operating conditions on the performance and maintenance on BAC adsorption process.

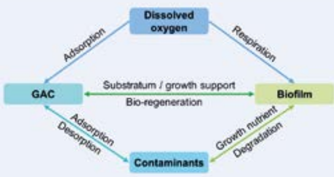

Figure 2 Theoretical interactions in BAC system [2].

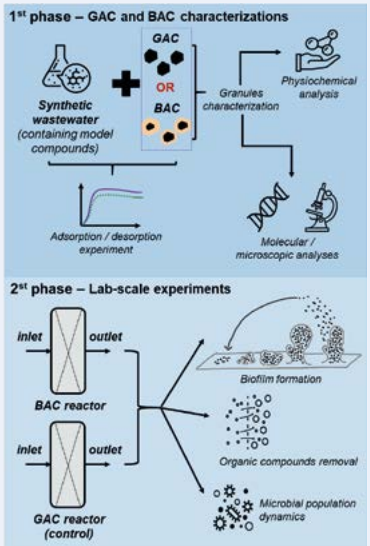

Figure 3 Graphical abstract of the project (some illustrations were adapted from [5, 6]).

Approach

This research will be divided into two parts. In the first phase, a thorough physical and biological characterization of raw GAC and BAC granules used in UPW plant will be done. Adsorption/desorption experiments of model organic pollutants by GAC and BAC will also be investigated. These experiments will give light to the underlying mechanism of organic compounds removal by GAC and BAC and the possible role of biofilm on organics removal and BAC regeneration.

Subsequently, a lab-scale BAC reactor together with a control reactor will be set up. This experiment will enable real-time observation of biofilm formation, organic compounds removal and microbial population dynamics in the system.

Once the reactor reaches a steady state, it can be subjected to various operational conditions to evaluate their effects on biofilm fitness and organic compounds removal. The obtained data will be used to control the process conditions for efficient organic compounds removal and bio-regeneration.

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Nanofiltration of greywater for micropollutant removal

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Motivation

Separation of wastewater at the source into black water and greywater streams, with the intent of reuse, has gained popularity in the last three decades[1]. The separate collection of black- and greywater has several benefits such as higher concentrations of organics in black water leading to more efficient nutrient recovery and more efficient water use and reuse[2][3].

Prior research has shown the reuse potential of greywater, but risks associated with micropollutants, and other emerging contaminants must be considered[1][2][4]. Advanced oxidation processes and adsorption to remove these contaminants have been studied extensively in source-separated sanitation plants. However, membrane technologies, like spiral wound nanofiltration, have seen limited implementation, due their high fouling potential and the need for extensive pretreatment[5]. The emerging technology of hollow fiber nanofiltration membranes has the potential to alleviate these drawbacks and will be able to produce a high-quality water stream for reuse and increase the recovery of valuable resources[6][7].

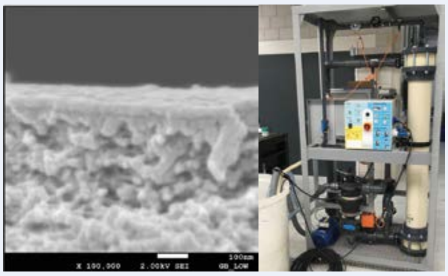

Fig 1. (A) SEM-picture of the hollow fiber with polyelectrolyte multilayer indicated[10] (B) Pilot setup used during the project

Technological challenge

While the new generation of nanofiltration membranes which use polyelectrolyte multilayers as separation layer (Fig. 1A) have shown to be promising method for micropollutant removal[8], implementation of these membranes in full scale applications has not been studied in detail yet. Moreover, influences of the water matrix and membrane fouling on the rejection of micropollutants are yet to be studied.

Because of the decentralized nature of source separated sanitation, it is required to monitor membrane integrity and permeate quality in-line. While some research has been done[9], no sufficient methods has yet to be developed.

Lastly, while a high-quality permeate will lead to a multitude of water reuse possibilities, a highly contaminated concentrate stream will be produced as well. This concentrate stream could lead to potential increased resource recovery, but will also require a suitable treatment, which has not yet received much attention.

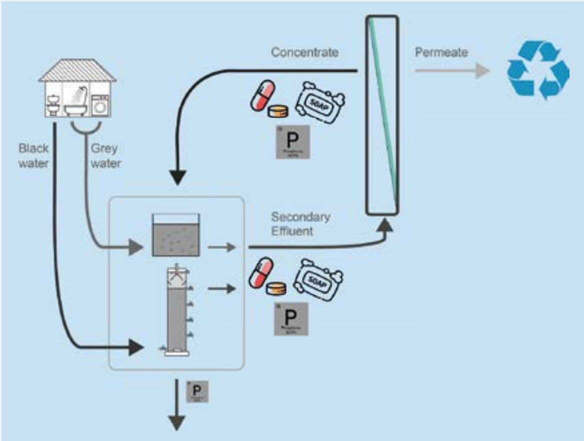

Fig 2. Graphical Abstract of the research project.

Research goals

During the project, the integration of a hollow fiber nanofiltration pilot (Fig 1B) in a full-scale source separated treatment plant will be studied. The goal of this integration is to create a self-sustaining treatment plant which will have a clean enough permeate to be re-used and an environmentally appropriate method to treat the concentrate treatment. The achieve this the following questions will be answered.

- How effective is the implementation of hollow fiber nanofiltration in terms of operational cost and treatment plant stability?
- What is the influence of process parameters, such as transmembrane pressure and crossflow velocity, on the permeate quality?
- What is the efficiency of the total source separated treatment plant in terms of micropollutant removal and resource recovery?
- What is the most suitable monitoring method for membrane integrity and permeate quality?
- What are potential areas of application for the nanofiltration permeate?

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Concentrates

Membrane filtration and ion exchange are both well proven technologies in the beverage and industrial water preparation fields. They have major advantages over the traditional methods; excellent product quality, limited use of chemicals and the simultaneous removal of numerous parameters. There is a disadvantage however; the creation of a concentrated salt effluent. Current practice is to release these concentrates into the sewer system or directly to surface water. This can lead to exceeding the (local) emission standards. The increasingly strict emission standards (including the European Framework Directive on Water) mean that more sustainable recycling techniques must be found.

The "Concentrates" theme is focused on finding solutions for membrane concentrates, ion exchange reclaim and concentrated salt industrial effluent. The research is aimed primarily at:

- technologies to remove (and preferably reuse) specific components such as salts and anti-scalants
- concepts for the reuse of concentrates in agriculture and industry
- possibilities for reducing the volume of concentrate etc.

Research projects

- **Hanieh Bazyar**, University of Twente
  Adaptive pores in next generation membranes
- **Ettore Virga**, University of Twente
  Produced water treatment by low fouling polyelectrolyte multilayer based nanofiltration membranes
- **Rose Sharifian**, Delft University of Technology
  Synergistic CO_2 capture & scaling prevention for desalination
- **Anthony Cyril Arulrajan**, Wageningen University
  Chemically modified carbon electrodes for electrochemical separation processes

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Adaptive pores in next generation membranes

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Motivation

Petroleum extraction unavoidably generates large volumes of produced water. The environmentally acceptable discharge of produced water is a current challenge to the petroleum industry. Therefore, there is an urgent need for treatment of produced water. Among many different techniques, membrane separation processes have become an emerging technology due to high oil removal efficiency and relatively facile operational process. However, membrane fouling which results in flux decline and rejection deterioration, is the main drawback of this technique. As a result, improvement of anti-fouling properties of polymeric membranes has attracted a lot of attention recently.

Approach

In this work the novel **Slippery Liquid Infiltrated Membranes (SLIM)** with adaptive pores will be used to reduce fouling deposition in treatment of produced water. The principle of liquid infiltration is based on well-matched solid and liquid surface energies, combined with the microtextural roughness. The **Infusion Liquid (IL)** fills the spaces within the texture (pores) and forms a continuous overlying film. The capillary-stabilized liquid in the micro- or nanometer-sized pores leads to a reversible gate mechanism which can coordinate multiphase transport (see Figure 1) [1, 2].

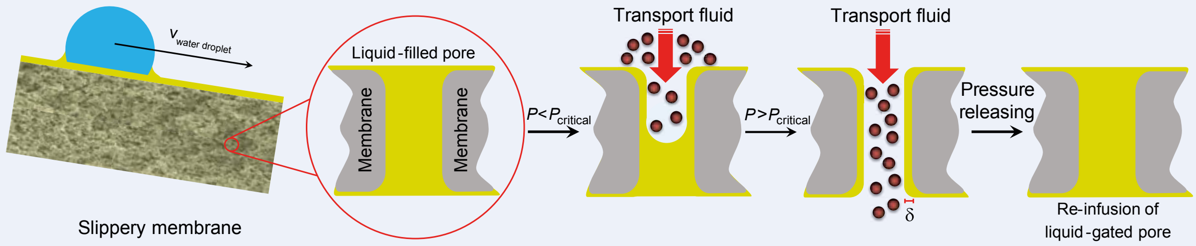

Fig 1. Schematic illustration of SLIM and gating mechanism of adaptive pores (from left to right). In this figure, δ is the liquid film thickness lining the pore and $P_{critical}$ is the pressure required to open up the liquid-filled pore.

Technological challenges

In order to ensure constant experimental conditions, model synthetic produced water (oil/water emulsion) will be used. The main technological challenges in the application of **SLIM** for oil/water separation include determination of optimal operating conditions, stability assessment of the liquid-lined pores, and **SLIM**s reuse.
The critical pressure of the individual components of the emulsion and **SLIM**s properties such as surface slipperiness and others will be studied to address technological challenges.
The performance and stability of **SLIM**s for oil/water separation will be investigated by performing:

- long term separation experiments
- experiments at high shear conditions
- separation tests in the presence of surfactants

Research goals

In order to accomplish the intended approach of the project, **SLIM** will be fabricated and characterized and various aspects, such as re-infusion of the liquid-lined pores will be evaluated. An extended experimental data set obtained at various experimental conditions, will be at first used to better understand the gating mechanism and then to validate the theoretical description.
Fouling and anti-fouling properties of **SLIM** will be investigated by performing filtration experiments. The performance of the membrane will be evaluated by considering the effect of operating parameters such as salinity, pH and temperature.

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Produced water treatment by low fouling polyelectrolyte multilayer based nanofiltration membranes

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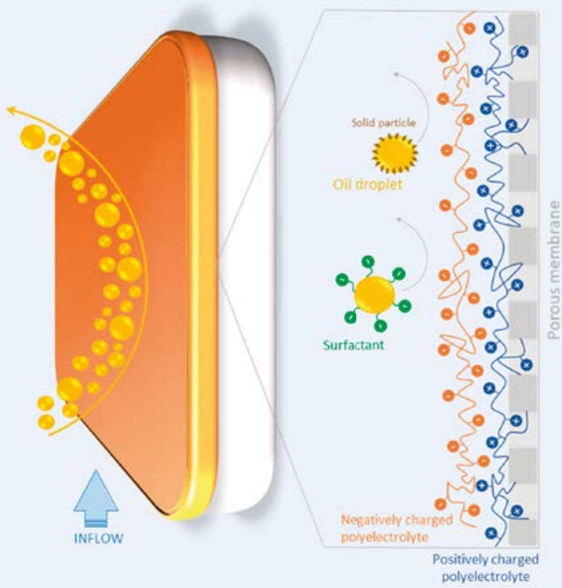

Motivation

Produced water (PW) is the largest waste stream generated by oil and gas (enhanced) recovery operations [1,2]. Many technologies are available to treat produced water, including gas flotation, hydrocyclones, adsorption, media filtration and membrane technology. Typically, only a process including multiple of these techniques can really give the desired effect [1], hence each of these technologies will be part of a larger process. In such a large process, membrane technology is especially interesting as it is one of the few techniques that can successfully remove the smallest (< 10 μm) and most stable oil droplets. Membrane technology also has clear downsides, and in produced water treatment membrane fouling is a very serious problem. Since PW is a complex mixture, many of its components can foul the membrane, leading to very substantial decreases in the flux of treated water. In this project we propose the development of a novel nanofiltration (NF) membrane, with a surface chemistry optimized towards a low fouling propensity in PW treatment.

Technological challenge

Low fouling NF membranes will be prepared by polyelectrolyte layer-by-layer deposition on ultrafiltration (UF) supports. A large benefit of this approach is its versatility, allowing us to control the chemistry of the membrane surface, and the membrane geometry on which the layer is applied. In this way it also becomes possible to study membrane fouling in PW treatment from a very fundamental viewpoint, by careful variation of chemistry and geometry. We propose that this membrane will allow a unique process where de-oiling and control over the salinity can be achieved in a one-step membrane process.

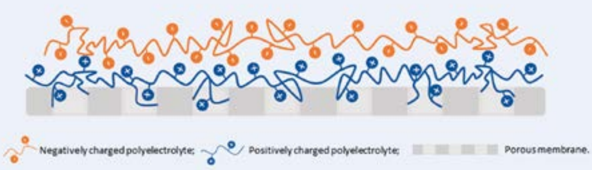

Fig 1. Schematic illustration of a low fouling fouling NF membrane prepared by polyelectrolyte layer-by-layer deposition on ultrafiltration membrane.

Research goals

Fundamental understanding of membrane fouling in PW treatment will lead to the development of a NF membrane with good separation and permeability performance optimized towards a low fouling propensity in produced water treatment. We will control the separation properties, the membrane chemistry and the membrane geometry, while studying membrane performance against artificial PW to reach the following project goals:

- To demonstrate the conditions under which polyelectrolyte multilayer (PEM) based NF membranes can be successfully applied in PW treatment;
- Good fundamental understanding on the effect of membrane surface chemistry and membrane geometry on membrane fouling during PW treatment;
- To translate this understanding into an optimized PEM based NF membrane, that does not require pre-treatment for its operation.

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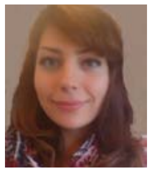
Synergistic CO_2 capture & scaling prevention for desalination



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Motivation

In order to reduce or even eliminate the scaling (Figure 3) risk in membrane based seawater desalination methods, a pre-treatment using **Bi**polar **M**embrane **E**lectro**d**ialysis (BPMED) can be used. BPMED can decarbonize the seawater, by removing CO_2 in gaseous form on the acidic side of the BPM or as solid $CaCO_3$ precipitate on the alkaline side Figure 1 [1]. Furthermore, decarbonization of seawater can reduce the carbon-footprint of desalination units such as, Reverse Osmosis (RO).

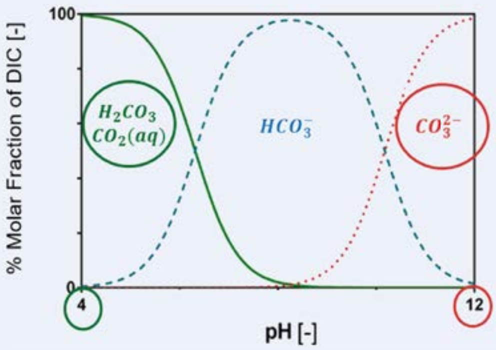

Figure 2. Effect of pH on Carbonate equilibrium (for a closed system where total Dissolved Inorganic Carbon, DIC, remains constant as pH changes).

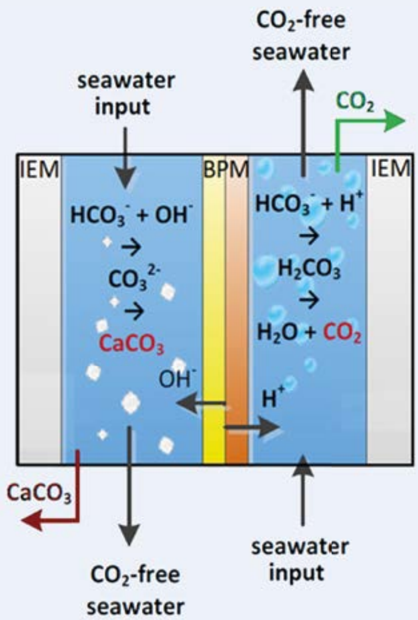

Figure 1. Decarbonization using BPMED; Acid route (right) and Base route (left). Ion Exchange Membrane (IEM) can be anionic or cationic type, depending on the stack design.

A BPM consists of an anion exchange membrane (AEM) and a cation exchange membrane (CEM). When inserted in an electric field, it can produce acid and base through enhanced water dissociation [2-3]. The subsequent alteration in pH of the input seawater shifts the carbonate equilibrium as indicated in Figure 2 [4].

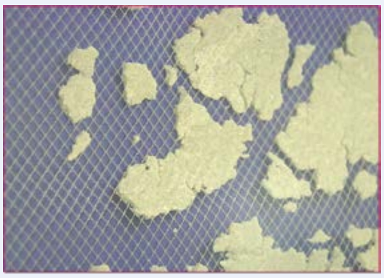

Figure 3. Membrane scaling (www.impomag.com)

Technological challenge

Although a rather new technology, CO_2 capture using BPMED has been investigated by different authors from flue gas, atmosphere, remains a challenge in this field. The bipolar membrane, usually takes up around 80% of the energy input in BPMED. Therefore, This research aims to explore and optimize influential parameters that affect the BPMED energy consumption for decarbonization.

Research goals

This project aims to:

- Determine the main factors affecting the energy consumption of BPMED for sea/brackish water decarbonization.
- Study the effect of DIC present in the BPMED cell, on the BPM resistance and eventual carbon recovery.
- Investigate the ion transport near and through the BPM's, especially for low pH gradient and low current densities.
- In-situ crystallization control of carbonate [5].
- Investigate on membrane scaling removal techniques for calcium carbonate removal, such as air sparging.

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Chemically modified carbon electrodes for electrochemical separation processes

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Motivation

Water, being the most essential need for all living creatures, becomes scarce as consumption rapidly increases every year. To overcome the scarcity of potable water, technologies to desalinate and to purify ground water, surface water and sea water can be developed and employed. Electrochemical methods can be used to remove ions and charged molecules from water.

Capacitive Deionization (CDI)

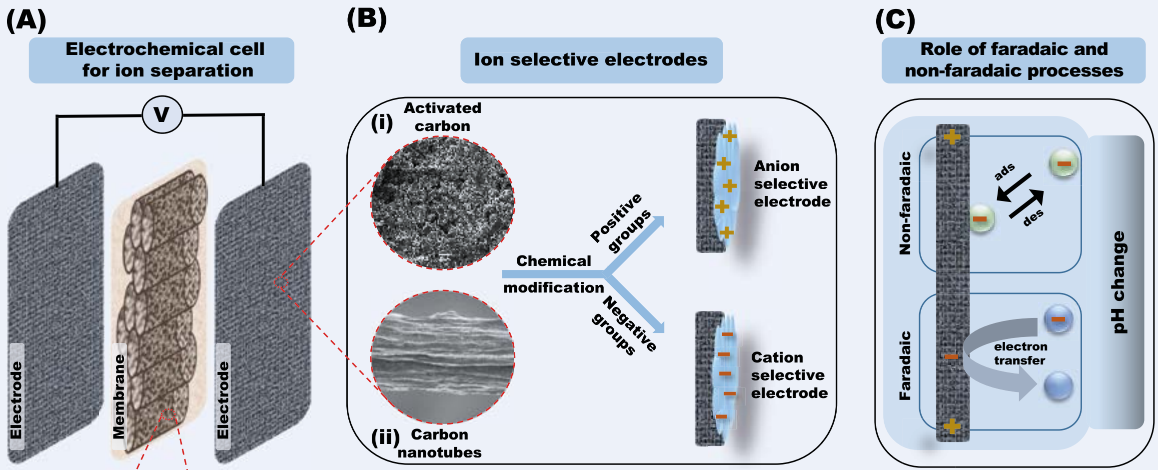
CDI is an electrochemical method for ion removal using porous electrodes. These electrodes adsorb ions from water, resulting in a desalinated stream. Later, the electrodes are regenerated, and the ions are released, resulting in a concentrated stream. Traditionally, CDI uses a cell design with one porous carbon electrode that adsorbs and releases the cations (cathode), and another electrode that adsorbs and releases the anions (anode).

Technological challenge

Since carbons do not have a natural preference for the adsorption of either anions or cations, the ion adsorption is solely based on the potential applied. This results in a reduced ion removal efficiency due to phenomena such as co-ion adsorption.

To overcome this, following strategies can be employed.

- *Selective ion adsorption* by the electrodes can be increased.
- *Selective ion transport* across the electrodes can be achieved through *ion-selective membranes*.
- The effect of faradaic and non-faradaic processes on (selective) ion adsorption, and on potential pH changes during operation, should be understood to increase the performance and stability of the electrodes and membranes.



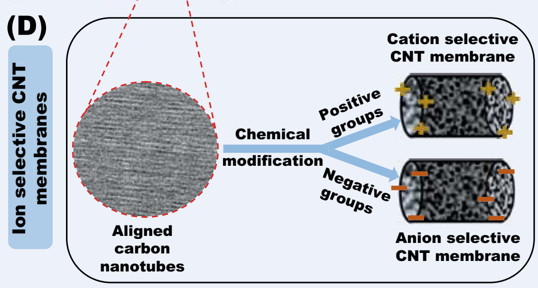


Fig.1: (A) General configuration of an electrochemical cell for ion separation. (B) Preparation of ion selective carbon electrodes from (i) activated carbon (AC) and (ii) carbon nanotubes (CNTs). (C) Effect of faradaic and non-faradaic processes on the performance and stability of the electrodes and membranes. (D) Chemical modification of aligned carbon nanotubes (CNTs) to prepare an ion-selective membrane.

Research goals

- To prepare, characterize and test anion- and cation-selective electrodes based on surface modification of carbon electrodes with chemical groups such as amines, carboxylic acid, etc. **(Fig.1(B))**
- To better understand the effect of faradaic and non-faradaic processes and of pH changes due to these processes, on the performance and long term stability of electrochemical (selective) ion separation processes. **(Fig.1(C))**
- To test carbon nanotubes as ion selective membranes in the CDI cell to improve selective ion transport through the membrane. **(Fig.1(D))**

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[3] Gao, X.; Porada, S.; Omosebi, A.; Liu, K.-L.; Biesheuvel, P. M.; Landon, J. Water Res. 2016, 92, 275–282.
[4] Dykstra, J. E.; Keesman, K. J.; Biesheuvel, P. M.; van der Wal, A. Water Res. 2017, 119, 178–186.

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WAGENINGEN UNIVERSITY & RESEARCH

Natural flocculants

After appropriate treatment, wastewater can provide a secondary resource for reuse, for instance as industrial process water. In highly populated delta regions and other regions facing water scarcity, this can help to relieve the pressure on the available fresh water resources. Micro-, ultra, nano- and other types of membranes can help to achieve this objective because they are a (selective) barrier for pollutants. In addition, membranes can also be applied in combination with biological or physical-chemical processes. Examples are the removal of micropollutants, concentration or extraction of valuable compounds from wastewaters and the retention of slow growing or non-flocculating microorganisms responsible for bulk pollutant removal or conversion. The main objective of this theme is to provide innovative solutions to make processes for wastewater treatment more robust, cheaper, to reduce their energy and chemical consumption and to alleviate the negative impact of the waste (concentrate) streams they generate. For this purpose we use a multidisciplinary approach including disciplines such membrane technology, biotechnology and process technology.

Research projects

- **Victor O. Ajao**, Wageningen University
  Biological flocculants from and for saline (waste) water treatment
- **Emanuel Dinis**, Wageningen University/University of Twente
  Biopolymer based membranes for (waste) water filtration
- **Evelyn Da Silva Antunes**, University of Twente
  Flocculant extraction by mild fractionation techniques

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WAGENINGEN UNIVERSITY & RESEARCH

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for sustainable water technology

Biological flocculants from and for saline (waste) water treatment

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Motivation

Large amounts of saline wastewater are generated by industries such as food, petrochemical and tannery. This has adverse effects on aquatic life, water potability and agriculture when discharged into the environment untreated. Currently, wastewater particle removal is widely achieved with the use of inorganic coagulants or/and oil-based organic polymeric flocculants. Both have non-negligible drawbacks: the former leaves residual metal particles in treated water and the latter leads to formation of toxic degradation products[1]. Hence, the use of synthetic coagulants/flocculants can hardly be considered a sustainable wastewater treatment approach.

Technological challenge

Microorganisms responsible for the biological degradation of organic pollutants in (waste) water excrete biopolymers, generally referred to as extracellular polymeric substances (EPS). These EPS provide attractive and non-toxic flocculating properties.
More often than not, single-type EPS (usually polysaccharides) are obtained by the enrichment of isolated microbial strain[2]. Although this strategy yields biodegradable polymers, the disadvantage is that pure cultures need to be fed with expensive and unsustainable carbon sources as well as valuable nutrients. Our approach is to utilise a mixed microbial population used in wastewater treatment to concurrently produce EPS as flocculants.
The technological challenge is therefore to develop strategies on how saline industrial wastewater treatment can be combined with maximum EPS production, and further fundamental studies on the biopolymer characterization (Figures 1 and 3) and flocculation mechanisms.

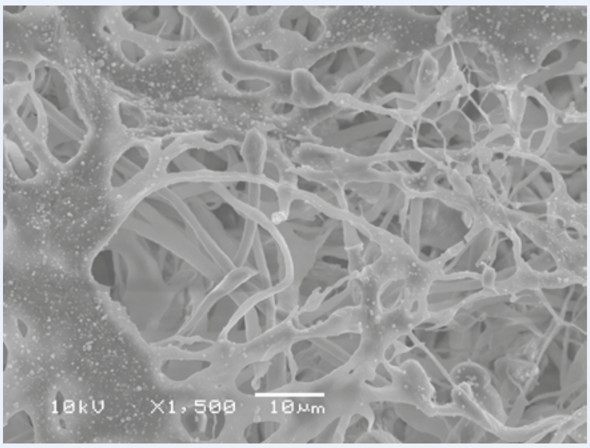

Fig 1. Scanning Electron Microscopy image of purified and lyophilised EPS

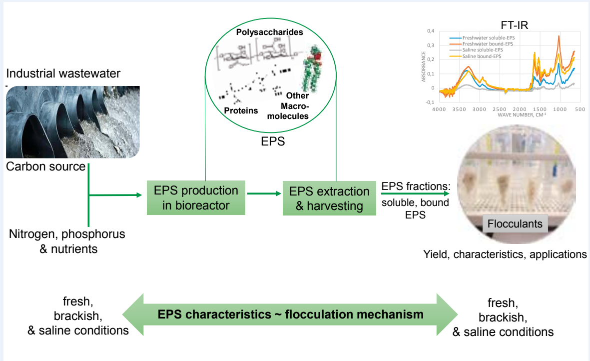

Fig 2: Graphical Abstract

Research goals

- To develop a reactor system that combines wastewater treatment with production of cheap, effective and sustainable 'saline flocculants'.
- To compare the flocculation performances of 'saline EPS' with 'fresh water EPS' and synthetic flocculants, and explain the differences.
- To elucidate the flocculation mechanisms of mixed EPS under saline conditions.

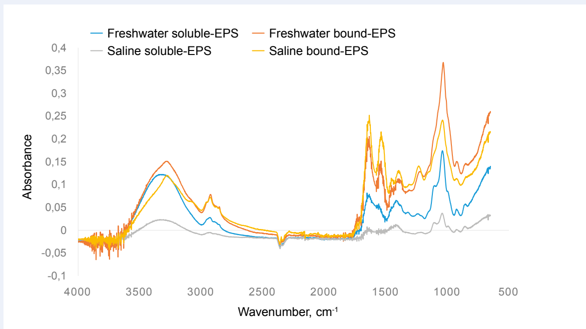

Fig. 3: Fourier transform infrared spectroscopy (FT-IR) of extracted EPS fractions (soluble and bound) reveals the presence of carboxyl, hydroxyl and amine groups, which are typical of carbohydrates and proteins.

[1] B. Bolto and J. Gregory (2007), Water Research, 41 (11), 2301–2324.
[2] S. A. Zaki, M. F. Elkady, S. Farag, and D. Abd-el-Haleem (2013), J. Environ. Bio., 34 (1), 51–58

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WAGENINGEN UNIVERSITY & RESEARCH

Biopolymer based membranes for (waste) water filtration

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Motivation

Anaerobic treatment of wastewaters offers several advantages over aerobic treatment, including the production of methane that serves as a renewable energy source. However, the retention of slow growing biomass and of the slowly biodegradable wastewater solids (to give them enough time to be biodegraded) can be troublesome [1]. Thus, a good retention system is essential and one of the methods that can be applied for this purpose is a microfiltration membrane.

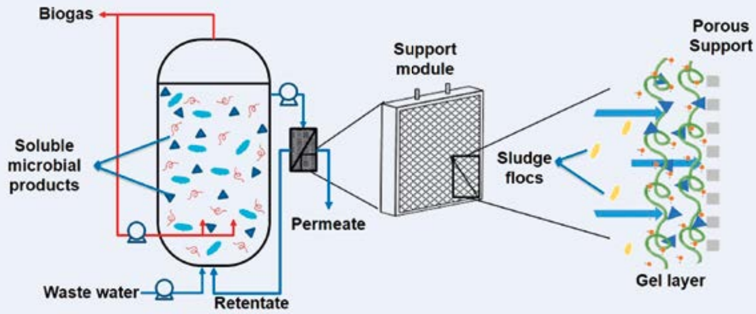

Fig 3. Graphical abstract: Anaerobic bioreactor coupled with a support module where the EPS gel layer is developed

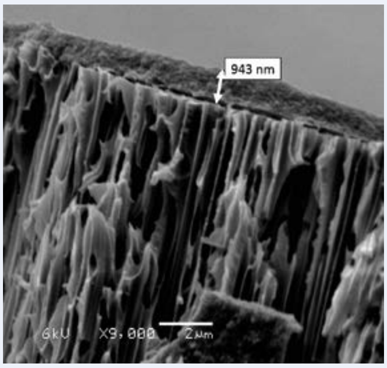

Fig 1. SEM image of the sEPS layer formed on top of a membrane (adapted from Kanwal Shahid)

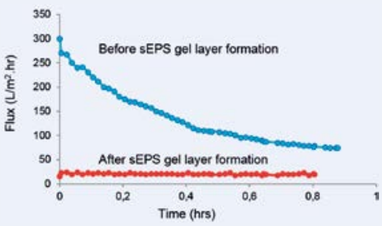

Fig 2. MiliQ water flux profile of polycarbonate (PC) 0.2µm membrane, applying constant TMP of 0.2bar in a dead-end mode, before and after the formation of sEPS layer (adapted from Kanwal Shahid)

Technological challenge

The treatment costs are high because the membranes are expensive and suffer from fouling.

In aerobic membrane bioreactors, a gel layer is formed on the surface of the membrane [2]. This is caused by gelation of extracellular polymeric substances (EPS) such as polysaccharides and proteins excreted by microorganisms. It is generally accepted that this gel layer (Fig 1.) dictates the filtration process, i.e. determines the retention of compounds and the permeability (Fig 2.).

Research goals

The objective of this project is to create a gel layer of anaerobic EPS on a porous support as a cheap alternative for expensive membranes. This is accompanied by several challenges and research questions:

- Can a suitable gel layer be formed from anaerobic EPS, what is the composition and structure of this gel layer and what is the effect of environmental conditions such as temperature and cation concentrations?
- Under which operational conditions and with what type of porous carrier material is the performance of this layer optimal with respect to solids retention and permeability?
- How can a gel layer be formed in-situ and what is its long-term stability?

[1] Lin, H., et al. "A review on anaerobic membrane bioreactors: Applications, membrane fouling and future perspectives" Desalination 314 (2013): 169-188.
[2] Van den Brink, P., et al. "Potential of mechanical cleaning of membranes from a membrane bioreactor." Journal of Membrane Science 429 (2013): 259-267.

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Natural flocculant recovery by mild fractionation techniques

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Motivation

Biological wastewater treatment employs a (mixed) microbial culture to degrade organic pollutants. During this process, under specific conditions, the microorganisms excrete large amounts of extracellular polymeric substances (EPS). These EPS mainly consist of polysaccharides, proteins and glycoproteins, and have the potential to be applied as value-added products such as (biodegradable) flocculants and biosorbents for metals [1]. To explore these and other applications, it is necessary to develop a recovery process capable of separating different EPS fractions from other compounds present in the wastewater treatment broth.

Technological challenge

Solvent extraction is a promising separation technique to recover EPS and one of the challenges is to identify a suitable solvent. Due to the presence of ionizable functional groups in the EPS structure (e.g. carboxylic and amino groups), polar solvents with a limited affinity for water are required. Our approach is to use ionic liquids (ILs, Fig 1), which are regarded as green solvents because of their low flammability and negligible vapor emission [2]. Other steps in the recovery process is EPS back-extraction from the IL phase and solvent regeneration. This stage will use an aqueous biphasic system, which is created by the addition of a solvent able to induce the coexistence of two immiscible aqueous phase.

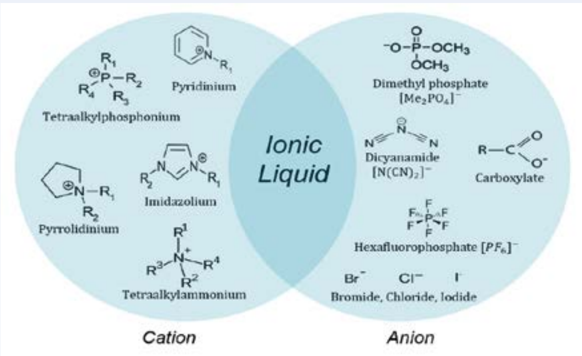

Fig 1. Common cations and anions in ILs.

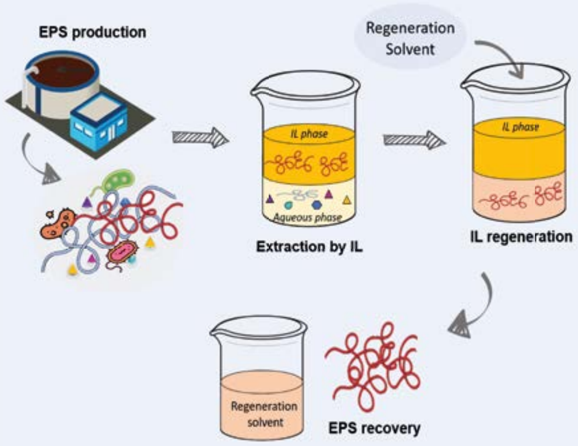

Fig 2. Graphical abstract showing the research approach of the project.

Research goals

- Identifying suitable ILs for extraction of EPS from the broth;
- Designing an aqueous biphasic system (ABS) for EPS back-extraction and IL regeneration;
- Recovering EPS fractions from the regeneration solvent;
- Investigating the potential of EPS recovered fractions for flocculation process and heavy metal removal.

[1] More et al., J. Environm. Management (2014), 1-25.
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Source separated sanitation

Source separation sanitation (SSS) is a concept in which waste streams with specific characteristics (e.g. urine, faeces, greywater, hospital waste streams) are collected, transported and treated separately at the source. Hospital wastewater, for instance, contains about 10 fold the concentrations of pharmaceuticals in municipal wastewater and is considered an important source of antibiotic resistant bacteria. By treating (hospital) wastewater at the source the risks associated to wastewater can be addressed more specifically and effectively, thereby preventing the spread of antibiotic resistant bacteria and other pathogens in the population and discharge of toxic components into the environment. Furthermore, sustainability objectives such as water reuse, recovery of resources and energy savings can also be more effectively reached within SSS. The main advantage is that source separation prevents dilution of wastewater streams. New technology must be developed to treat these concentrated waste water streams. For the treatment of hospital wastewater it is important to remove antibiotics and to develop a disinfection technology in which bacteria are not only killed but their DNA is destroyed.

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Research projects

- **Ilse Verburg**, University Medical Center Groningen
  Antibiotic resistance of public health concern in water
- **Gonçalo Macedo**, Utrecht University
  Manure based spread of antibiotic resistance in water and soil ecosystems
- **Rebeca Pallarés Vega**, Delft University of Technology
  Mechanisms of spread of antimicrobial resistance in biological wastewater treatment

Industrial partners

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Antibiotic resistance of public health concern in water

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Motivation

Antibiotics are commonly used to treat bacterial infections, but their overuse leads to rapid development and spread of resistance rendering these drugs ineffective (*Fig 1*). As a result, the once easy-to-cure infections have become untreatable.

This study focusses on the rise and spread of antimicrobial resistance in water, originating from the clinical environment up to the surface water (*Fig 2*). Antibiotic resistant bacteria (ARBs), antibiotic resistance genes (ARGs) and medicinal compounds (from clinical settings) end up in the wastewater that leads them to the wastewater treatment plants (WWTPs). WWTPs are not designed to remove either of these compounds, and they are partially released via the WWTP effluent into the surface water. Furthermore, the presence of trace medicine rests and heavy metals plays a role in the spread of resistance as they act as selectors for ARBs. In addition, the environmental reservoir for ARGs might increase the speed of resistance development. Therefore, water is believed to play an important role in the spread of antimicrobial resistance.

Technological challenge

The challenge is to address the impact of water on the rise and spread of antimicrobial resistance. It is proven that the environment is an important reservoir for ARGs and that water acts as a vector which enhances the transport of bacteria and genes. In this research the pathway of antimicrobial resistance in wastewater from different sources (i.e. hospital, nursing homes, community) up to the surface water will be investigated, and the human exposure to this resistance will be determined (*Fig 2*). Therefore, a reliable sampling campaign is necessary, and DNA extraction methods for genomic, plasmid and phage DNA have to be developed. Wastewater samples will be analyzed for the species and ARGs they contain by molecular methods such as 16S next generation sequencing (NGS) and whole genome sequencing (WGS).

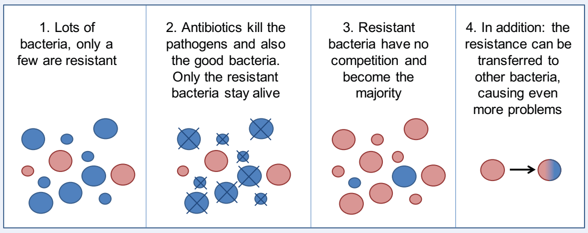

Fig.1 Antibiotic selection pressure

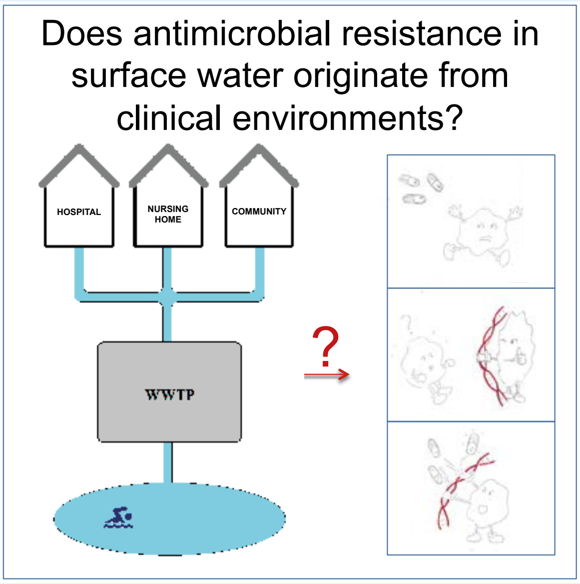

Fig.2 Graphical abstract

Objectives

The goal of this research is to map and monitor antimicrobial resistance in the (waste)water chain from the clinical setting into the environment. This will provide information about important ARBs and ARGs, also on species and genes that are less well documented. The comparison of different sources can lead to specific information about prevention measures. This research pursues the following objectives:

1. Identification of resistance genes on chromosomal DNA, plasmids, mobile genetic elements and/or phages
2. Revealing cross-resistance between heavy metals and antibiotics in water
3. Setting out the transmission of ARB/ARG in the wastewater-chain
4. Mapping the genetic similarity between resistance genes observed in micro-organisms from humans and from water

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Manure based spread of antibiotic resistance in water and soil ecosystems

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Motivation

The consumption of antibiotics worldwide, particularly at farm level, has triggered a higher incidence of antibiotic resistant bacteria(ARB) in animals and in their manure. Due to manure application to soils, these ARB, antibiotic resistance genes (ARG) and antibiotic residues present in themanure contaminate water and soil ecosystems[1].
Bacterial communities of manure and soil are largely distinct. However, with the application of manure to soil, introduction of new communities in an already established one occurs, potentially facilitating the spread of multiple ARG[2].
The fate of ARG in the environment is complex and some may even persist in the environment in the absence of selective pressures. The mobilization of genetic elements through conjugative plasmids plays a key role in this complex cycle.

Technological Challenge

This project aims at testing links and relations between multiple variables affecting ARG abundance, conjugation rates and bacterial diversity. This represents a great and crucial step to understand the fate of resistance in the environment.
The accurate monitoring of conjugation rates requires the selection of adequate bacterial strains and plasmids, followed by the establishment of testsystems that mimic, as close as possible, the "real" conditions occurring in the environment.

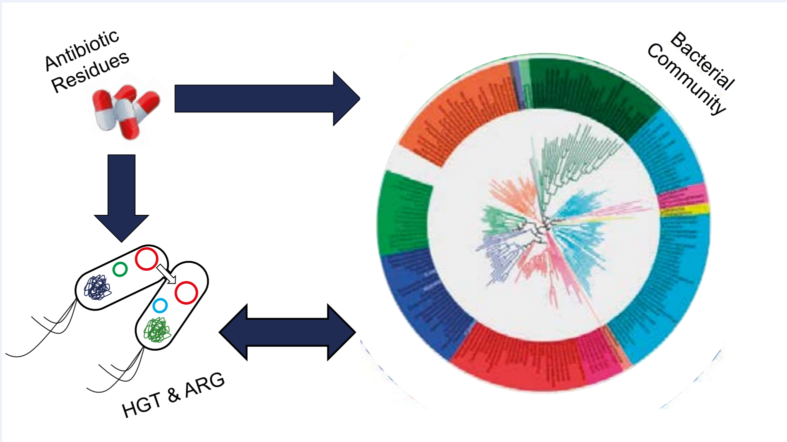

Figure 1. Impact of antibiotics residues, conjugation rates, ARG abundance and bacterial communities in manure, soils, manured soils and water runoffs.

Research goals

The main goal of the present research project is to study the factors affecting the exchange and proliferation of ARG in the microbial communities from different ecosystems (from gut to water). Therefore, this research will focus on:

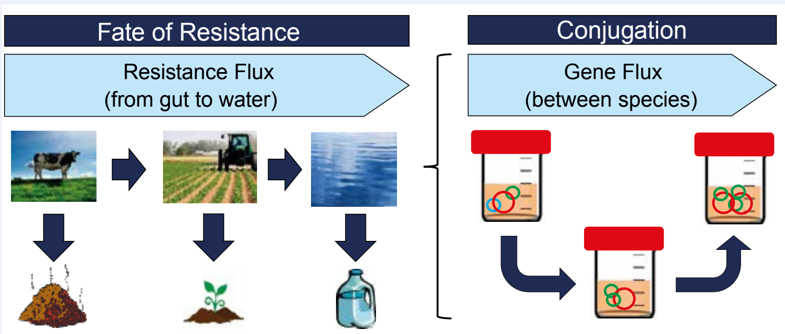

Figure 2. Overview of experimental design.

1. **Conjugation experiments**: modelling the effect of antibiotic residues on conjugation and identification of major resistance vectors, in a microcosm test system
2. **Fate of resistance**: impact of manure application on ARG abundance and on the native bacterial community. Role of riskfactors (type and treatment of manure, abiotic factors) for the persistence and transport of antibiotic residues and ARG in treated soils and receiving water

[1] Heuer et al. (2011) Curr Opin Microbiol 14:236–243
[2] Udikovic-Kolic et al. (2014) Proc Natl Acad Sci 111:15202–15207.

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source separated sanitation

Mechanisms of spread of antimicrobial resistance in biological wastewater treatment

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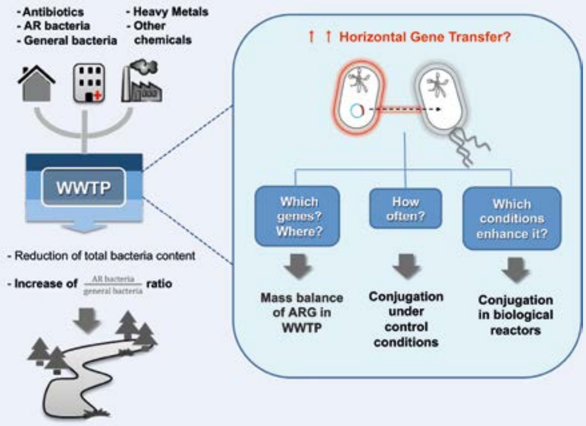
Motivation

Antibiotics have made it possible to cure and prevent infections in humans and animals improving life standards enormously. Unfortunately, the overuse of antibiotics has caused a rapid increase of antibiotic resistance (AR) that is contained in bacteria's genome and plasmids and can be transferred to other bacteria (Fig.1a).
Antibiotics and antibiotic resistant bacteria (ARB) from anthropogenic sources are not anymore restricted to clinical areas, but they happen to be released in the environment[1]. Wastewater coming from households and hospitals carries fecal residues including ARB from the human gut. Moreover it can also contain sub-inhibitory concentrations of antibiotics and other residual elements as heavy metals that contribute to increase antibiotic resistance by co-selection of the strains harbouring resistance to these compounds. Wastewater is treated in Wastewater treatment plants (WWTPs) which are primarily designed to remove nutrients rather than microorganisms. Despite of achieving significant reductions in bacterial concentrations, WWTP biological processes have been suggested to enhance gene transfer of antibiotic resistant genes (ARG), leading to an increase in the AR bacteria/ non AR bacteria ratio in the down-stream WWTP products[2] (Fig. 1b).



Technological challenge

Wastewater from biological processes comprises a complex matrix of abiotic and biotic constituents including a wide uncultivable bacterial community. Monitoring horizontal gene transfer (HGT) requires a robust approach that begins with the selection of the adequate bacterial and plasmids models, followed by the design of robust molecular microbiology tools to deliver good quality plasmid DNA and the ability of selectively targeting the genes of interest on the background of a diverse community. Moreover, assessing all variables (process parameters, biotic and abiotic parameters) possibly influencing HGT represents a great challenge in understanding the WWTP dynamics.

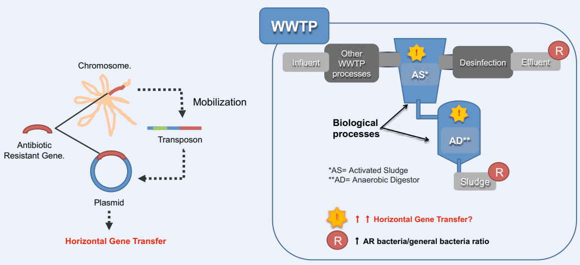


Fig 1a. Mechanims of mobilization of Antibiotic Resistant Genes.
Fig 1b. WWTP's Biological processes hipotesized as hotspots of Horizontal Gene Transference.

Research goals

The goal of the present original research project is to conduct fundamental investigations of the mechanisms of ARG transfer and ARB proliferation in the complex microbial communities of biological wastewater treatment processes. Consequently, the research pursues the following goals:

1. Catalogue the knowledge on and status of AR in Dutch WWTPs and the real contribution of WWTPs in "breeding" the AR by means of a mass balance study of the ARG across the WWTP processes.
2. The development of a robust bio-analytical method to detect and quantify horizontal gene transfer in WWTPs.
3. The systematic exploration and examination of the process, operational, and environmental conditions that cause this unfavourable mechanism.
4. The engineering of bio-based operational strategies for the suppression and prevention of this detrimental microbial phenomenon.

[1] Baquero et al., (2008) Curr. Opin. Biotechnol. 19: 260–265.
[2] Czekalski, et al., (2012) Front. Microbiol. 3: 106-112.

stowa

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Sulfur

This theme focuses on integrated processes for removal and conversion of volatile sulfur compounds from aqueous solutions. These aqueous are used to scrub volatile sulfur compounds from oil and gas and have a high pH and salt concentration. The process scheme consists of scrubbers and bioreactors and aims at removal of all volatile sulfur compounds like sulfide and thiols (e.g. methanethiol). The water consumption of this process can become zero by treating the bleed stream enabling recycling of all water. The scientific disciplines needed for development of such an integrated process are chemistry, microbiology, biotechnology and modeling.

Research projects

- **Karine Kiragosyan**, Wageningen University
  Biological removal of H_2S in the presence of thiols from sour gas streams
- **Suyash Gupta**, Wageningen University/University of Amsterdam
  Understanding and improving the haloalkaline biodesulfurization process

THEME MANAGER

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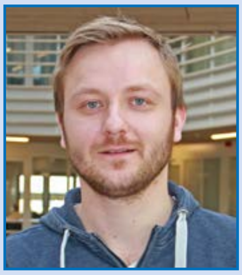
THEME COORDINATOR



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Academic partners

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Biological removal of H_2S in the presence of thiols from sour gas streams

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Motivation

Removal of sulfur containing compounds from sour gas streams plays a crucial role in environmental protection by decreasing sulfur dioxide emissions into the atmosphere. Among all available desulfurization technologies, biological processes are the most sustainable technologies for hydrogen sulfide removal. Besides H2S, sour gas streams can contain volatile organic sulfur compounds, such as thiols. Both organic and inorganic sulfur compounds are toxic, characterized with the obnoxious smell and potential corrosive effects [1].
A recent pilot study showed that with the addition of anaerobic bioreactor sulfur selectivity increased and the process did not abrupt with thiols addition. The added anaerobic bioreactor enabled selective pressure for sulfide oxidizing bacteria which are able to oxidize sulfide more efficiently. However, further insight into the underlining processes is required to fully understand work of newly proposed line-up.

The biotechnological desulfurization process offers:

- H_2S removal and recovery as elemental sulfur
- Operation at atmospheric pressure and ambient temperature
- Environmentally friendly process
- Produced elemental sulfur can be used as a soil fertilizer, fungicide and for sulfuric acid production

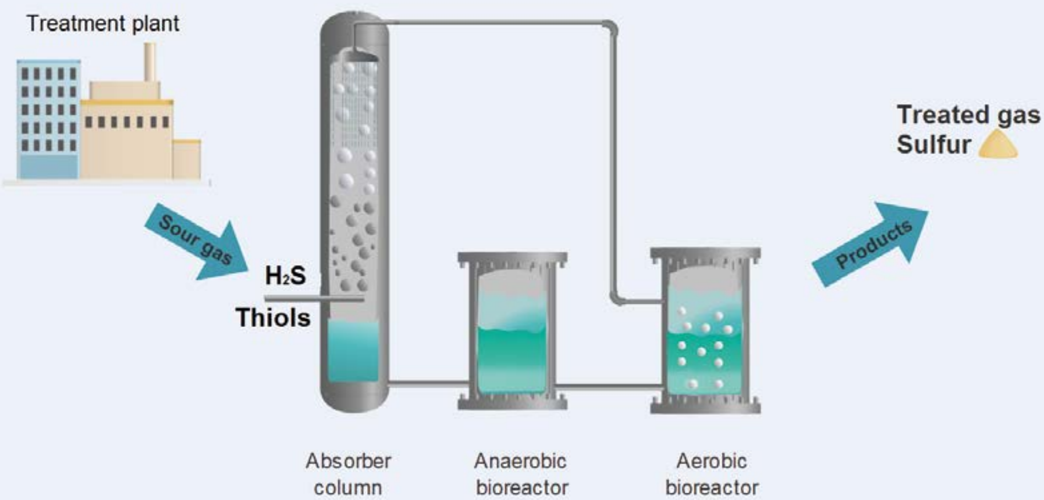
Technological challenge

To investigate the newly proposed biodesulfurization line-up and the reactions that are taking place, with the emphasys on the microbial communities composition shifts in the presence of thiols.
With the addition of the anaerobic bioreactor we hypothesize to enhance bacterial growth and eliminate cell death, when high concentration of thiols is present in the system.

Research goals

To achieve our research goal the following questions are addressed:

- Line-up evaluation and underling processes.
- Effect of thiols on microbial activity and composition under halo-alkaline conditions.
- Identification of involved enzymes in oxygen-reducing mechanism during bacterial H_2S oxidation.
- Determination of optimal process conditions in sequential system, that enable safe and stable biodesulfurization technology.



Research graphical abstract with a newly proposed line-up for hydrogen sulfide removal in the presence of thiols

[1] Smet, E., Lens, P., & Van Langenhove, H. (1998). Treatment of waste gases contaminated with odorous sulfur compounds. Critical Reviews in Environmental Science and Technology, 28(1), 89–117

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Karine Kiragosyan MSc, prof.dr.ir. Albert J.H. Janssen, dr. Paweł Roman, dr. Johannes B.M. Klok

Understanding and improving the haloalkaline biodesulfurization process

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Motivation

Dihydrogen sulfide (H_2S) is a malodorous and highly toxic compound, which can cause asphyxiation. It is a component which is present amongst others in natural gas and biogas streams. Upon combustion of these untreated gas streams in the environment, H_2S is oxidized to sulfur oxides which then become environmental pollutants. One of the economical and ecofriendly methods to remove H_2S from gas streams is the biodesulfurization process. This process make use of haloalkaliphilic sulfur oxidizing bacteria to convert dissolved sulfide to biologically formed elemental sulfur. However, the bio-production of elemental sulfur is often accompanied by the production of undesired acidifying sulfur compounds, such as sulfate (SO_4^{2-}) and thiosulfate ($S_2O_3^{2-}$) [1].

Technological challenge

A recent study has shown formation of 98% sulfur from removed H_2S by addition of an anaerobic reactor in the existing line-up of the biodesulfurization process (Fig 1.) compared to around 90% [1] formation using the traditional process. The microbiological mechanisms behind the enhanced sulfur production are still unknown. Also, little is known about the microbial community involved in the biological H_2S conversions and about their stability after perturbations. Finally, it is needed to obtain insights into the biochemistry of the sulfur oxidation process of these bacteria to know the associated metabolic mechanisms, biochemical pathways and enzyme complexes involved. Hence, an integrated approach combining novel concepts from bioprocess technology with state-of-the-art 'omic' techniques will be used to study the microbial communities. The information obtained will be applied to improve the robustness and reliability of the new line-up in the long run.

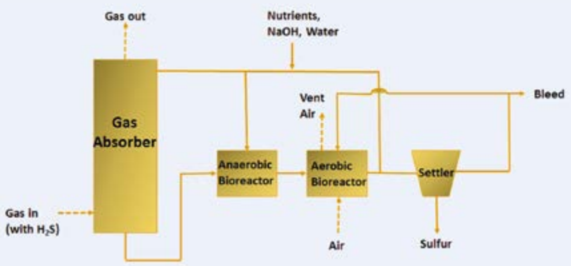

Fig 1. New line up for biodesulfurization process

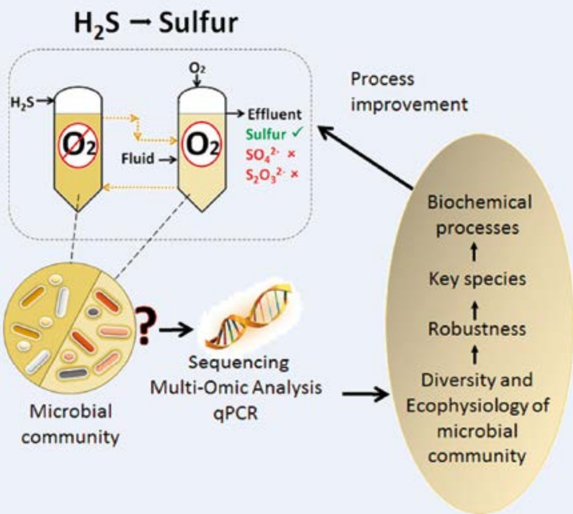

Fig 2. Graphical abstract of the project

Research goals

The main goal of the research is to obtain a comprehensive understanding of the diversity and ecophysiology of haloalkaliphilic sulfur bacteria with the final aim to obtain a robust and reliable biological desulfurization process.

In order to achieve this goal, the study is divided into four interacting tasks:

(i) Acclimation of microbial communities towards optimal sulfide oxidation
(ii) Study of diversity and ecophysiology of the sulfur bacteria
(iii) Study of robustness of the biodesulfurization process
(iv) Physiology and biochemistry of sulfur oxidizers

[1] J.B.M. Klok *et al.*, Pathways of Sulfide Oxidation by Haloalkaliphilic Bacteria in Limited-Oxygen Gas Lift Bioreactors. Environment Science and Technology, 46(14),2012, pp 7581–7586.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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UNIVERSITY OF AMSTERDAM

Capacitive deionization

Capacitive deionization, or CDI, uses porous electrodes is a new promising technique to remove salt from water by reversibly adsorbing ions in selective electrodes. The electrodes can be made of porous activated carbon, or of an intercalation material. Ion-exchange membranes make the technology more efficient in energy and removal capacity. CDI can be used not just to desalinate water, but also to selectively remove one metal ion from a mixture of other ions of the same charge sign. Novel developments in CDI include the use of chemically modified carbon electrodes, application of flowing carbon slurries and fluidized beds, and the use of optimized charge/discharge schemes. Wetsus plays a prominent role in CDI research worldwide and is founder of the international working group on CDI, see www.cdi-electrosorption.org. In the theme the CDI-technology is further developed.

Research projects

- **Tania Mubita**, Wageningen University
  Capacitive Deionization with membranes for selective ion removal
- **Kaustub Singh**, Wageningen University
  Advanced materials for electro-driven separation for selective resource recovery

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Industrial partners

Voltea

Dow

Academic partners

Wageningen University & Research

Capacitive Deionization with Membranes for Selective Ion Removal

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Motivation

Existing technologies that allow the removal of ionic compounds are facing a major challenge regarding to the separation of ionic species with the same charge and valence without using chemicals. The nitrate removal from groundwater, the reduction of sodium concentration in irrigation water, and the preferential separation of lithium ion from seawater are some examples of processes which would strongly benefit from the selective removal of ions.

Membrane capacitive deionization (MCDI) technology is able to remove a wide range of ionic species from water. In MCDI, the ion exchange membranes (IEMs) are important components which enhance the salt adsorption capacity of the electrodes [1]. IEMs can be either placed as a separate layer or coated in front of the electrodes, see **Fig.1**. Replacing IEMs for ion selective membranes can be seen as a strategy to selectively extract one type of ion from multi-ion aqueous solutions, see **Fig. 2**.

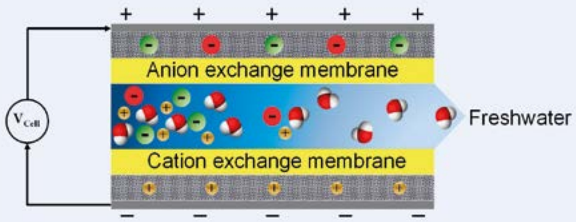

Fig.1 Schematic diagram of membrane capacitive deionization showing the removal of charged ions by two charged electrodes

Scientific challenge

IEMs enable the transport of only one type of ions: cations or anions [2]. However, state-of-the-art IEMs exhibit poor performance when the selective uptake of ions is the aim, e.g., the removal of ions with the same charge and valence.
Endowing IEMs with selective properties most often results in modification of other electrochemical properties of IEMs, such as electrical resistance.
In addition, MCDI systems with ion selective membranes requires a deep understanding of ion transport processes and the interaction of ions with the membranes and the porous carbon electrodes.

Research goals

To develop IEMs with good electrochemical properties, that allow the selective uptake of ions from aqueous solutions containing multicomponent mixture of salts.
To study the ion-removal process based on MCDI with carbon electrodes covered by ion-selective membranes.

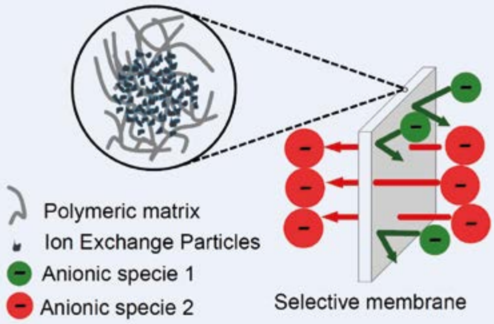

Fig.2 Schematic view of a heterogeneous ion selective membrane retaining one type of ion from a mixture of ions having the same charge and valence

Approach

To separate ionic species of the same charge and possibly the same valence, we propose to combine the use of electrosorption of ions via the formation of an electrical double layer (EDL) inside porous carbon electrodes and ion-selective membranes. Initially, we will focus on studying free-standing membranes which will be synthesized by three fabrication routes, see Fig. 3.

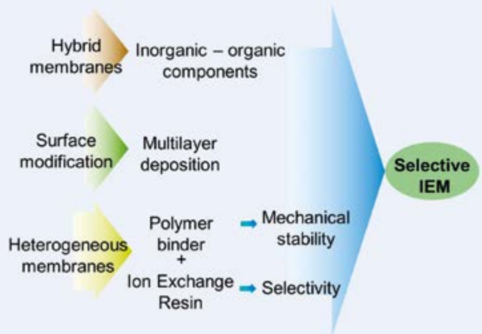

Fig.3 Overview of fabrication routes proposed for preparation of ion selective membranes

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[2] Ran, J. et al. 2017. *J. Mem. Sci.*, **522**, 267–291.

MSc. T. Mubita, Dr. ir. S. Porada, Prof. dr. ir. A. van der Wal

Advanced materials for electro-driven separation for selective resource recovery

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Motivation

Capacitive deionization is an upcoming water desalination technology [1]. It has the potential to rival existing technologies for treatment of water with moderate to low salt concentration because of its cheap and energy-efficient nature. This technique can be made to function in a continuous mode resulting in a constant production of desalinated water. The material used for the fabrication of porous electrodes is of prime importance as it underlines the performance of the cell (salt removal capacity, stability over time, energy consumption). The most-studied and used electrode materials for the CDI technique are made of carbon [2]. This research explores the field of advanced materials for CDI, other than carbon. The first potential candidate chosen for electrode is a class of material called Prussian blue analogues (PBAs). These compounds are of interest for the purpose of water desalination (apart from cost-effective and easy fabrication) because of their open framework structure, lower energy consumption than conventional CDI materials, fast charge transfer kinetics and long cycle life [3]. The ions are stored in the lattice spaces of the PBA by a process referred to as intercalation. It is a redox reaction and is given in Figure 1. A schematic of the desalination cell is given in Figure 2.

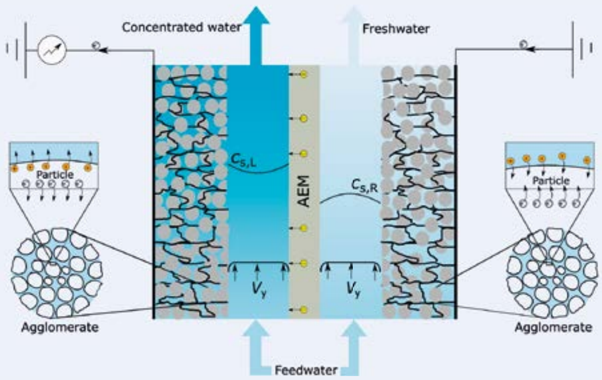

Figure 2: Schematic of the desalination experiment demonstrating the functioning of the desalination cell with PBA electrodes. Intercalation in one electrode (right) is complimented by de-intercalation in the other electrode(left).

Technological challenge

The Prussian blue analogue to be used for electrode material has the chemical formula of $Na_xNi[Fe(CN)_6]_yZ_{1-y}.mH_2O$ (0 < x < 2; 0 < y < 1; Z: $Fe(CN_6)$ vacancy). These compounds have a face cantered cubic (FCC) structure. The main challenges to integrate PBAs with the CDI technology are :

- Synthesis of PBA. Imperfect reaction conditions may lead to a defective crystal structure.
- Deficiency of lattice sites in the crystal structure.
- Porosity of the electrodes and their characterization.

Research goals

In this research, we aim to:

- Investigate the synthesis of PBAs to reduce the defects in the crystal structure.
- Understand the impact of electrode porosity on the kinetics of ion and charge transfer.
- Study the influence of synthesis of the electrodes on their salt intake capacity.
- Introduce selectivity in the electrodes towards different kinds of ions.
- Develop a theoretical model to explain charge storage in PBAs.

(a) (b)

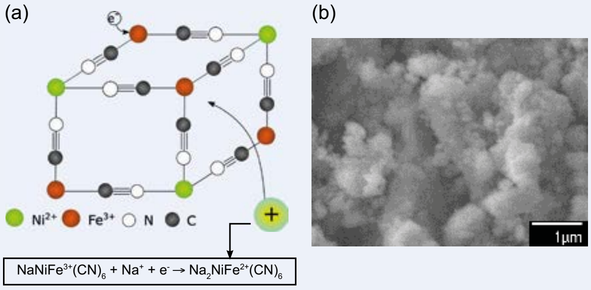

Figure 1: The PBA molecule (a) Unit cell of PBA depicted with the mechanism of charge storage observed in PBA electrodes (b) SEM image of as-synthesized PBA. Agglomerates of size < 1 μm are formed during the co-precipitation reaction.

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This work has been supported by the European Research Council (ERC Consolidator Grant 682444, E-motion, PI: L.C.P.M de Smet)

K. Singh MSc, Dr. S. Porada, Prof. Dr. H. Zuilhof, Dr. Ir. M Biesheuvel, Dr. L.C.P.M. De Smet

Dehydration

This theme focuses on enhancing the efficiency of dehydration processes. A key element for enhancing this efficiency is selective water vapor removal. This enables small scale water production systems that can produce water directly from air at the location where it is needed. The approach is to use water vapor selective membranes to separate water directly from air before cooling it. In this way only the water vapor is condensed without producing cold air. By this means up to 60% of energy could be saved reducing the price of water significantly. The quality of water is improved drastically as no pollutants can permeate the membrane.

Super critical CO_2 is applied in food drying technology as alternative to hot air drying, vacuum drying or freeze drying. However, continuous operation of such process requires efficient dehydration of the pressurized CO_2 stream. Water vapor selective membranes are used to efficiently separate water from a CO_2 stream. Membrane development is needed to produce membranes which are resistant against CO_2.

Research projects

- **Hakan Kandemir**, Wageningen University
  Selective particle separation in suspensions using acoustics
- **Ruben Halfwerk**, Wageningen University
  Recovery of valuable heat sensitive products and concentrates by eutectic freeze crystallization

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Avebe

FeyeCon

COOLSEPARATIONS
The experts in low temperature crystallization

Academic partners

WAGENINGEN
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dehydration

wetsus
european centre of excellence for sustainable water technology

Selective Particle Separation in Suspensions Using Acoustics

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Motivation

Acoustic separation is a relatively new method for the recovery of valuable particulate matter from suspensions and/or purification of liquid streams [1,2]. This technique of acoustic separation is mainly applied in biotechnology and medical technology [3,4]. Our aim is to apply this technique on separation of valuable suspensions in small to medium scale industrial water applications.

Concept

By creating ultrasonic standing waves in a suspension flow in a reactor, particles are forced to move to specific grid points in the reactor Figure 1).

Although in a standing wave the forces are small, this effect on particles is strong enough to manipulate particles for separation purposes. In addition to particle properties, such as radius, density and elastic modulus, this force also depends on excitation frequency, pressure amplitude and properties of ambient medium. Depending on the particle properties it is possible to move particles to a different position (Figure 2). Larger particles experience larger effects in terms of acoustic radiation force and drag resistance. They move to the target locations much faster than smaller particles (Figure 3). In addition to standing waves, travelling waves can be used, too (Figure 1).

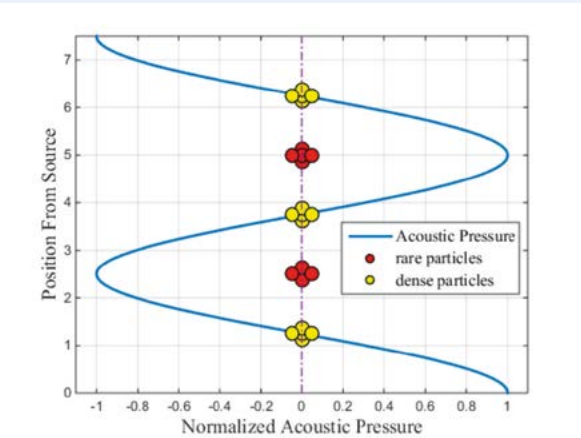

Figure 2. Particles are trapped in either pressure nodes or antinodes

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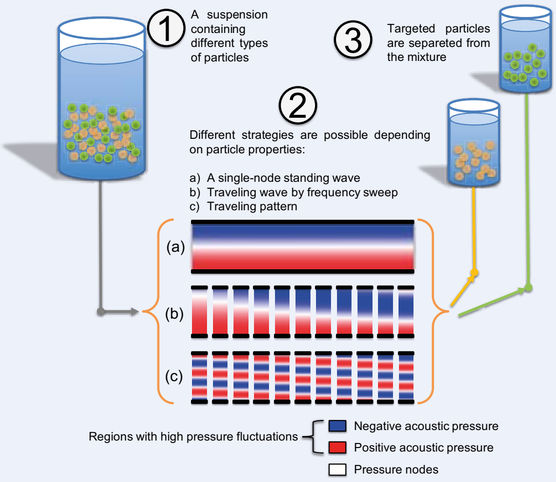

Figure 1. Particles can be selectively separeted with appropriate strategies based on their relative size, density etc.

Research goals

- ➢ Investigate the sound field under different excitation conditions such as standing and traveling waves
- ➢ Understand the particle behavior under a given sound field
- ➢ Exploit the behaviour of particles to develop selective separation strategies
- ➢ Design a separator that can separate particles based on given criterion
- ➢ Explore the energy efficiency of the separator and possible improvements for industrial applications

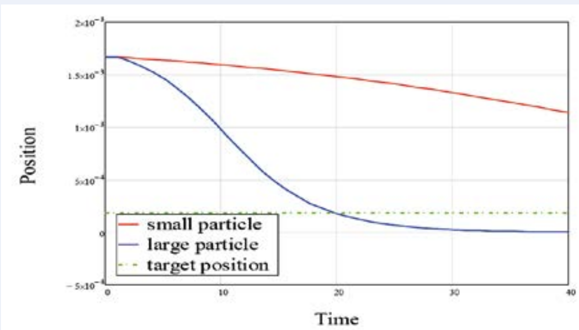

Figure 3. Large particles experience larger force than small particles, thus providing options to selectively separate

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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dr ir. D.R. Yntema, dr.ir. R.M. Wagterveld.

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dehydration

Recovery of valuable heat sensitive products and concentrates by eutectic freeze crystallization

wetsus
european centre of excellence for sustainable water technology

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Motivation

Eutectic freeze crystallization (EFC) is a newly developed crystallization technique that operates at subzero temperatures. The eutectic point of an aqueous solution is the concentration and temperature where both the solvent as the solute start to crystalize simultaneously[1], see figure 1. Due to the density difference between the solvent and solute, separation by gravity is possible. A pure stream of ice and solute can then be extracted, the remaining liquid can be separated further or recycled again into the process. See figure 2.

In comparison with other separation technologies like evaporation, EFC has a low energy requirement and has the ability of complete conversion of feed into water and solidified solutes. In addition there is no thermal degradation of the product because of the low temperatures used.

Fig. 2 process description of an EFC process

Technological challenge

Previous research has shown that it is possible to separate brines into ice and salt with a high purity. In theory however it is possible to separate both organic and inorganic aqueous solutions.
This research focuses on the recovery of heat sensitive products and concentrates in the agro and food industry by EFC. The first part of this research will look at the recovery of lactose from delactose whey permeate (DLP), which is a byproduct created during cheese and protein production.
DLP contains minerals, acids, residual proteins, residual lactose and water [2]. As DLP is difficult to process with conventional methods it is currently only used for low value application like cattle feed [3]. EFC could be used for treating this waste streams by concentrating and extracting minerals and lactose. It is currently unknown if it is possible to treat DLP with EFC: if it is possible to concentrate and extract different components without simultaneous crystallization. Furthermore it is unknown what the effect will be of low temperature crystallization on the rate, quality and quantity of lactose crystals.

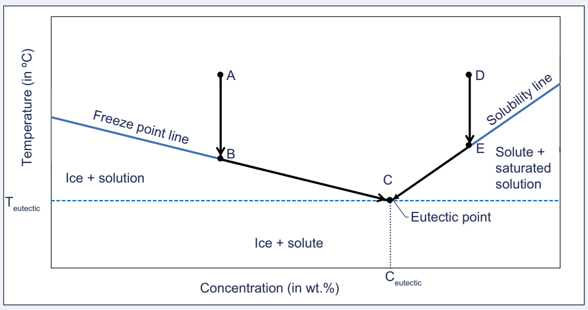

Fig. 1 Typical binary phase diagram of salt-water solution, the arrows show the two routes an EFC process can take(A-B-C or D-E-C)

Research goals

To test the effectiveness of EFC for food an agricultural streams the following parameters will be investigated:

- Crystal size and morphology
  - Solid-liquid separation
  - Effect of impurities
- Quality of product and ice
- Crystal nucleation and growth rate

After the initial experiments an investigation will be made of scaling up the process: a conceptual design of a reactor will be made and a economic evaluation as well as an energy and mass balance of an EFC process will be investigated.

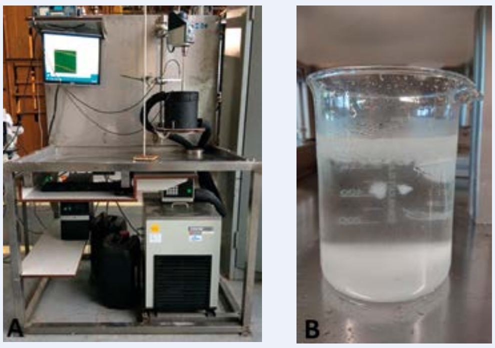

Fig. 3 (A) 1 L setup at laboratorium in Wetsus, (B) MgSO4-solution at eutectic conditions

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WAGENINGEN UNIVERSITY & RESEARCH

Desalination

To face the current and future demands for fresh water and water reuse, sustainable desalination of seawater, groundwater and wastewater is required. Wetsus focuses on research and development of innovative, sustainable and cost-effective desalination technologies that are complementary or substitutionary to state-of-the-art thermal or membrane desalination techniques. These new technologies can be incorporated in closed-loop schemes for water treatment schemes or mineral extraction. Key aspects the PhD projects contribute to are (i) low impact desalination, (ii) specific removal of ions that limit downstream processing or water reuse, (iii) recovery of water and/or valuable organics and inorganics from (saline) waste water, and (iv) brine treatment towards zero liquid discharge. Several new approaches based on various know-how disciplines are being studied by Wetsus. Fields like electrochemistry, crystallization, membrane separation, extraction and adsorption are combined in the research projects.

Research projects

- **Gijs Doornbusch**, Eindhoven University of Technology
  Multistage electrodialysis for low energy seawater desalination
- **Enas Othman**, University of Twente
  Extraction and recovery of valuable metals from wastewater using ionic liquids
- **Zexin Qian**, Wageningen University/Delft University of Technology
  Selective membranes for the removal of sodium from irrigation water in greenhouses
- **Paulina Sosa Fernandez**, Wageningen University
  Recovery of valuable polymeric solutions by lowering the salinity with electrodialysis
- **Surika van Wyk**, University of Twente
  Supercritical water desalination (SCWD)
- **Daniele Chinello**, Wageningen University
  Advanced Materials for Selective Nitrate/Chloride Separation (Anchor) **NEW**
- **Niki Joosten**, Eindhoven University of Technology
  Membranes with ordered, self-aligned pores for valorization of aqueous streams and ion separations **NEW**

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Academic partners

University of Twente · TU Delft Delft University of Technology · TU/e Eindhoven University of Technology · Wageningen University & Research

desalination

Multistage electrodialysis for low energy seawater desalination

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Motivation

Desalination of seawater and brackish water can significantly contribute to the global problem of water scarcity, but lowering the energy consumption of desalination technologies limits their application. Highly optimized state-of-the-art technologies, like pressure-driven reverse osmosis (RO), have an energy consumption for seawater desalination of 3 kWh/m^3, which is still a factor 3 off from the thermodynamic minimum of 1 kWh/m^3 of fresh water produced, assuming a water recovery of 50% [1]. A major part of the inefficiency of RO desalination can be attributed to a maldistribution of the water production over the installation. The first membrane element produces 10-20 times more than a last membrane element, just due to the fact that the driving force for desalination cannot be adjusted for each membrane element individually [2].

Technological challenge

Electrochemical desalination systems, on the other hand, can be operated with adjusted driving forces at each stage of desalination. Electrodialysis (ED) is applied for brackish water desalination and selective ion removal from industrial waste streams, but has not yet been used widely for seawater desalination. In this project we investigate multi-stage electrodialysis (ED) for seawater desalination. ED is an electrochemical desalination technology based on ion-selective membranes. A typical ED system consists of anion- and cation- exchange membranes alternatingly stacked between an anode and a cathode. Once an electric potential is applied, cations migrate in the direction of the cathode and anions in the direction of the anode. Our challenge is to design an upscaled multi-stage ED system which can be operated close to the lower limit of specific energy for seawater desalination.

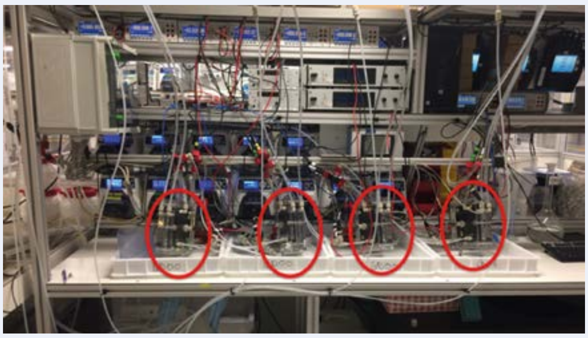

Fig 1. Experimental setup for a 4-stage ED that can be operated at co-current and counter-current staging.

Research goals

Along the different ED stages, desalination conditions vary. When operated in co-current, the first stage typically has a low internal resistance due to the high conductivity of both concentrate and diluate. Hardly any concentration gradient exists over the membranes. The last stage has a high internal resistance due to the decreased conductivity of the diluate and a high concentration gradient over the membranes. In case all stages are designed equally and operated at a single applied voltage, the ionic current will be unevenly distributed over the system leading to similar inefficiency as in RO. However, in order to get an efficient desalination process, each of the stages can be designed and operated separately and the goal of this research is to manipulate the current distribution per stage or even within each stage by further segmentation of the electrodes. Some examples of design parameters are given in figure 2a.

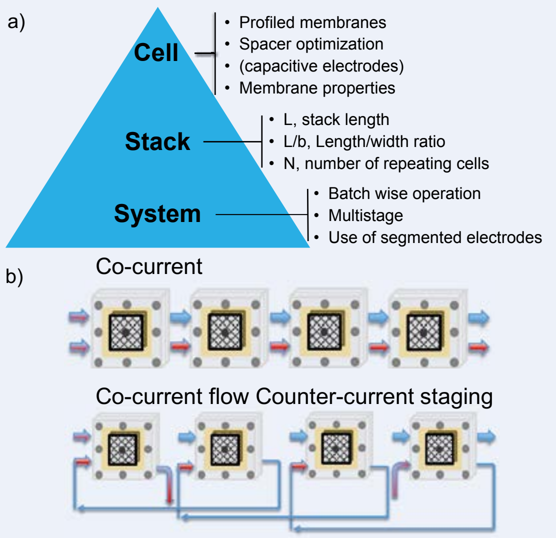

Fig 2. a) system parameters that will be investigated b) Multistage electrodialysis flow arrangement schemes for co-current flow, and co-current flow counter-current staging.

In addition operation parameters can be investigated, such as flow arrangements (figure 2b), retention times, and different current densities per stage. The ultimate goal is to obtain a seawater desalination with an energy consumption of <1.5 kWh/m^3.

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desalination

Extraction and Recovery of Valuable Metals from Wastewater Using Ionic Liquids

wetsus
european centre of excellence for sustainable water technology

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Motivation

Water purification companies, chemical and mining industries produce numerous aqueous streams polluted with valuable (heavy) metal salts [1]. There is an environmental and economy-based incentive to recover these impurities from the water before reuse or discharge. Furthermore, it is challenging to selectively separate the different metal salts from each other.
One of the most widely used separation techniques is liquid-liquid extraction (LLE) as both capital and operational costs are relatively low [3]. The main disadvantage of LLE is however the use of toxic, flammable water-immiscible volatile organic solvents [2]. In order to improve the sustainability of the LLE process, an attractive alternative is the use of a new class of nature-based, water-immiscible extractants. These so-called hydrophobic ionic liquids (HILs) have much lower volatility, water-solubility and toxicity but a higher biodegradability compared to conventional volatile organic solvents.
In this research the initial focus is on the hydrophobic quaternary phosphonium-based ionic liquid tetraoctylphosphonium oleate [P8888][oleate], which will be synthesized and utilized for the extraction of cobalt chloride. This IL has been selected because:

1. it has the ability to selectively extract transition (Zn, Cu, Co, Mn, Ni etc) and rare-earth (La, Nd, Sm, Dy, Er, Yb etc) metal ions depending on pH,
2. it consists of hydrophobic anion and cation which minimize the loses to the aqueous phase,
3. it acts as both solvent (due to its relatively low viscosity of 200 mPa.s at room temperature) and extractant for the removal of metal ions.

Technological challenge

To develop an efficient continuous (multi-stage, countercurrent, regenerative) HIL-based LLE process for the selective recovery of metals from waste water. Even though the proof-of-principle already has been demonstrated [2,3], specific challenges of the present project are, first, in terms of economic viability 1) to extent the process duration from a single cycle (extraction - regeneration) to >1000 cycles, 2) to regenerate the loaded HIL effectively and 3) obtain the cobalt in the form of an economically attractive salt. Challenges in terms of sustainability are 1) to minimize the loss of HIL to the aquatic phase and 2) to either recover or break-down the minute amount of HIL that does escape to the water phase, the latter by UV and/or peroxide treatment.

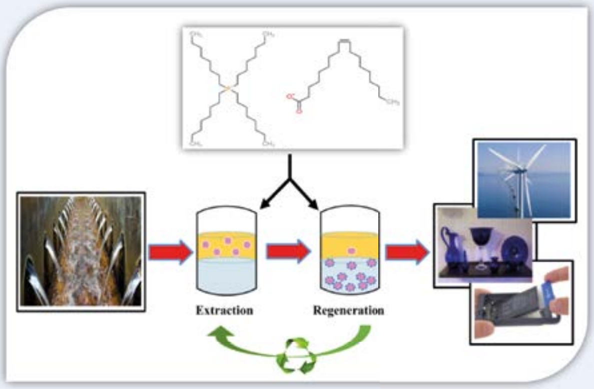

Fig.1 Research graphical abstract for metal extraction and recovery using ionic liquid

Research goals

The following process aspects will be tested and evaluated:

1. Developing, testing and optimizing the extraction and regeneration cycle using HIL for the extraction of cobalt chloride.
2. Definition of technical process parameters that allows up-scaling from lab to industrial scale.
3. Performing a technical and economical evaluation that allows a comparison with currently existing technologies.

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Selective Membranes for the Removal of Sodium from Irrigation Water in Greenhouses

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Motivation

Dutch crops are mainly grown on substrates, detached from soil, which allows for recirculation of the irrigation water. High concentrations of Na^+ in water affect the permeability of soil and causes infiltration problems. And most importantly, it is toxic for the crops. Reuse of irrigation water is therefore often limited by the accumulation of Na^+. Nowadays, this irrigation water, containing valuable nutrients, has often to be discharged to the environment as a brine stream. Therefore, reuse of water and nutrients would be enhanced if Na^+ could be selectively removed from irrigation water. However, up to now there is still no cost-effective industrial technology that can selectively remove Na^+.[1] This project aims to develop a membrane-based material that can separate Na^+ from the irrigation water meanwhile preserving other nutrients present, notably K^+. Selectivity will be imposed by using a crown ether with a high Na^+ over K^+ affinity (Fig. 1).

Technological challenge

Regarding real-life applications, the main challenges include:

- The Water Framework Directive (WFD) aims for zero brine emission[2].To comply with this regulation, all drain water should be treated prior to discharge to the environment or fully recycled.
- Regarding their chemical and physical properties (e.g., atomic diameter and valence), Na^+ and K^+ are two very similar ionic species. By implication, the material to be used needs to have the required Na^+ over K^+ selectivity.
- In contrast to an absorbent, a membrane that exclusively permeates Na+ requires no regeneration. Given the high affinity of the crown ether for Na^+, in order to generate a Na^+ flux over the membrane, equally important is the ability of the crown ether to again release Na^+. The system to be developed should demonstrate a delicate balance between these two requirements of high affinity (interaction) and release.

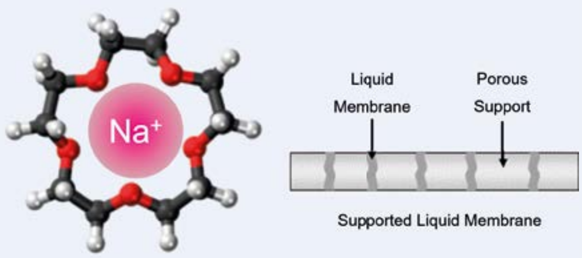

Fig 1. Structure of the Na^+ selective crown ether and Supported Liquid Membrane (SLM)

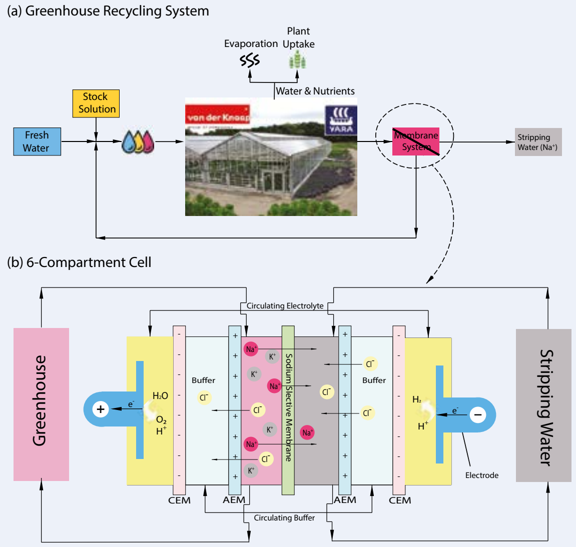

Fig 2. Schematic of the Greenhouse Recycling System

Research goals

In view of the challenges, this project aims developing a membrane-based system for the selective removal of Na^+ suitable to operate under greenhouse conditions. The project comprises the following research goals:

- Investigating and developing a membrane system, e.g. based on the concept of Supported Liquid Membranes (SLMs) as shown in Fig. 1.
- Synthesis of an extractant based on a Na^+ selective crown ether and use as ion carrier in the SLMs.
- Studying the feasibility of electric field-enhanced Na^+ membrane transport using a 6-compartment electrodialysis cell (Fig. 2b).
- Investigating of the membrane system under real-life conditions while exposed to a large scale continuous flow of greenhouse drain water.
- Optimizing the system from both environmental and economic aspects.

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Recovery of valuable polymeric solutions by lowering the salinity with electrodialysis

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Motivation

Every year, millions of cubic meters of polymer-flooding produced water (PFPW) are generated in the world, and the figure is likely to keep increasing. Just in the Daqing field in China, the amount is $6x10^7$ m^3 of PFPW/year [1], equivalent to the volume of 24,000 Olympic pools. This water results from applying enhanced oil recovery (EOR) techniques, and in general contains a viscosifying polymer, varying amounts of salts, solids, and some emulsified oil, a combination that makes its treatment for reuse or disposal very challenging. Even after removing the oil and solids, the high salt content makes the mixture unsuitable for reuse in EOR. This is because the swelling degree of the polymer decreases with increasing salinity of the solution, consequently lowering its viscosifying effect.

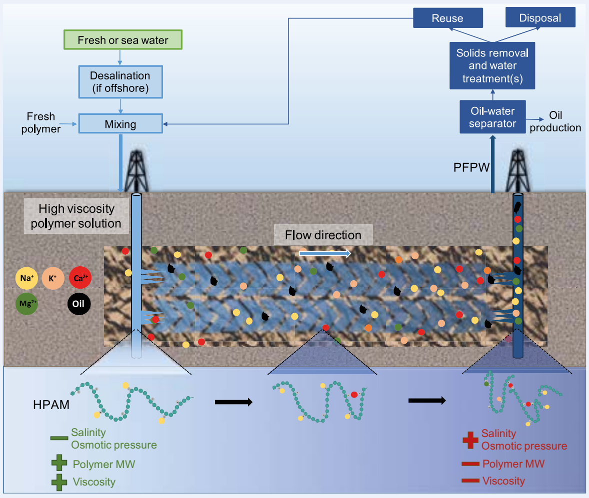


Fig 1. Origin of PFPW. In EOR, large volumes of water viscosified with polymers are pumped through an injector well in order to sweep the oil and/or gas and increase their recovery. The PFPW is later recovered still containing the polymer, but also high amounts of salts, solids and some emulsified oil.

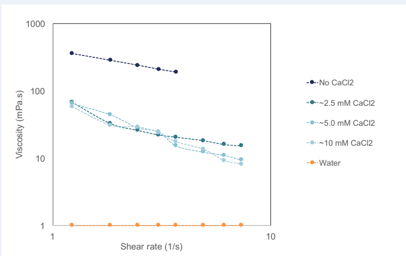
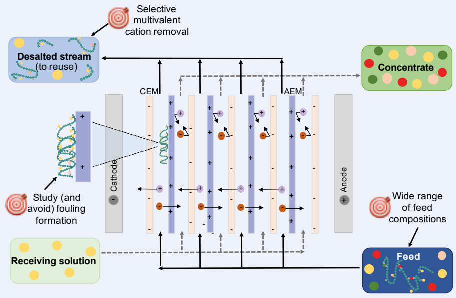


Fig 2. Viscosity curves of HPAM solutions (1.0 g/L) with varying salt content (CaCl2). The higher the salt content, the lower the viscosity.



Electrodialysis, a salt selective technology that relies on ion-exchange membranes to desalinate streams, will be employed during this project to reduce the salinity of the PFPW stream and, consequently, restore the expanded state of the polymer. This will increase the viscosity of the solution and lead to a reduction in the consumption of fresh water and polymer in EOR operation.

Technological challenges

1. **Produced water is a complex mixture.** The types and amounts of salts, oily compounds, and even polymer vary from location to location. Although the most common EOR polymer is partially hydrolyzed polyacrylamide (HPAM), many other types of polymers are being developed and employed.
2. **Selective removal of multivalent cations.** Since the viscosity of HPAM solutions is much more affected by the presence of multivalent cations when compared to monovalent cations[2], their selective removal is highly desirable.
3. **Membrane fouling.** Due to the intrinsic negative charge of HPAM, it could have electrostatic interactions with the positively charged anion-exchange membrane (AEM)[3], causing fouling problems. In adition, concentration polarization may be affected by the viscous fluid layers near the membrane.

Research goal

The main research objective is to investigate the desalination process of synthetic PFPW by electrodialysis, placing special attention in understanding the membrane fouling mechanism. In order to achieve this, three main lines will be followed:

- Physical chemical characterization of the polymer in different salt solutions and its interaction with the positively charged surface of the AEM.
- Process and membrane characterization.
- Optimal electrodialysis cell design and operation for desalination of polymeric solutions, based on the insights of the two aforementioned research lines.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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WAGENINGEN UNIVERSITY & RESEARCH

SuperCritical Water Desalination (SCWD)

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Motivation

The demand for fresh drinking water is increasing due to the growing global population and industrialisation, and the simultaneous decrease of freshwater resources. Conventional technologies are able to produce potable water from saltwater, but concurrently produce waste streams with high saline concentrations. The discard of these waste streams is harmful to the environment and therefore alternative methods of freshwater production should be investigated, which reduces the waste discharge and/or is able to treat the brackish waste streams. When water is at supercritical conditions, P>221bar and T>374°C, it becomes non-polar, thereby decreasing the solubility of inorganic components in water. Consequently, this results in the precipitation of solid salt or the separation of a concentrated brine from supercritical water[1]. Supercritical water desalination (SCWD) is a promising new zero liquid discharge (ZLD) desalination technology that is able to produce a low saline water stream and solid salt. This technology on itself can be energy intensive due to the operating conditions, but could become more efficient when integrated with conventional methods as either a pre– or post treatment step.

Technological challenge

Before this process can be applied industrially or integrated with conventional technologies, it first needs to be optimised in terms of energy costs and recovery. Once the optimum conditions have been established, the influence of different salts and feed concentrations need to be investigated as the separation behaviour of the salts vary depending on type 1 and 2 salts. Afterwards, the incorporation of the SCW process can be examined both experimentally and through modelling and process simulation. From the results, it can then be determined if the integration of this process is economically feasible and also energy efficient.

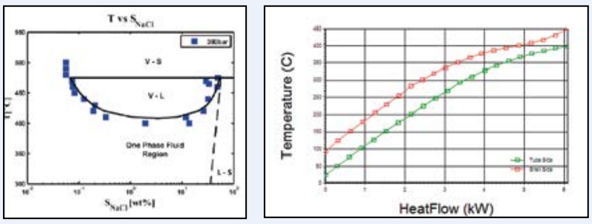

Fig 1. Phase diagram of NaCl-H_2O system at 300 bar (left); Axial temperature profile of heat exchanger at 300 bar (right)

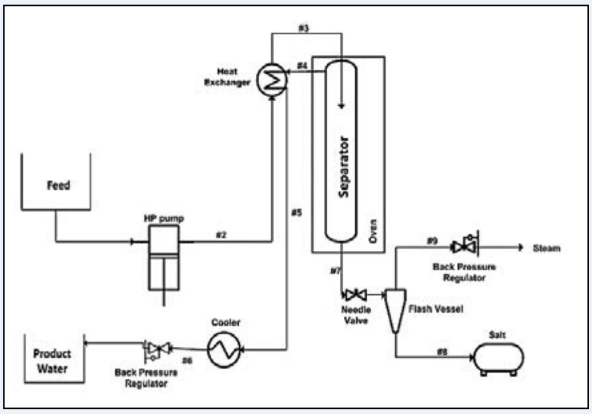

Fig 2. Supercritical water desalination (SCWD) pilot plant

Research goals

- Energy recovery and optimization of SCWD pilot plant (Fig 3a).
- Different operating modes *i.e.* separation temperature and feed concentration.
- Influence of different salts and salt mixtures on operation.
- Modelling and simulation of supercritical phase behaviour and the SCWD process.
- Integration of SCWD with existing water/salt production processes including techno-economic evaluation.
- Visual investigation of phase behaviour and crystallisation.

Fig 3a. SCWD Pilot plant (5 kg/h Brine)

Fig 3b. Solid salt (NaCl)

Fig 3c. Drinking water (< 750 TDS)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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desalination

Advanced Materials for Selective Nitrate/Chloride Separation (Anchor)

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Motivation

The selective removal or recovery of elements from a multicomponent stream plays a key role in many industrial and agricultural applications. For instance, nitrate needs to be removed from industrial brines. In closed horticulture systems however the aim is to retain the nitrate in the recirculating water but to selectively remove the chloride, a requirement also mandatory in the production process of fertilizers. Currently used electrochemical and biological methods deal with safety issues, season-dependent environmental factors, time-consuming process steps and/or high capital costs. For all these reasons, alternative approaches have to be explored.

Technological challenge

The separation of nitrate and chloride is particularly challenging. The reason is that these two equally charged ions are similar in size, resulting in a rather similar (de)hydration energy as well [1]. Apart from these similarities, a clear difference between the two ion species is related to their (hydrated) structure. Whereas nitrate is a rather planar molecule, chloride is relatively symmetrical in three dimensions [2]. This structure difference can be exploited by new materials possessing chemical moieties that allow discrimination between the two ion species. Together with differences in hydrophobicity, the structural difference between the (solvated) nitrate and chloride will be the starting point for Anchor.

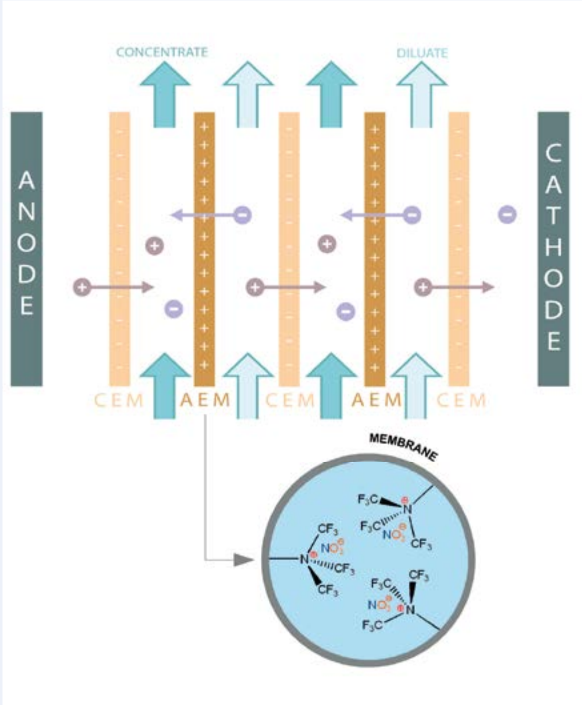

Fig.1 Scheme of an electrodialysis system, identifying the repeating unit (cell pair); in the outer circle is represent the exemplary and generalized structure of the ion-exchange polymer membranes that will be studied.

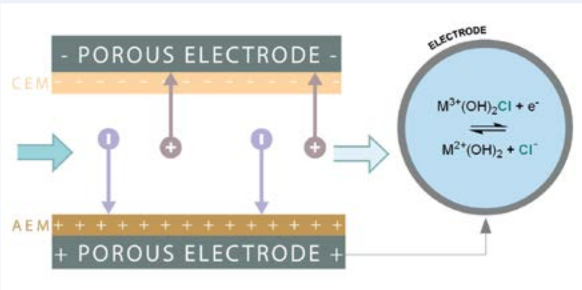

Fig.2 Schematic design of a cell for Membrane Capacitive Deionization (MCDI); in the outer circle is represent the exemplary and generalized mechanism of the electro-adsorb ions materials that will be studied.

Research goals

- The design and engineering of nitrate or chloride selective materials based on the physico-chemical properties of the two ion species.
- The functionalization of membranes by fine-tuning their hydrophobicity. Assessing the nitrate and chloride membrane permeation by using Electrodialysis (ED) *(Fig. 1)*.
- The functionalization of adsorption materials (electrodes) by including chemical moieties that can distinguish between nitrate and chloride. Characterizing the adsorption (and desorption) of nitrate and chloride by using Membrane Capacitive Deionization (MCDI) *(Fig. 2)*.

The research received funding from Netherlands Organization for Scientific Research (NWO) in the framework of the collaboration programme of NWO with Wetsus on Sustainable Water Technology.

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Natural water production

Precipitation is the only sustainable water source in a watershed. Water scarcity occurs when more water is used than is supplied via precipitation. The new theme natural water production started in 2019 and aims at enhancing precipitation to make more fresh water available. The key to enhancing precipitation is to increase evaporation and increase in this way the water recycling in a watershed. To make this vision a reality, a strong interdisciplinary program is under construction, including disciplines like meteorology, hydrology, forestry and water technology.

Research projects

- **Jolanda Theeuwen**, University of Utrecht
  Stimulating the natural water cycle over the Mediterranean for more water **NEW**

THEME MANAGER

Ties van der Hoeven
(The Weather Makers)

THEME COORDINATOR

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Industrial partners

the WEATHER MAKERS holistic engineering

Dredging International Marine & Waterway Solutions

Academic partners

Universiteit Utrecht

Stimulating the natural water cycle over the Mediterranean for more water

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Motivation

Unsustainable land use is an important driver for desertification and land degradation in dryland areas. Because of this, extreme weather patterns (e.g. droughts) will become more recurrent and intense, intensifying land degradation. Additionally, climate change enhances intensity and frequency of these patterns. Especially in the Mediterranean areas there is a high risk for droughts.
There are indications that vegetation reduces the risk of droughts (Figure 1). However, the exact impact of vegetation restoration on weather patterns is difficult to assess. This project aims at **better understanding the influence of vegetation restoration in the Mediterranean area on land-atmosphere interactions**. In this regard, this project aims to assess the feasibility to increase fresh water availability through vegetation restoration in Mediterranean areas.

Technological and Scientific challenge

Land-atmosphere interactions are not fully understood due to the uncertainty in multiple relations (see Figure 2). These relations need to be better understood to improve land surface models and experiments. **To increase this understanding more data sets of evapotranspiration and soil moisture are required and new methods to analyze these and existing datasets need to be acquired**. We will investigate how this knowledge can contribute to improve the assessment of the impact of vegetation restoration on land-atmospheric processes. For this, it is important to first, determine the location dependency of land-atmospheric processes to get a better understanding where greening should be applied, and second, understand the influence of the construction of wetlands on the energy balance and thereby on moisture transport.

Research goal

The goal of this research is **to investigate whether vegetation restoration in Mediterranean areas can increase fresh water availability**. For this research, four objectives are formulated:

- Determine where in the Mediterranean an increase in evaporation could enhance precipitation.
- Determine the effects of vegetation restoration on the local hydrological balance.
- Determine the effects of vegetation restoration on the hydrological balance of a remote area.
- Determine the effects of vegetation restoration on large scale weather and its impact on the hydrological balance.

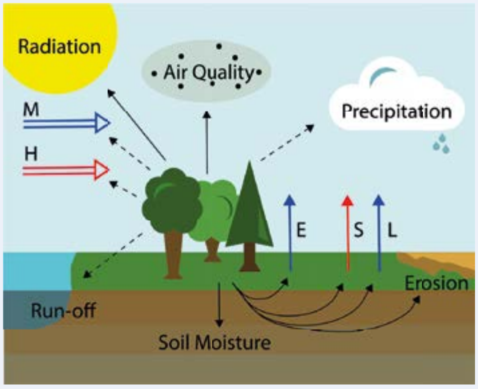

Figure 2. Schematic overview of land-atmospheric relationships. Black arrows indicate direct (continuous) or indirect (dashed) relation. M: transport of moisture, H: transport of heat, E: evaporation, S: sensible heat flux, L: latent heat flux.

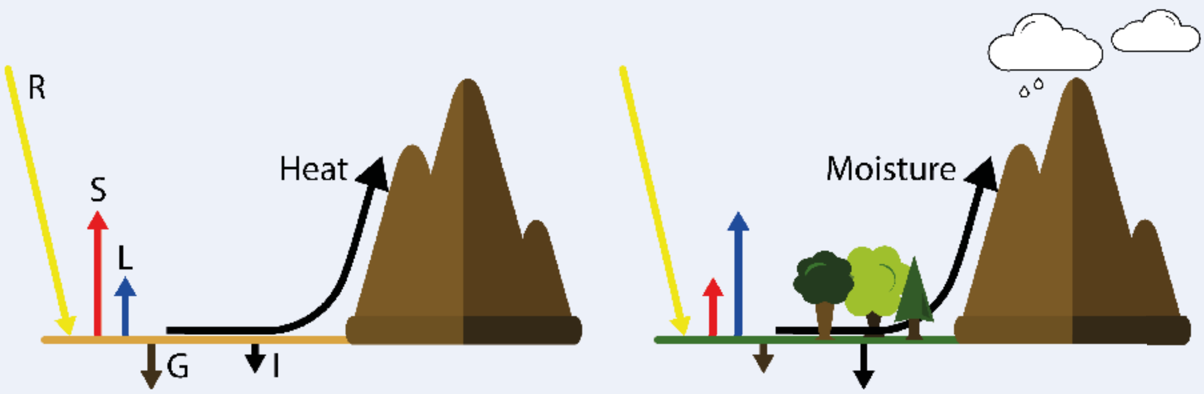

Figure 1. Graphical abstract: Vegetation restoration changes the energy balance the latent heat flux (L) is enhanced and the sensible heat flux (S) is reduced which minimizes the advection of heat and improves the advection of moisture, possibly resulting in fresh water. Also, vegetation enhances Infiltration (I) of water into the soil which allows for an increase in evaporation. R: incoming radiation, G: ground flux. (Icon made by Freepik from www.flaticon.com)

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J.J.E. Theeuwen MSc, dr. O.A. Tuinenburg, dr.ir. H.V.M. Hamelers, prof.dr. S.C. Dekker

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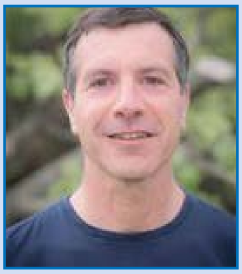
Biopolymers from water

Wastewater treatment most often involves the use of biological processes to reach effluent water quality objectives. The by-product of biological treatment is a surplus biomass that is rich in microbial activity. Research has shown that it is possible to engineer biological treatment processes for both municipal and industrial wastewater to be naturally enriched with bacteria that can store an excess of biopolymers. The biopolymers are from the family of polyhydroxyalkanoates (PHAs). PHAs are biodegradable thermoplastic materials that are attractive ingredients for bioplastics. The status of current know-how provides for an interesting opportunity of synergy to combine water quality management services with resource recovery and the realization of new biopolymer value chains in regional circular economies. Research in this theme is to build on and bridge fundamental bioprocess engineering and materials science with downstream commercial opportunities for platform chemicals and bioplastics. The theme is an incubator to reach optimal insights and strategies to produce value added biopolymers for industry in combination with the ongoing demands for increasingly more effective wastewater treatment methods.

Research projects

- **Ruizhe Pei**, Delft University of Technology
  Recovering Biopolymers for the Bioplastic and Chemical Industries
- **Angel Estevez Alonso**, Delft University of Technology
  Producing biopolymers for the bioplastic and chemical industries
- **Erik de Vries**
  SCALIBUR project: PHA production from surplus activated sludge and fermented organic municipal wastes in a pilot system

THEME COORDINATOR



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Industrial partners

Paques, Stowa (Stichting Toegepast Onderzoek Waterbeheer), SNB – Haalt meer uit slib!

Academic partners

TU Delft – Delft University of Technology

wetsus
european centre of excellence for sustainable water technology

Recovering Biopolymers for the Bioplastic and Chemical Industries

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Motivation

In 2016, 335 million tons plastics were produced from which crude oil is the principal feedstock[1]. Waste plastics in the environment are affecting ecosystems. Thus, there is a growing need to produce bio-based and biodegradable polymers – bioplastics. Polyhydroxyalkanoates (PHAs) represent a family of such biopolymers which could supplant use of petroleum-based plastics in selected applications. PHAs can be accumulated in bacteria intracellularly by using renewable organic residuals as feedstock (*Fig 1.*). The techno-economic feasibility was demonstrated to produce PHAs from surplus municipal activated sludge, recently. It is anticipated that activated sludge may accumulate up to 60% PHAs (w/w)[2]. Converting WWTPs to PHA production factories generates an opportunity for lowering the cost of both surplus activated sludge handling and bioplastics production. Methods to improve the downstream polymer recovery are of interest in order to enable the wider potential for commercial production of PHAs.

Technological Challenge

Polymer recovery requires ways to separate the intracellular PHAs from the surrounding Non-PHA Biomass (NPB). One of the methods is solvent extraction. However, solvent extraction becomes cost-efficient only with increased scale and/or with increased polymer content (less NPB). Viable commercial PHA recovery initially with niche production volumes and smaller scale are served by inexpensive and environmentally friendly methods to reduce NPB. This method requires a balance of selective metabolism of polysaccharides, proteins, lipids, genetic elements, and inert solids without undue loss of the mass and Mw of PHAs.

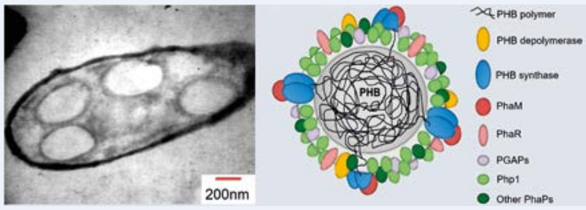

Fig 1. TEM image of intracellular PHA granular (left) [3] and proposed structure of intracellular PHA granular (right) [4]

The digestive tract of higher organisms (e.g. rats and worms) exhibits such selective digestion of NPB over PHAs. In these cases, PHAs were significantly purified in the fecal castings. In principle, their digestive tracts may be regarded as a synergetic bio-process involving enzyme and microbial activities. The challenge is to mimic these observed outcomes ex-vivo (*Fig 2.*).

During selective digestion, bacteria can degrade PHAs extracellularly and intracellularly. Strategies to mitigate intra/extra-cellular depolymerase activities are required. The ideal methods should effectively limit the unwanted enzyme activity on PHAs and require minimal input of energy and resources.

Research Goals

1. Characterization of the composition of the PHA-rich biomass.
2. Evaluation of the dominant activities of NPB digestion in Vivo.
3. Imitation of digestive processes of higher organisms ex Vivo.
4. Develop viable strategy to limit depolymerase activities.
5. Balancing outcomes of NPB stripping with polymer quality.

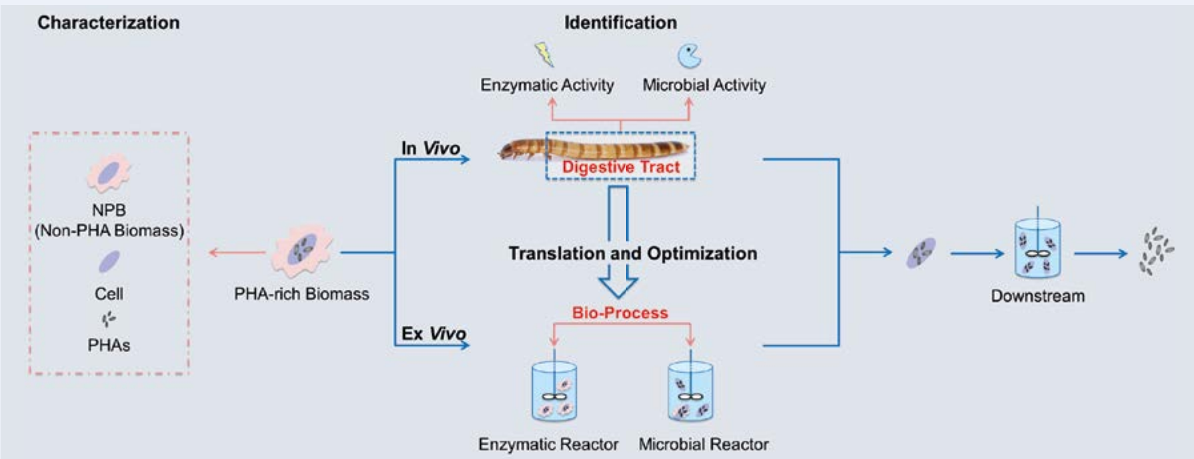

Fig 2. Concepts and key activities to translate the digestive tract of the higher organisms into a bio-process for the recovery of PHAs

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Producing biopolymers for the bioplastic and chemical industries

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Motivation

Activated sludge (AS) is normally produced as a waste by-product in biological wastewater treatment plants (WWTP) and its production, and subsequently disposal, contributes significantly to the operational costs of the WWTP. Within regionally based circular economies, AS does not necessarily need to be a waste by-product. It can be considered as a resource for the production of renewable products, for instance, polyhydroxyalkanoates (PHAs). PHAs are polyesters with attractive properties: renewable and biodegradable. Surplus AS can be a raw material input for a PHA production process if a volatile fatty acid (VFA) stream can be made sufficiently available as feedstock[1].

Technological challenge

The use of AS has been demonstrated for PHA accumulation[2] or as inoculum for a biomass enrichment by feast and famine cycles[3]. At the same time, municipal biomass, from full-scale treatment systems without previous enrichment have demonstrated potential to produce already significant amounts of high quality polymer[1] (Fig. 1). However, there is a **lack of fundamental understanding in methods that can ensure for reproducibility and consistent efficiencies** in the production process when a municipal AS is supplied directly into a PHA production process.
Moreover, strategies that address needs in both productivity and polymer quality are essential towards establishing regional economies with surplus AS as an abundantly available raw material for biopolymer value chains. Fundamental insights leading to innovative process methods are anticipated to come from steering the biomass condition prior accumulation (physiological state), control and exploitation of flanking metabolic activity and reactor configuration with its process control (Fig. 2).

Fig 1. Business card holder made during the PHARIO project using municipal activated sludge[1].

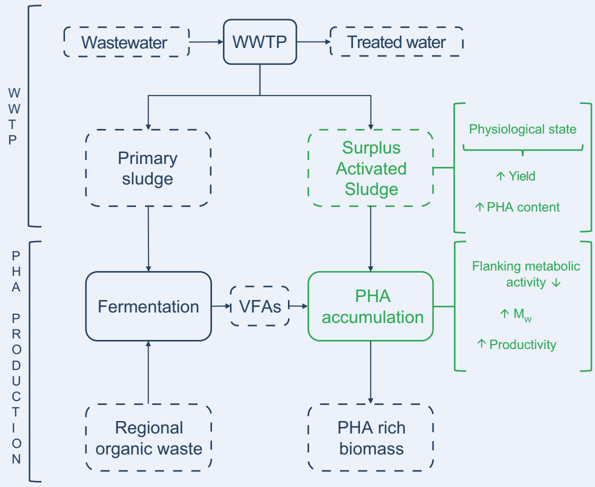

Fig 2. Research strategy of the project: steering the biomass condition prior accumulation (physiological state), control and exploitation of flanking metabolic activity and reactor configuration with its process control.

Research goals

The objective of this project is to **establish robust and optimal bioprocess engineering design principles for mixed culture PHA accumulation** (Fig. 2). The approach will be with fundamental evaluations of biomass physiological state, respiration response, and polymer molecular weight control, while developing monitoring strategies to ensure that:

- biomass condition before accumulation is primed for maximum PHA content and yield,
- process operations are selective and controlled for high polymer molecular mass (M_w),
- bioprocess methods are generic for varied biomass sources and feedstocks,
- control strategies give selective advantage to the PHA storing phenotype in the biomass, and
- process configuration and design are optimized for productivity and economy

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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Blue energy

The Blue Energy Theme focuses on the development of a sustainable technology for electricity generation by using the salinity gradient between river water and seawater. This technology, called Blue Energy, combines electrochemistry, polymer chemistry, process engineering and water pretreatment technology to generate renewable electrical energy. New investigations are directed towards anti-fouling measures and the development of membranes that are not susceptible for fouling. The Blue Energy Theme also focuses on the development of the Blue Battery that uses a reversible bipolar membrane for the storage of the electrical energy in acids and bases while this chemical energy is turned into electrical energy during discharge. This Blue Battery is the core of the Horizon 2020 project BAoBAB (2017-2021) with Wetsus as coordinator. Both for Blue Energy as well as for the Blue Battery the target is the development of new membrane technology to fulfill the requirements. The membrane development is done in collaboration with the Technical University of Eindhoven (group Prof. Kitty Nijmeijer) and with FUJI Europe (Tilburg, The Netherlands). On-site tests for Blue Energy are done at De Afsluitdijk together with REDstack.

Research projects

- **Malgorzata Roman**, Ghent University
  Transfer of organic solutes through ion exchange membranes in (R)ED systems
- **Diego Pintossi**, Eindhoven Technical University
  Material design for fouling control in reverse electrodialysis
- **Emad Al-Dhubhani**, Eindhoven Technical University
  Development of membranes for the Acid-base flow (blue) battery (ABFB)
- **Catarina Simões**, University of Twente
  Scale-up of novel redox free concepts for generating salinity gradient energy
- **Barbara Vital**, Wageningen University
  Fouling and Process Design in reverse electrodialysis: a case study with real waters
- **Ragne Pärnamäe**
  Electrochemical characterization of bipolar membranes

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Transfer of organic solutes through ion exchange membranes in (R)ED systems

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Motivation

The REvivED project aims to contribute to overcoming worldwide water scarcity issue, by establishing electrodialysis (ED) as a new standard for desalination. ED utilizes ion exchange membranes (IEM) to separate ions from water, under the influence of an external electrical field [1]. IEMs were widely investigated in terms of their limiting factors affecting ED, e.g.: water transport and water splitting. Nevertheless, in the past few decades, researchers became aware of the presence of organic micropollutants (OMP) in the source water further used in ED systems. OMPs refer to broad range of products, (e.g. herbicides, pesticides and pharmaceuticals) present in environment in the concentration range of ng/L up to µg/L. The influence of OMPs on the quality of drinking water produced by ED has not been studied in detailed. Although, their environmental impact remains largely unknown, their negative effect on human health was already investigated and reported [2,3]. For this purpose, it is crucial to prevent their migration to drinking water. It is of special importance considering application of ED in hybrid systems, which use waste water as an ionic concentrate.

Technological challenge

In a stand-alone mode of operation, conventional desalination systems are energy and cost intensive. In this respect, implementing cogeneration of electricity and desalination is a promising approach for fresh water production. Reflected hybrid desalination systems concists two stage pretreatment: salinity reduction (assisted reverse electrodialysis) and energy recovery (reverse electrodialysis). In both stages we consider to apply impaired water, as an ion recieving phase. However, this solution creates a risk, caused by the organic trace contaminants present in the impaired water.

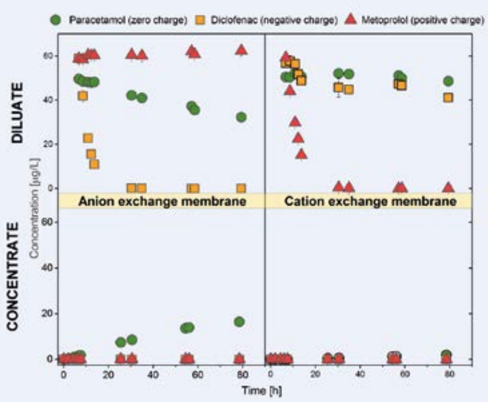

Fig 1. Concentration profile of paracetamol (non-charged), diclofenac (negative charge) and metoprolol (positive charge) in a diffusion experiment with anion and cation exchange membranes

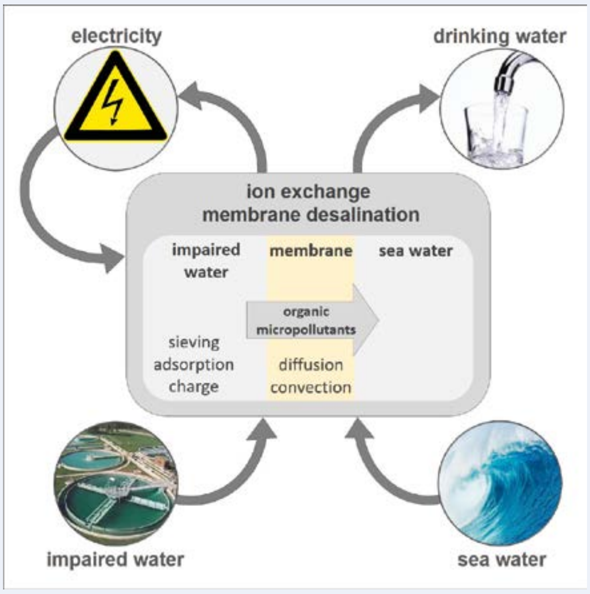

Fig 2. Graphical abstract

Research goals

Information on the effect of OMPs on the quality of drinking water produced in ED and the OMPs transport mechanisms in ion exchange membranes (IEM) is scarce. Therefore, the aim of this study is to improve our understanding of the transport mechanisms of OMPs through IEMs, as a step to developing strategies to prevent their presence in final water stream produced by ED.

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Material Design for Fouling Control in Reverse Electrodialysis

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Motivation

Renewable energy sources are crucial to meet the growing world energy demand in a sustainable way. In recent years, salinity gradient energy has shown an increased potential as a viable source of renewable energy. This energy is based on the generation of electricity from the mixing of aqueous solutions with different salinity, such as river and seawater. Reverse electrodialysis (RED) is used to harvest the salinity gradient energy by using ion exchange membranes (Fig. 1).

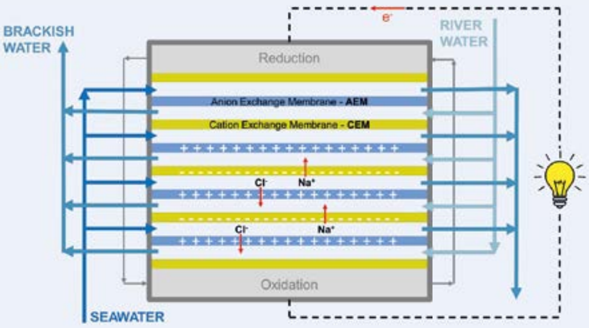

Fig.1 Schematic illustration of the working principle of RED. River water and seawater flow alternately in channels separated by anion and cation exchange membranes (AEM and CEM, respectively), which enable the selective transport of anions and cations. The ion current flowing inside the stack is converted in an electrical current by a redox couple at the electrodes.

Wetsus has extensively investigated RED at laboratory and pilot plant scale in the past decade. Testing with real feedwaters at the Afsluitdijk research facility (Fig. 2) opens up new opportunities to study and to overcome issues related to membrane fouling.

Fig.2 Full scale 50 kW RED research facility at the Afsluitdijk in the North of The Netherlands [1].

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Technological challenge

Natural feedwater streams contain several foulant species like e.g. multivalent ions, micro-organisms, silicates and humic acids. These species interact with the membrane surface in the RED stack, reducing the power output up to 60% in the first few days of operation (Fig. 3) [2]. To run the RED stack at a stable and high performance level, fouling control needs to be developed based upon modification of the chemistry of the membranes.

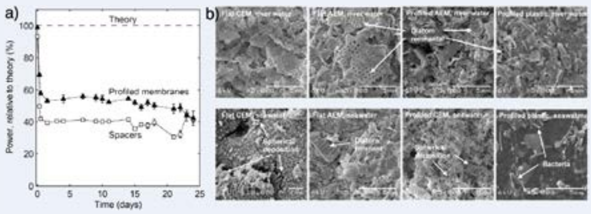

Fig.3 (a) Loss of normalized power output over time for RED stacks in natural feedwater streams for stacks with spacers and with profiled membranes (less fouling) (b) SEM images of foulants on the membrane surface like diatomic species and bacteria [2].

Research objectives

The aim of this PhD project is to investigate the influence of the chemistry of RED membrane materials on fouling in natural conditions. In particular, a study of the interactions taking place at the membrane-feed interface will be followed by the development of suitable membrane to control them. Newly designed membrane materials and surface modifications will be implemented to develop membranes capable of optimal RED performance with natural feedwaters (Fig. 4).

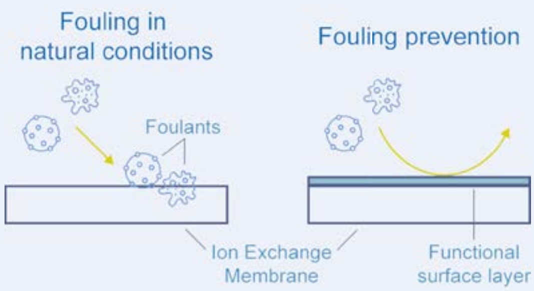

Fig.4 Surface modification of RED membranes is one of the possible approaches to prevent fouling.

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Membrane Materials & Processes

TU/e

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european centre of excellence for sustainable water technology

Development of membranes for the Acid-base flow (blue) battery (ABFB)

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Motivation

Along the last decade, renewable energy sources have been revolutionary growing with more than 12% growth rate per annum. However, renewable energy sources despite being abundant and cheap they are intermittent sources where their supply does not necessarily match the consumers demand. Energy storage systems provide an alternative solution to store the excess energy and then recover it when needed, such systems ensure reliability and efficiency of renewable energy supplies.

Recently, there have been advancements in energy storage systems capable of storing GWh-scale energy capacity, such systems despite being promising they still possess several environmental and safety issues. In this project, Acid-base flow battery ABFB is employed as a storage system with water and salt as active materials. Figure 1 is an illustration of the system concept where water is dissociated into acid and base at the junction of the bipolar membrane during the stage of charging. Then acid and base are stored in tanks till the discharge state where they recombine to produce water and salt.

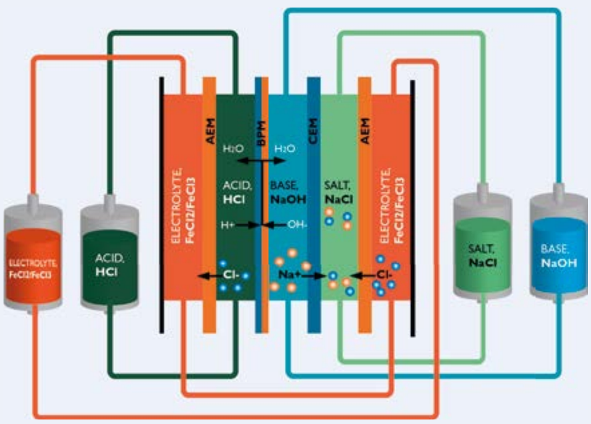

Figure 1. A Schematic illustration of ABFB

Technological challenge

In this system, the bipolar membrane is the most crucial and limiting part, during charging water molecules diffuses into the BPM junction and dissociates into a proton and hydroxyl ions while during discharging proton and a hydroxyl ions form water.

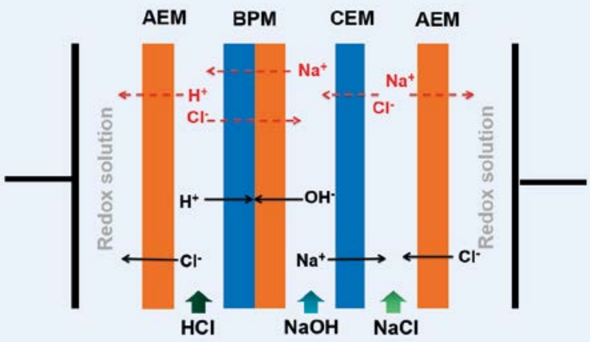

Fig 2. Possible routes of co-ion transfer through ion exchange membranes and bi-polar membrane in ABFB (in red).

The ABFB exhibits several drawbacks mainly due to the bipolar membrane performance :

1. BPM delaminates when discharging at higher current densities due to the high rate of water formation at the junction of AEM and CEM which surpasses the level of water diffusion.
2. Low round trip efficiency (27%) as a result of unwanted co-ion transfer as shown in Figure 2 (the transfer of ions/protons through membranes with the same charge) [1].
3. Internal resistance of the system needs to be lowered.

Research goals

The aim of this project is to develop bipolar membranes and ion exchange membranes which could overcome the drawbacks of the state of art membranes. This includes developing bipolar membranes capable of discharging at higher current densities without delamination. In addition, development of anion and cation ion exchange membranes that mitigate undesired co-ion transfer.

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Acknowledgment:
This work is performed within the BAoBaB project (Blue Acid/Base Battery: Storage and recovery of renewable electrical energy by reversible salt water dissociation). The BAoBaB project has received funding from the European Union's Horizon 2020 Research and Innovation program under Grant Agreement no. 731187 (www.baobabproject.eu).

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BAoBaB BLUE ACID/BASE BATTERY

blue energy

Scale-up of novel redox free concepts for generating salinity gradient energy

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Motivation

To meet the world energy demand in a sustainable way, new renewable energy sources need to be investigated. Salinity gradient energy (SGE) has gained attention during the past decade showing an increased potential. SGE is the available energy from mixing seawater and river water. By using Reverse ElectroDialysis (RED) with ion exchange membranes (Fig 1.), energy is harvested.

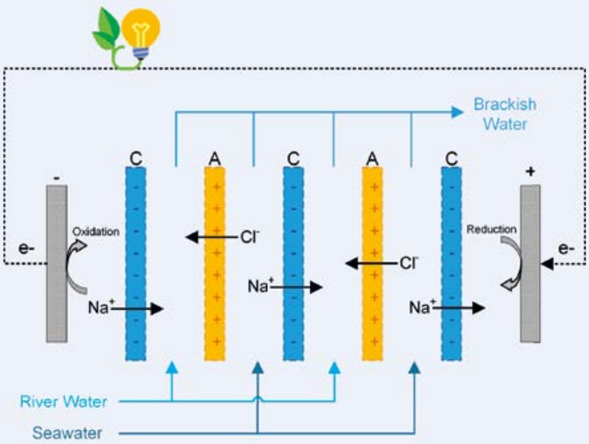

Fig 1. Principle of RED in scheme. The anions and cations selectively cross the anion and cation exchange membranes, respectively. At the electrodes, redox reactions occur which allows the ionic current to be transformed into electrical current.

As a result of Wetsus research, RED has been brought from idea to a pilot scale at the Afsluitdijk, where the IJsselmeer and the Wadden sea meet (Fig 2.). Henceforth studies can be conducted regarding the scale-up and new concepts in real-life conditions.

Fig 2. Full scale RED research facility at the Afsluitdijk, The Netherlands, built in 2014 [1].

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

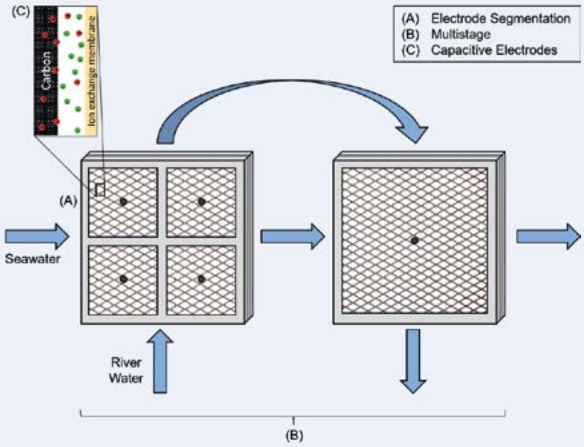

Fig 3. Different concepts to be investigated. (A) Electrode Segmentation. (B) Multistage. (C) Capacitive Electrodes.

Technological challenge

Up to now, most research focusses on a single pass continuous operation of RED stacks. To overcome existing limitations in RED performance and to become economically attractive, new operational concepts will be developed and further investigated (Fig 3.) [2,3].
In addition, current RED stacks use a redox component at the electrode compartments. A system without expensive materials, hazardous chemicals, and possible unwanted by-products, would be both more sustainable and economical. The first direction towards a redox free operation can be the use of capacitive electrodes [4].

Research goals

The aim of this research project is optimizing the RED process performance by developing new operation modes. This includes:
- Investigation of the gradient behaviour within the stack by electrode segmentation and multistage operation.
- Study of capacitive electrodes to achieve a redox free operation.
- Scale-up optimization under real-life conditions.

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[3] D.A. Vermaas et al., ACS Sustain. Chem. Eng. (2013).
[4] D.A. Vermaas et al., Energy Environ. Sci. (2013) 6, 643.

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blue energy

Fouling and Process Design in reverse electrodialysis: a case study with real waters

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Motivation

To include renewable energy in the energy matrix can be a challenge for many societies. Blue energy is a promising energy source that uses the controlled mixing of the salinity gradient between river and sea water to produce energy. Reverse Electrodialysis (RED) is a process that allows to harvest this energy. It uses a series of alternating anion (AEM) and cation (CEM) exchange membranes to direct ions and convert the membrane potential between the anode and cathode of a cell into electrical current, by the means of a redox reaction. This principle is represented in Figure 1.

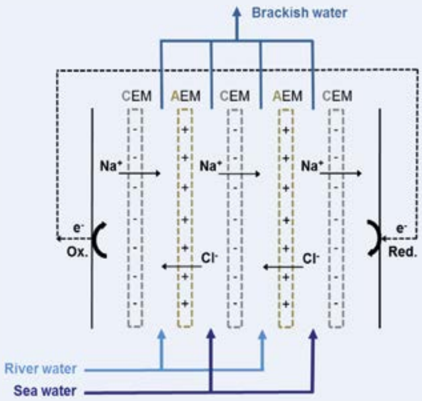

Fig 1. Simplified principle of RED.

The by-product of the process is only brackish water, so it does not generate any harmful substances to the environment. The estimated salinity gradient power available globally is estimated to be between 1.4 and 2.6 TW [1].

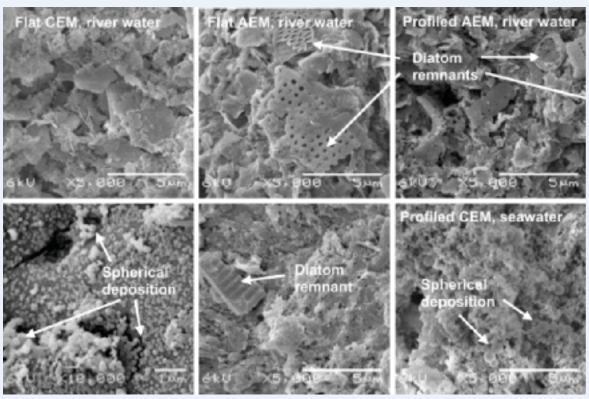

Fig 2. Fouled membranes with river and sea water, different types of AEMs and CEMs. Adapted from [2]

Technological challenge

Fouling of the ion exchange membranes is known as one of the most severe problems within RED applications, since it decreases the overall power output that can be harvested. Fouling can be present in diverse ways, like organic, inorganic, biofouling and scaling. Figure 2 shows different types of fouling.

When performing RED under natural conditions, it is important to better understand how fouling is acting on the membranes, by knowing which fouling components are present and how they interact with membranes surfaces. This can be done by using a so-called fouling monitor, allowing to visualize the evolution of fouling, as seen in Figure 3.

For a successful RED performance it is believed that a feed water pre-treatment is necessary to inhibit fouling and enable a sustainable energy production. Energetically and environmentally reasonable pre-treatment combinations will be studied. It can consist of different types of filters, like fast sand or activated carbon, or innovative treatments, like ecological filters.

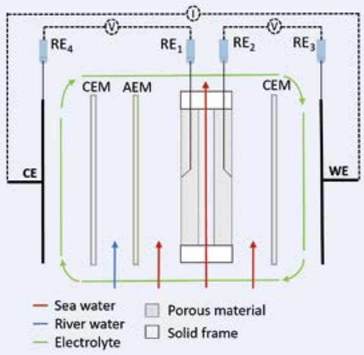

Fig 3. Schematic illustration of fouling monitor. Adapted from [3]

Research goals

The objectives of this project are:

- Identify the effect of individual foulants present in natural waters (river and sea) on RED performance,
- Identify how the foulants interact with different membranes (CEM and AEM) and how this impacts the RED process,
- Propose and test process modifications and new designs, including pre-treatment combinations and membrane cleaning.

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dr. ir. H.V.M. Hamelers, prof. dr. ir. C.J.N. Buisman

Phosphate recovery

Phosphate is an important fertilizer needed for food production. The sources are finite and mining and processing of the ore is an energy intensive and polluting process. Furthermore, sources of phosphate rock in the world are limited to a few countries and Europe is fully dependent on import of this critical resource for its food production. An appreciable part of the phosphate in food ends up in the wastewater and manure and cannot be reused effectively. In addition, the global phosphorus flows lead to accumulation of phosphorus in densely populated regions and regions with intensive livestock farming.
This theme focuses on the development of new technologies for wastewater and manure treatment that not only remove phosphate buts combine this with the recovery of phosphate into concentrated high value products. Such high value products can be transported over large distances in order to make it possible to transform on a global scale the current linear use of phosphate into a true circular use.
Core competence of the research theme is the understanding of interactions of phosphate with iron and calcium in complex organic matrices like sewage sludge and manure. This knowledge is currently used to stimulate recovery of the iron phosphate mineral vivianite from sludge and manure, to remove and recover phosphate from surface water and sewage effluent to ultra-low concentrations using reversible adsorption and to stimulate calcium phosphate agglomeration in manure digestion.

Research projects

- **Thomas Prot**, Delft University of Technology
  Phosphorous recovery from iron phosphate containing sewage sludge
- **Carlo Belloni**, Delft University of Technology
  Improved recovery of phosphate through manipulation of iron phosphate chemistry using Mössbauer spectroscopy
- **Wokke Wijdeveld**
  ViviMag project: magnetic recovery of vivianite from sludge

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Academic partners

TU Delft
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Phosphorus recovery from iron phosphate containing sewage sludge

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Motivation

Phosphorus is an essential nutrient for plant growth, but at the same time the resources of phosphate rock are limited and concentrated in a few countries outside Europe. Linear use of phosphorus also creates environmental problems like eutrophication and wastes. Recovery can help to secure access to phosphorus for food production. Sewage sludge and manure are the most important potential sources for recovery of phosphorus.

Fig.1. Sludge in the aeration basin of a WWTP

Fig.2. Fertilizer is spread on crops

The majority of municipal wastewater treatment plants (WWTP's) use iron salts to co-precipitate iron phosphates. This method of operation is popular as it presents low investment costs and is easier to operate. Incineration is the only available method to recover phosphate from these types of WWTP's.

Unfortunately, this technique presents limitations like the lack of ash treatment facilities and the required investment costs to realize an incineration facility. The objective of this research is to develop a new technology for recovery of phosphorus from these sludges.

Recently it has been found that almost all phosphorus in sludge is present as vivianite, provided that enough iron is present and the sludge is digested. This discovery opened new perspectives for phosphorus recovery from sludge and possibly also for manure. This places vivianite central in this project.

Fig.3. Vivianite crystals from a natural environment

Technological challenge

The presence of vivianite in sludge has been reported in literature but the mechanism of its formation in sludge is unclear and has never been studied. Recent information indicate that the particles are small (max 100µm) and are most likely impure. Therefore the analysis of such small particles in a complex matrix like sludge will be challenging.

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3. P. Wilfert, Unpublished results

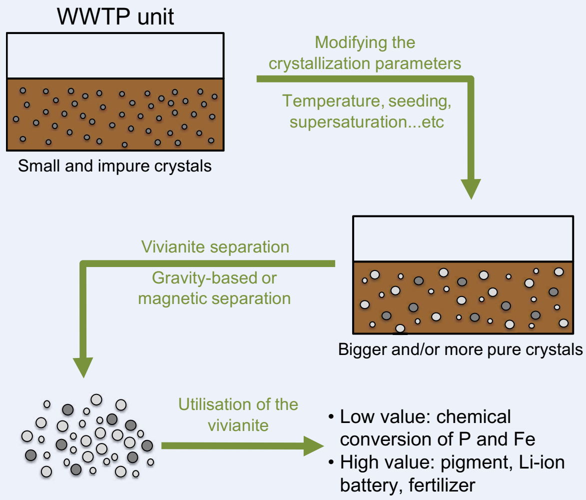

Fig.4. Graphical abstract of the project

Technologies for recovery of struvite ($NH_4MgPO_4{*}6H_2O$) from sludge are already developed (Airprex principle for instance) but are not applicable for the recovery of vivianite since the vivianite particles found in sludge are too small.

However, extraction of vivianite from sewage sludge is, for instance, possible through magnetic separation. The extraction efficiency is currently low but increasing the particles size or the purity of the product may enhance it as well as open new separation opportunities like the use of gravity-based technologies.

Research goals

- Understand the crystallization process of vivianite through the study of rates and mechanisms of the nucleation, growth and agglomeration to increase the purity and size of the vivianite crystals.
- Understand the mechanisms behind the oxidation of vivianite in order to find working conditions preventing vivianite oxidation.
- Propose an efficient and cost-effective method for vivianite separation from the sludge.
- Develop ways to utilize the harvested vivianite taking into account the purity of the recovered product.

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Improved recovery of phosphate through manipulation of iron phosphate chemistry using Mössbauer spectroscopy

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Motivation

Phosphorus (P) is both an essential nutrient for life and a polluting agent. It is involved in vital functions of every living being and it is used in fertilizers. On the other hand, the excess of dissolved phosphate (PO_4^{3-}) in water bodies causes eutrophication and algae bloom. It is generally accepted that P levels below 10 µg/L entail a good ecological status of a water body[1-3]. Moreover, phosphate is also a finite resource, which led the EU to identify it as a critical raw material, demanding for a more circular use of phosphate in the world[4]. Thus, it is very important to remove phosphate from water, as to recover it to allow its reuse.

Compared to the conventional precipitation technique, adsorption is more efficient both in phosphate removal at low concentration and to obtain a purer recovered product. Among all adsorbents, iron oxides represent a low-cost material, which display high affinity to phosphate. However, several iron oxides species exists (Fig. 1), each one displaying different characteristics, both from a structural point of view (oxidation state, degree of crystallinity, etc.) and the chemical point of view (affinity, stability, etc.).

Technological challenge

A further insight into iron oxide structure, as well as adsorption and desorption features, is needed, in order to outline the main parameters affecting the process and to be able to design an ideal, cost-effective adsorbent with higher performances.

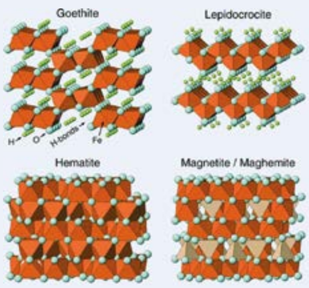

Fig.1 Structure scheme of some different iron oxide species[5].

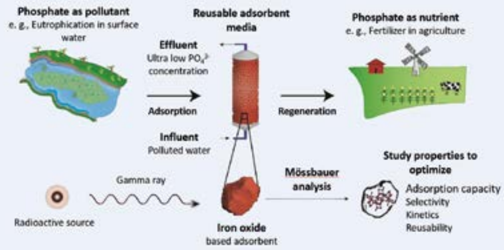

Fig.2 Summary of the project.

The fundamental aspects of the interaction between phosphate and iron oxides will be investigated performing batch and column experiments, involving commercial and synthesized samples. By means of Mössbauer/IR Spectroscopy as an analysis tool (Fig. 2), a better understanding of the binding mechanism, type of adsorbed complexes (Fig. 3), adsorbent affinity, size-effect, structure and its stability during the entire process (involving surface chemistry modification through doping), will be achieved.

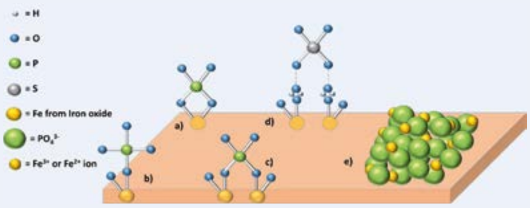

Fig.3 Scheme of the different binding types: a) mononuclear bidentate, b) mononuclear monodentate, c) binuclear bidentate, d) outersphere complex and e) precipitate[6].

Research challenge

In order to be able to design an optimized cost-effective adsorbent for phosphate removal and recovery, the main goals of the research project are:

- to understand the different behavior of the different iron oxide species;
- to understand the binding mechanism and type of complexes;
- to improve the capacity, kinetics and selectivity of the adsorbent;
- to improve the regeneration procedure and the reusability of the adsorbent.

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[5] Cornell, R. M., Schwertmann, U., The Iron Oxides: Structure, Properties, Reactions, Occurrences, And Uses, 2nd ed.; Wiley-VCH: Weinheim, 2003.
[6] Wilfert, P., Kumar, P. S. et al., The Relevance of Phosphorus and Iron Chemistry to the Recovery of Phosphorus from Wastewater: A Review. Environ. Sci. Technol. 2015;

This research received funding from the Netherlands Organization for Scientific Research (NWO) in the framework of the Innovation Fund for Chemistry, and from the Ministry of Economic Affairs and Climate Policy in the framework of the TKI/PPS-Toeslagregeling.

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Protein from water

The theme Protein from Water aims to develop technologies to upgrade nitrogen and other nutrients from wastewater and manure into valuable microbial proteins. By upgrading treatment plants to factories in which the incoming materials are first deconstructed to units such as ammonia, carbon dioxide and clean minerals, one can implement a highly intensive and efficient microbial resynthesis process. In this process the used nutrients are harvested as microbial protein which can be used for animal feed and food purposes. The theme focuses on the technological breakthroughs needed to create sustainable and economical production of microbial proteins and to ensure product safety. High-quality microbial proteins will be produced efficiently at high rate and can be applied as a substitute for proteins in the feed and food chain originating from soy and fish. This concept has the potential to revolutionize the water-energy food nexus. Compared to current food production, less land and less water is needed while off-peak electricity can be used.

Research projects

- **Raquel Barbosa**, Ghent University
  Assembly of synthetic microbial communities for the valorization of recovered nutrients into biomass

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Industrial partners

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Academic partners

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protein from water

Assembly of synthetic microbial communities for the valorization of recovered nutrients into biomass

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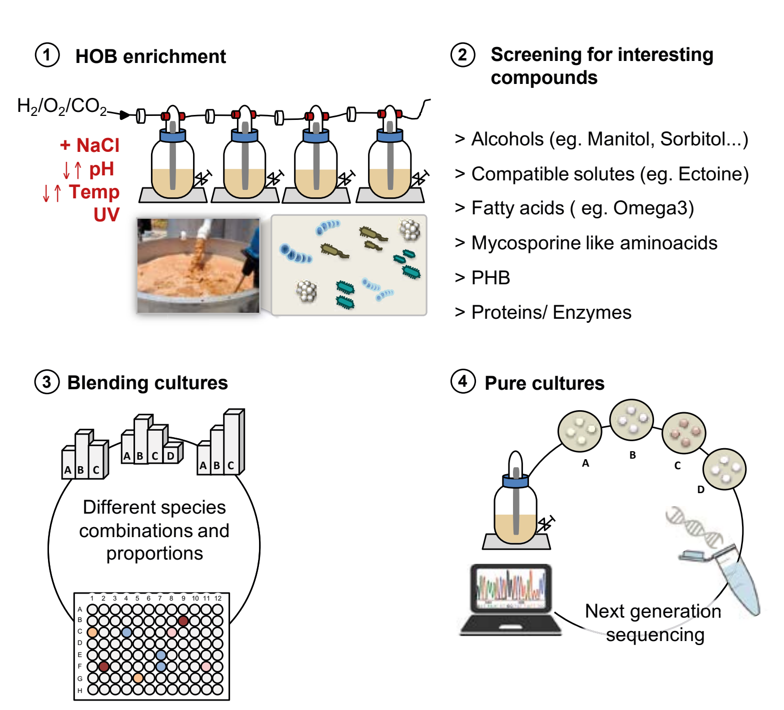
Motivation

The increase in the world population and improving standards of living, together with the continuous urbanization, are rising the pressure on available nutrient resources. In order to help address this issue, domestic wastewater is now being looked at as a resource rather than waste. By upgrading treatment plants to factories in which the incoming materials are first deconstructed into elemental units such as ammonia, carbon dioxide and clean minerals, one can implement a highly intensive and efficient microbial resynthesis process in which the used nutrients are harvested as microbial protein or other interesting compounds.



Research goals

- Compose in vitro synthetic communities consisting of hydrogen oxidizing bacteria (HOB, primary producers) and heterotrophic bacteria (secondary consumers).
- Select the communities towards interesting biotechnological endpoints (2).
- Elucidate the crucial members and interaction mechanisms.

Technological challenge

Within this project, we will use the end products of water electrolysis, hydrogen and oxygen, to upgrade the recovered nutrients into biomass. Initially, isolation will be used to dissect various mixed microbial communities, each of them enriched from different environmental samples (1), into culture collections of heterotrophs and hydrogen oxidizing bacteria (3). Subsequently, different sets of isolates will be assembled and the best performing community will be selected by evaluating its performance (specific metabolite production) in high-throughput essays (4).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

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R.G. Barbosa MSc, dr.ir T.H.J.A Sleutels, prof.dr. Ir W. Verstraete and prof.dr.ir. N. Boon

Resource recovery

Within Wetsus new technology related to the harvesting of energy from waste water is developed. With technologies involving microbial fuel cell and biocatalyzed electrolysis electricity or hydrogen is produced from waste water. Hydrogen production from biocatalyzed electrolysis in this innovative design makes a much wider variety of wastewaters suitable. This is a revolutionary breakthrough technology in the field of biological hydrogen production from waste water. Apart from upgrading waste water into electricity or hydrogen also other energy rich compounds can be produced from waste water. For example, specific bacteria are able to accumulate a high amount of lipids in their cells when they grow in waste water. These lipids are subsequently used to produce bacterial oil.

Research projects

- **Casper Borsje**, Wageningen University
  Capacitive Bioanodes for electricity production in microbial fuel cells
- **Sebastian Canizales Gomez**, Wageningen University
  Phototropic Polypeptide Production from Urine
- **Steffen Georg**, Wageningen University
  Bioelectrochemical Systems for ammonia recovery from wastewater
- **Mariana Rodrigues**, Wageningen University
  Optimization and upscaling of electrochemical ammonia recovery
- **João Pereira**, Wageningen University
  Optimization of BES by unravelling the storing mechanisms of electro-active bacteria
  NEW

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Academic partners

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Capacitive bio-anodes for electricity production in Microbial Fuel Cells

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Motivation

Wastewater treatment is an essential part of the contemporary society and will remain so in the future. The organic material in wastewater can be recovered as electricity with Microbial Fuel Cells (MFCs), while the wastewater is treated simultaneously[1]. The dissolved organic material in wastewater is directly converted to electricity via oxidation by electroactive bacteria growing on the anode: a bioanode (Figure 2, top left). Industrial application of the technology is hampered by clogging, pH gradients and slow, expensive cathodes compared to the anode, limiting scale up and power densities. A new development: the capacitive MFC can in principle solve these challenges[2]. Bacteria grow on the surface of a porous structure and oxidize the organic material. Electrons from the oxidation are stored in the porous structure. A highly porous structure has high internal surface area, which allows for a high capacitance. The combination forms a capacitive bioanode, shown in Figure 1 as a porous activated carbon granule. The electricity is produced by discharging the capacitance.

Technological challenge

The capacitance allows decoupling of the wastewater treatment and the electricity production, which allows both steps to be optimized separately. In the larger anode volume, the bioanode granules, which provide high capacitance and growth surface per volume of reactor, are charged. The charged granules move to a smaller discharge cell, where the electricity is produced, which reduces the costs per volume. See Figure 1 for a schematic representation.

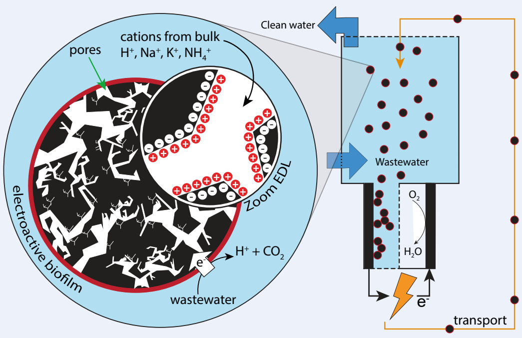

Fig 1. Schematic overview of a capacitive granule MFC, where the wastewater treatment and electricity production steps are separated. The zoom to the granule shows the capacitive charging process via oxidation on the bioanode electroactive bacteria and charge storage at the pore surface in the electric double layer.

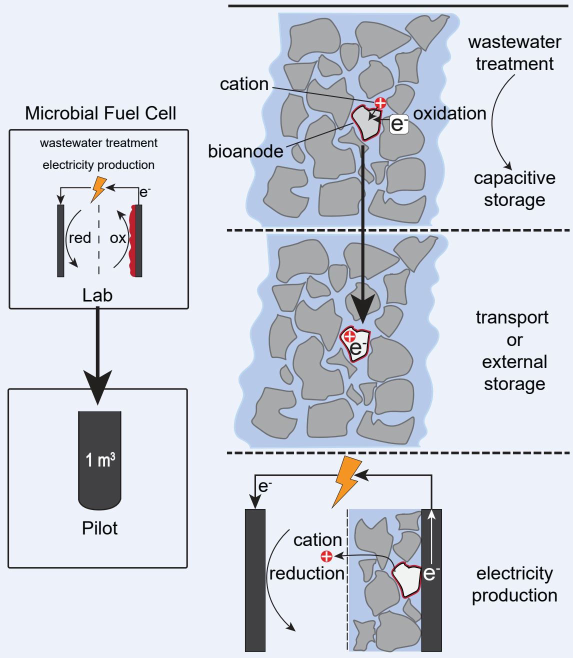

Fig 2. Graphical abstract, showing the goal to pilot scale (left) and the capacitive bio-anode process (right).

Research goals

The aim this research project is to develop the capacitive bioanode Microbial Fuel Cell concept towards application, by:

- Studying optimization of the discharge characteristics of granular (bio)anodes (discharge cell, capacitive materials and interaction of biofilm with material)
- Designing a moving bed reactor
- Optimization of operational parameters
- Pilot scale application with real wastewater.

[1] Logan, Environ Sci Technol (2006) 5181-5192.
[2] Deeke, Environ Sci Technol (2015) 1929-1935.

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WAGENINGEN UNIVERSITY & RESEARCH

Phototrophic Polypeptide Production from Urine

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Motivation

Human urine is rich in nutrients, containing up to 70% of the nitrogen and 40% of the phosphorous that end up in household wastewater. Therefore, urine is a potential medium for cyanobacteria cultivation. Most of the species of cyanobacteria under certain stress conditions produce a nitrogen (N) storage material called Cyanophycin Granule Polypeptide (CGP). In this perspective urine can be treated while producing CGP as a valuable product with potential applications as dispersant and in the bioplastics industry. Additionally phycobiliproteins and other compounds can be recovered as by-products.

Technological challenge

In other studies it has already been demonstrated that cyanobacteria can grow on diluted urine (Dao-lun and Zu-cheng, 2005). Microalgae have even been shown to grow in undiluted urine when employing high light supply rates and short light path photobioreactors (Tuantet et al., 2014).

Several challenges will have to be overcome such as high concentrations of ammonium nitrogen in urine (up to 8.1 g $N \cdot L^{-1}$), which can inhibit growth of cyanobacteria; and light limitation, which has to be minimized in order to reach high densities of biomass for significant process efficiencies.

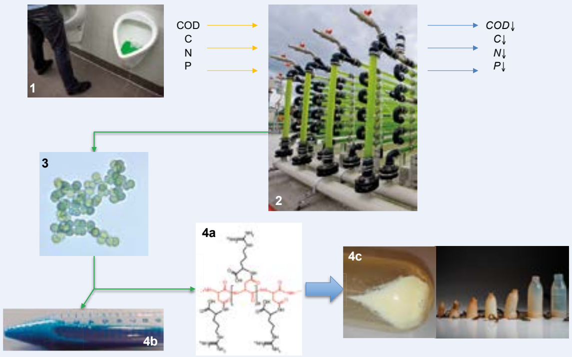

Figure 1. Steps of the process: source separated urine is collected (1) and treated by cyanobateria in photobioreactors (2), the cyanobacteria biomass is harvested (3) and fractionated by extracting CGP (4a, c) and phycobiliproteins (4b).

Cyanophycin is soluble at pH<3 and >9 and can be extracted form commercially available Spirulina. The product obtained is shown in figure 2.

Figure 2. CGP after extraction. Left: After centrifugation, Center: Lyophilized, Right: After 24 h at 105ºC.

During the CGP extraction process phycobiliproteins remain in the water soluble fraction while CGP precipitates after the neutralization step.

Figure 3. Phycobiliproteins in supernatant during the CGP extraction process.

Research goals

The aim of this project is to grow cyanobacteria on urine and in this manner combine urine treatment with recovery of valuable products. In this way, the biomass can be fractionated in high value products focusing on CGP to be used as dispersant and in the bio-plastics industry and phycobiliproteins as by product to be used as natural dyes (figure 1).

In the next steps of this project it will be assessed if also cyanobacteria can be grown on minimally diluted urine while accumulating CGP. In addition, the natural diversity of cyanobacteria will be further explored in order to find strains with metabolic advantages for CGP accumulation. Specific process conditions will be tested for their effect on cyanobacterial growth and CGP accumulation and optimized for high productivity by means of a mathematical model. The high N:P ratio of urine, for example, is expected to have an effect on CGP accumulation.

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- Feng, D.L., & Wu, Z.C. (2006). *Journal of Zhejiang University. Science. B, 7*(1), 34–37.
- Tuantet, K., Janssen, M., Temmink, H., Zeeman, G., Wijffels, R. H., & Buisman, C. J. N. (2014). *Journal of Applied Phycology, 26*, 287–297.

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Bioelectrochemical Systems for Ammonia Recovery from Wastewater

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Motivation

An increasing world population and rising nutrient demand will require higher agricultural output and therefore more fertilizer to sustain humanity. At the same time, nutrients in wastewater need to be removed to protect waterbodies from eutrophication. Therefore nutrient recovery from wastewater streams is important to create a sustainable future. Bioelectrochemical Systems (BES) can convert biodegradable organic compounds in waste streams into electricity (Figure 1). This electrical current can be used to recover total ammonia nitrogen (TAN) as resource (i.e. fertilizer), combining both needs in an elegant and energy efficient solution. [1]

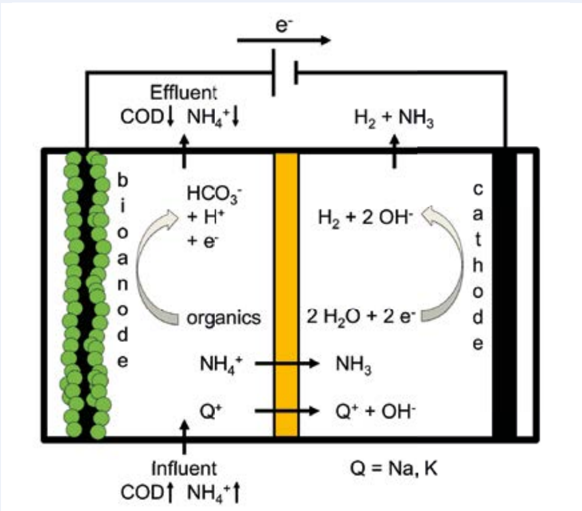

Figure 2: Ammonia separation with a microbial electrolysis cell as BES. Credits: M. Rodríguez Arredondo.

Research goals and challenges

Current research recovers TAN from human urine (Figure 3). Since urine collection is not widely performed, new waste streams were identified by literature review to broaden the TAN recovery application. These potentially suitable wastewater streams will be screened with small-BESs and degradation assays. The most promising wastewaters will be tested in lab-scale BES reactors to identify limiting factors as well as best reactor designs and operating conditions. Resulting insights will be used to design, build and run an up-scaled BES to recover ammonium as resource from the most suitable wastewater stream and clean the effluent from organic compounds at the same time.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

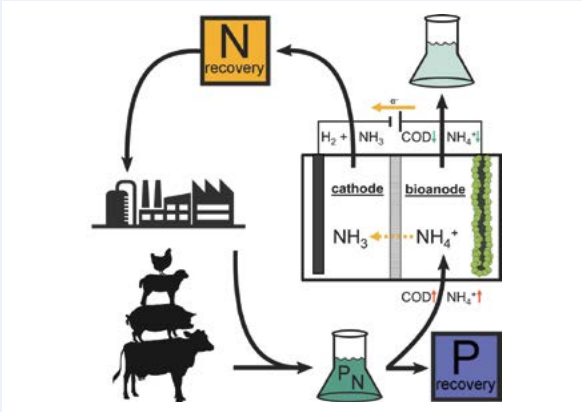

Figure 1: Envisioned phosphorus and nitrogen recovery from industrial and agricultural wastewaters. BESs are used as ammonia separation and organics removal technology. This helps to create a resource cycle, less polluted water and hence a more sustainable world.

Technological approach

Organic compounds in wastewater are degraded and ammonium (NH_4^+) recovered by combining a BES with a membrane distillation unit (Trans Membrane ChemiSorption, TMCS). Microbes growing on the anode of the BES convert organic compounds into electricity (Figure 2). The electric current is used to drive NH_4^+ across a membrane to the cathode. There, H_2 and OH^- are produced by water reduction and the ionic NH_4^+ is deprotonated under these alkaline conditions into gaseous ammonia (NH_3). This NH_3 is extracted from the cathode via the TMCS, where it diffuses through a gas permeable membrane into an acid solution. This converts NH_3 back into NH_4^+ and hence a solubilized, ready-to-use resource.

Figure 3: Bio-electrochemical ammonium recovery setup with microbial electrolysis cells (1), trans membrane chemisorption units (2) and acidic ammonium recovery solutions (3) . [2]

[1] M. Qin, Y. Liu, S. Luo, R. Qiao, Z. He (2017) Integrated experimental and modeling evaluation of energy consumption for ammonia recovery in bioelectrochemical systems; doi: 10.1016/j.cej.2017.06.182
[2] M. Rodríguez Arredondo, P. Kuntke, A. ter Heijne, H.V.M. Hamelers, C.J.N. Buisman (2017) Load ratio determines the ammonia recovery and energy input of an electrochemical system; doi: 10.1016/j.watres.2016.12.051

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Optimization and upscaling of electrochemical ammonia recovery

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Motivation

The intensive use of fertilizers in EU regions is degrading sensitive water bodies. When these nutrients make their way into rivers, they considerably disturb aquatic ecosystems. Recycling the reactive nitrogen could reduce the energy needed to both produce fertilizers and dispose of nutrients, cutting greenhouse gas emissions on both ends of their production chain.

Electrochemical systems (ES) can be the new solution for this nitrogen issue, as they are capable to both remove and recover nitrogen. Earlier results using ES to treat urine showed an effluent with a lowered TAN (total ammonia nitrogen) concentration and a product with potential use as a fertilizer (ammonium sulphate).

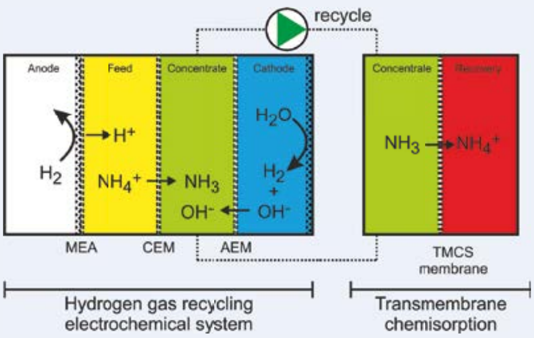

Fig 1. Scheme of the up-scaled electrochemical system for TAN recovery.[1]

Technological challenge

This project aims to improve and **scale-up** an electrochemical system for TAN recovery using different **real wastewater streams** (source separated urine, digester effluent, etc.) in a **multiple stacked** cell system.

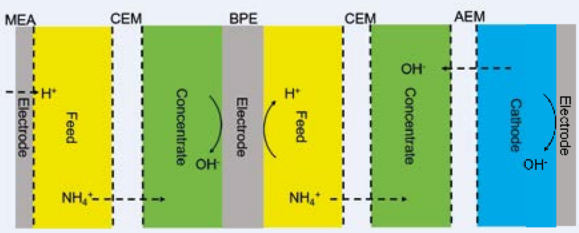

Fig 2. Principle of operation of an up-scaled electrochemical system using a bipolar configuration (BPE – Bipolar eletrode) for TAN recovery.

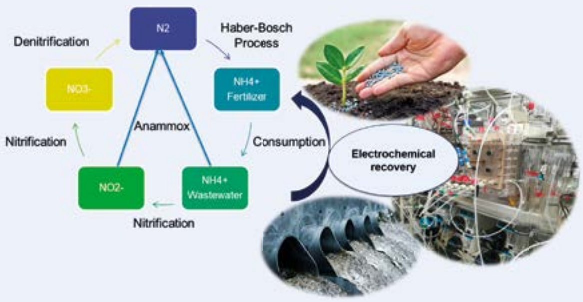

Fig 3. Electrochemical recovery, a new alternative in the Nitrogen cycle.

Research goals

The process will be optimized to a simple and compact system, capable to treat a significant volume of influent and to achieve high TAN recovery at low energy input. We propose the following work packages:

- Demonstrate a novel technique to extract ammonium.
- Study the Donnan dialysis effect on the performance of the system.
- Up-scale an ES by integrating multiple cell pairs with a bipolar configuration (Figure 2).
- Investigate wastewaters with different N concentration
- Mathematical modelling of the ammonia recovery system.

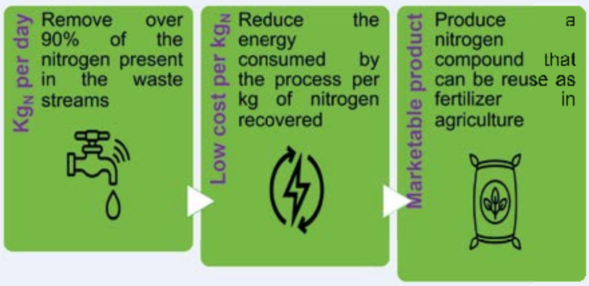

Fig 4. New Challenges for ES.

[1] P. Kuntke et. al, Journal ACS Sustainable Chemistry & Engineering (2018) 7638-7644.

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Optimization of BES by unravelling the storing mechanisms of electro-active bacteria

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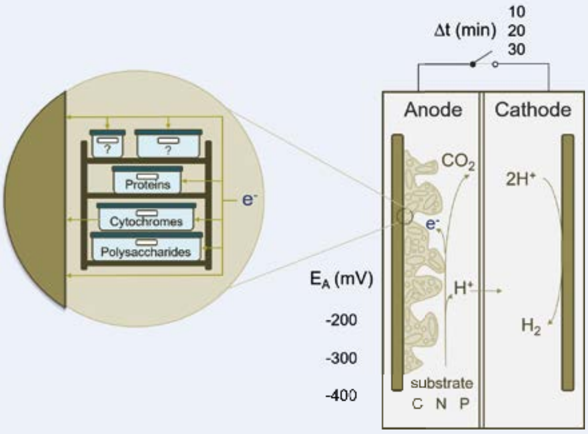
Motivation

Bio-electrochemical systems (BESs) have been referred as a new technology for chemicals productions, bioremediation and power generation [1]. The role of electro-active microorganisms in these systems is crucial [2-3]. However, their performance in terms of current output is not competitive for practical application. Recently, higher currents have been reported for electro-active bacteria (EAB) controlled under intermittent polarization. Using this regime, biofilm morphology also differed from the structure typically observed under continuous polarization. However, the underlying mechanisms are still to be unraveled. In this project we propose the study of charge storage capabilities of electro-active bacteria by integrating several techniques to understand biofilm growth kinetics and biochemical composition. These results will provide valuable information to control and optimize biofilms performances in BES.



Technological challenge

The main challenge will be the integration of different quantification and characterization methods to assess the biofilm development on the anode. Due to the limited number of in-situ techniques available to track biofilm growth kinetics and chemical composition, the integration of several optical and electrochemical approaches is essential to a better understanding of biofilm behavior and a more detailed biofilm analysis (Figure 1). By studying the effect of operational conditions on the biofilm development, a final inherent challenge will be the creation of knowledge to control biofilm growth kinetics towards better performances in BES.

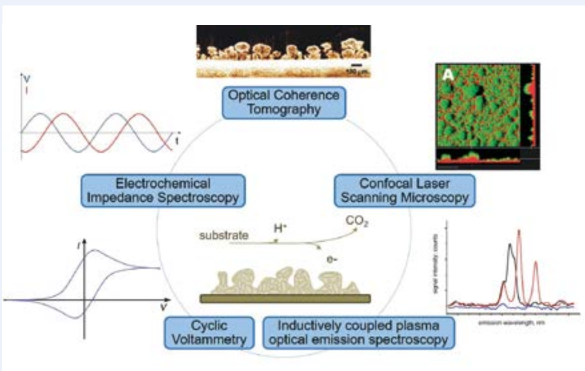


Fig 1. Examples of techniques to evaluate biofilm growth in BES: optical techniques (Optical Coherence Tomography and Confocal Laser Scanning Microscopy), electro-chemical analysis (Electrochemical Impedance Spectroscopy, Cyclic Voltammetry) and chemical methods (Inductively Coupled Plasma Optical Emission Spectroscopy)

Research goals

With the outcomes of this research we will be able to explain and establish the causality between biofilm development and intermittent polarization, unravelling the fate of electrons and formulating a more accurate electron balance in BES. The following topics will be considered:

1. Comparison of the effect of continuous and intermittent potential in electro-active biofilms growth dynamics;
2. Evaluation of electron storage mechanisms as function of intermittent/continuous polarization;
3. Starving and stress conditions effect in biofilm structure and composition;
4. Integration of visualization methods for more detailed in-situ analysis of biofilm development.

[1] Borole, Energy & Environmental Science, 4(12), 2015, 4813-4834
[2] Erable, Biofouling, 26(1), 2010, 57-71
[3] Deeke, Journal of Power Sources, 243,2013, 611-616

Aknowledgements
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Soil

Soil is as essential to human well-being as air and water. It is a key component of many ecological processes and assures the provisioning of ecosystem services such as food production, water depuration, carbon storage, crop resistance to pests and diseases.
Soil organic matter/humus affects the biological, chemical and physical properties of the soil and therefore, plays a central role in maintain soil functionality and productivity. Especially, organic matter, contributes to prevent soil erosion and land flooding and can play a role in climate mitigation. Therefore, the steady decline of organic matter in many European soils is one of the biggest environmental threats.
The use of organic residues from different sources as soil amendment represent an opportunity to increase organic matter in the soil and strength re-use of resources.
Treatment of organic residues (e.g. composting, anaerobic digestion and fermentation) prior to land application is widely used to improve soil fertility. However, a complete understanding of the short and long term effects of these treatments on soil organic matter is still lacking.
The soil theme investigates the effect of organic residues on soil organic matter with the aim to promote the reuse of organic residues, strengthening circular economy and increase soil fertility. Relying on the gained insight, the Soil Theme will investigate how to integrate knowledge and expertise of Wetsus on water treatment technology to find most suitable form of organic matter addition for agricultural application.

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Research projects

- **Yujia Luo**, Wageningen University
  Improving Agricultural Soils by Organic Residues
- **Chris Schott**, Wageningen University
  Recovery of phosphorus from animal manure
- **Vania Chavez Rico**, Wageningen University
  Organic residues engineering to increase organic matter in agricultural soils

Industrial partners

AGRITON
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Mulder Agro
Koninklijke oosterhof holman
Waterschap Zuiderzeeland – uw waterschap

Academic partners

Nederlands Instituut voor Ecologie (NIOO-KNAW)
Wageningen University & Research

Improving Agricultural Soils by Organic Residues

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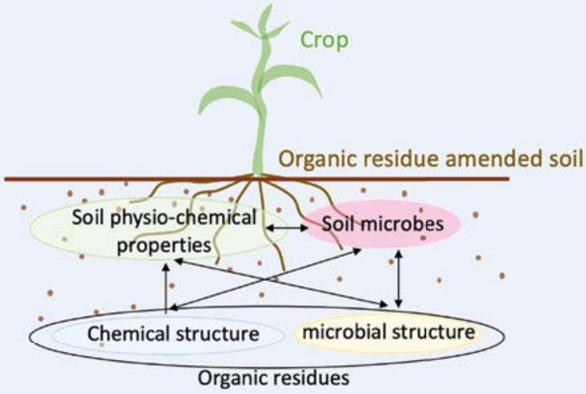
Motivation

It is general accepted that organic residues like compost and digestate have great potential to improve physical, chemical and biological status of soil. Different treatments for instance composting and digestion of organic waste will result in organic residues with different chemical and microbial compositions. Here, chemical composition means chemical structure of humic-like substances in organic residues; microbial composition means microbial activity, abundance and diversity.

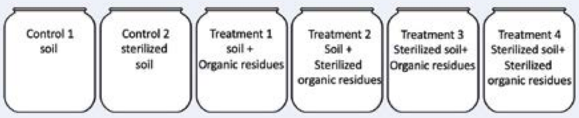
The effect of organic residues with different chemical [1,2] and microbial compositions [3] on soil matrix is very complex and surrounded by riddles, especially the relationship with soil microbial characteristics and crop growth. In this project, environmental technology specialists and soil ecologists are going to cooperate and shed light on this complex context.



Above- and below-ground interactions in organic residue amended soil

Technological challenges

- Processes involved in the soil matrix are complex and always inter-related;
- Relate intrinsic properties of organic residues to their effects on soil microbial characteristics;
- Identify/isolate/enrich specific groups of crop beneficial or detrimental soil microorganisms;
- Relate the changes in soil characteristic to crop growth, and study the mechanisms



Soil incubation experiments with addition of different organic residues in glass jars. Pot experiments will also be conducted afterwards

Research goals

Our hypothesis is that the influence on soils and crop growth depends on chemical and microbial composition of organic residues rather than their C, N, and P concentrations alone.

Our investigation intends to answer the following questions:

1. What is the relationship between the molecular C composition of added organic residues and soil microbial community composition?
2. How do organic residue associated microbial communities influence soil microbial community composition?
3. How do organic residue induced changes in soil microbial communities affect crop growth? And through what mechanisms?
4. Can we select organic residues to promote or reduce specific groups of crop beneficial or detrimental soil microorganisms?

Reference:
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Recovery of phosphorus from animal manure

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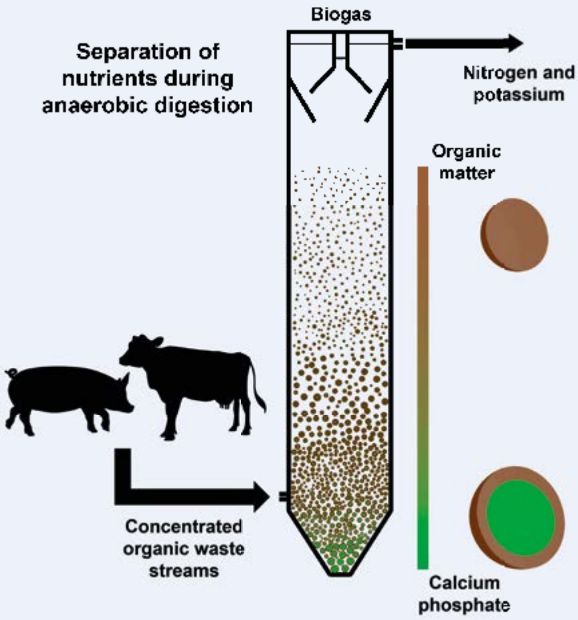
Motivation

Phosphorus (P) is essential for life on earth due to its various functions in growth and energy mechanisms of fauna and flora. However, the natural reserves of P are diminishing in quality and quantity. To ensure future food security, P needs to be recovered from waste streams [1].

In The Netherlands, 71 million kg of P are annually generated mainly as cattle and pig manure. To prevent run off and consequent eutrophication, the agricultural applicability of animal manure is limited. Therefore, its surplus is incinerated or transported at high economic and environmental costs to other countries [2,3].

This project aims to design a sustainable biotechnological process which enables the recovery of phosphorus as concentrated calcium phosphate granules (Figure 1) from thin manure. The separation of nutrients allows more nutrient specific and predictable crop fertilization than spreading raw animal manure. This approach increases the value of animal manure and stimulates circular agriculture.



Technological challenge

In animal manure, P is barely abundant as soluble PO_4^{3-} and the concentration of solids and organic matter is high. Therefore, calcium phosphate granulation is not occurring by simply adding calcium as previously demonstrated for black water treatment [4].

Releasing P into solution requires an understanding of how P occurs in animal manure. The phase in which P is present in cow and pig manure as well as various pre treatments to release P into solution will be investigated so that in the main reactor calcium phosphate may granulate.

After enabling calcium phosphate granulation, the collection from the reactor requires optimization. The recovered products need to be suitable for direct use in agriculture or for processing in the fertilizer industry.

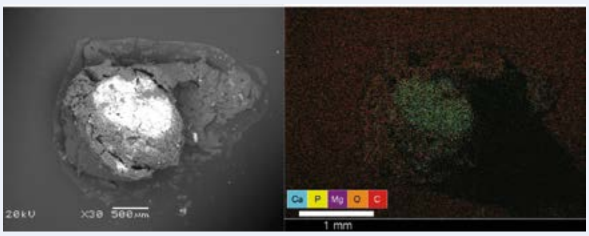


Fig 1. Scanning electron microscope (SEM, left) and electron dispersive x-ray (EDX, right) image of a calcium phosphate granule with an inorganic core consisting of calcium phosphate (EDX green) [4].

Research goals

- Characterizing cow and pig manure and specifically the P speciation
- Stimulating calcium phosphate granulation by increasing the ionic activity of PO_4^{3-}
- Optimizing bioreactor design for recovery of calcium phosphate granules
- Characterizing the products based on their composition, fertilizing performance and applicability

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Organic residues engineering to increase organic matter in agricultural soils

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Motivation

In the European Union, 970 Tg of soil is lost annually [1]. Despite the policy interventions, such as the "Common Agricultural Policy" and "Soil Thematic Strategy", soil erosion rates are 1.4 higher than soil formation rates [1, 2]. One of the most important driving factors of soil erosion is organic matter decline [3]. Ironically, only about one third of the total bio-waste is used to replenish the organic carbon losses [3]. By using organic residues engineering, we could use these residues to produce organic amendments (OA) to improve specific soil functions according the requirements of each specific case.

Technological challenge

Most of OA research and production has been done using an empirical/experimental point of view. The research focused on chemical composition by studying transitional pools and their stability, liability among other chemical characteristics. New insights on OA engineering are required to increase its efficacy, efficiency and effectivity. For example, assessing the fate of OA organic matter in soils will most likely enable the identification of key organic compounds that affect soil properties. OA composition might be modulated considering ecological stoichiometry principles to influence soil microbial activity. In this way, we may induce specific pathways of organic matter formation thereby increasing soil organic matter and associated soil properties.

The main technological challenges will be to:

1. Assess the influence of engineered OAs on soil properties.
2. Identify potential improvements for the design of OAs.
3. Modify operational parameters or/and system configurations to produce the designed OAs.
4. Identify strategies that involve engineered OAs to steer specific groups of microorganisms. This will be done by applying ecological stoichiometry principles towards the production of compounds leading to stable organic matter formation.

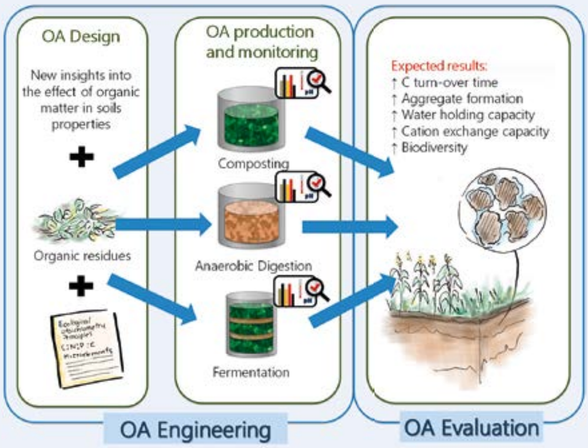

Fig.1 Research graphical abstract. Changes in engineered organic amendments (OAs) will be evaluated by monitoring specific soil properties.

Research goals

The research (Fig 1) will focus on engineering of OAs to increase the formation of stable soil organic matter improving associated soil functions. The OAs will be produced by using three technologies i.e. composting, fermentation and digestion. Specific objectives of this project are:

- Study how different technologies affect the physicochemical characteristics of the OAs.
- Study the relationship between physicochemical characteristics of OAs and its effect on specific soil properties and carbon pools.
- Identify key physicochemical characteristics of OAs that influence conversion of organic matter pools and its relation to soil properties.

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Sustainable carbon cycle

Advanced electrochemical methods to capture renewable CO_2 and recover energy from flue gas

Interest in Carbon Capture and Utilization (CCU) has been growing recently, i.e. the development of technologies to remove CO_2 from flue gas and from the atmosphere, and use the captured CO_2 as a working fluid, or as a source of carbon.
The development of such technologies should be based on sustainability criteria, i.e. creating low-energy solutions that will benefit the environment, the society, and the economy. To reach this target, further research is needed to develop novel CCU technologies.
At Wetsus, the Sustainable carbon cycle (SCC) theme aims to develop energy-efficient technologies to capture CO_2 from the atmosphere and from renewable sources, and convert the captured CO_2 into valuable chemicals. Our research focuses on electrochemical methods based on new electrode materials, ion exchange membranes, and new reactor design. The SCC theme builds on the long research experience at Wetsus in the field of applied electrochemistry for salinity gradients, capacitive deionization (CDI), and energy recovery from flue gas (CO_2 energy).
Together with industrial and academic partners, our final goal is to boost the sustainable development of carbon capture and conversion, by combining clean electrochemistry, low-cost capture technologies, and production of chemicals.

Research projects

- **Louis Legrand**, Wageningen University
  Reactive Gas Electrosorption (RGE): Electricity production/CO_2 capture
- **Qingdian Shu**, Wageningen University
  Novel methods for electrochemical capture and conversion of CO_2

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Industrial partners

alliander

Academic partners

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for sustainable water technology

Reactive Gas Electrosorption (RGE): Electricity production/ CO_2 capture

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Motivation

With the continuous increase of CO_2 concentration in the atmosphere and the growing need of energy, the generation of clean energy is vital. In 2013, Hamelers et al. introduce a new technology capable of generating electricity from the mixing of CO_2 emissions and air in a capacitive cell[1] (figure 1). This technology has been named Reactive Gas Electrosorption (RGE).

Process

In RGE, a capacitive cell is composed of :

- Activated carbon electrodes (AC electrodes), which can stored ions and generate a flow of electrons
- Ions exchange membrane (IEM), which can generate a potential in contact with different ions concentration
- An electrolyte, needed to dissolve the CO_2 into ions. The ions concentrations depend then on the CO_2 gas pressure.

The RGE capacitive cell can be operated in two different modes.

Operated as a CAPMIX (capacitive mixing) process[2], the capacitive cell can generate an electrical current based on the mixing process between an exhaust gas from power plant (10-20% CO_2) and an air stream (0.04% CO_2) dissolved into an electrolyte. By harvesting energy from CO_2 emissions, the RGE technology could potentially increase the thermal power plant efficiency by 5%. In other words, more energy could be produced from power plants without consuming more fuel and emitting any extra exhaust gas.

Operated as a CDI (capacitive deionization) process[3], an external energy supply can drive the absorption/desorption of ions to/from the AC electrodes. Since the electrolyte ions concentrations influence the CO_2 dissolution, the charging/discharging of the capacitive cell can either capture or concentrate a CO_2 gas stream.

Technological challenge

The Reactive Gas electrosorption is a young concept. Moreover capacitve cell were first designed mainly for different purposes. Thus, the main objective is to get scientific insight of the RGE process and develop new designs specific for CO_2-electrolyte. The main priority is to develop a capacitive cell, capable of harvesting energy directly from a CO_2 gas.

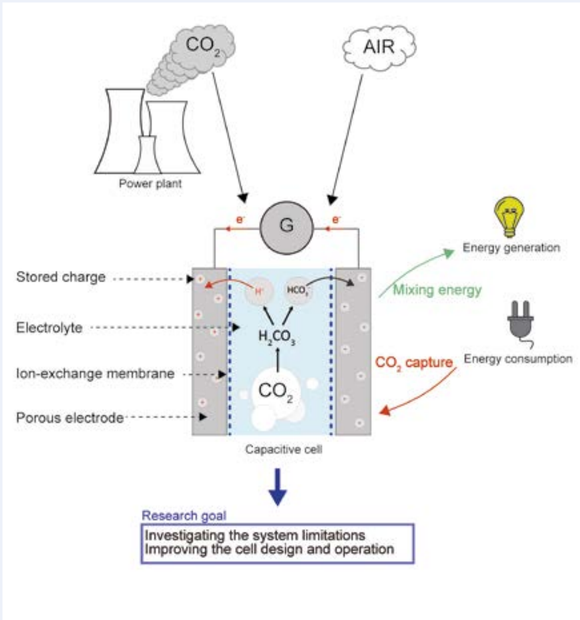

Figure 1. Graphical abstract of the project

Research objective

- Investigation of the major energy losses in the system
- Design of a direct gas capacitive cell
- Development of materials

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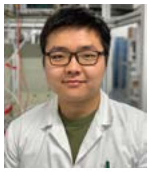
Novel methods for electrochemical capture and conversion of CO_2



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Motivation

Global warming is one of the most critical global challenges. Increasing atmospheric CO_2 concentration brought by anthropogenic emission is the major reason for this climate change problem. Capturing CO_2 from emission points and even directly from air provides a feasible solution to mitigate the amount of CO_2 emission and reduce the atmospheric CO_2 concentration. At Wetsus, under the theme Sustainable Carbon Cycle, we aim to develop novel CO_2 capture technologies that could be potentially energy efficient and environmentally benign[1].

Technological challenge

CO_2 can be captured by alkaline aqueous sorbent due to the high solubility of CO_2 under high pH. However, the conventional regeneration of the sorbent by calcination consumes a large amount of energy. Therefore, we aim to develop an alternative process for regenerating the alkaline solution in wet scrubbing process for direct air capture (DAC) application.

This alternative process is designed to create a pH-swing of the solution. We have noticed that the solubility of CO_2 in aqueous solvent is dependent on the pH of the solution (Figure 1). Thus, CO_2 can be desorbed at low pH and the sorbent can be regenerated at high pH. The configuration of the system is shown in Figure 2.

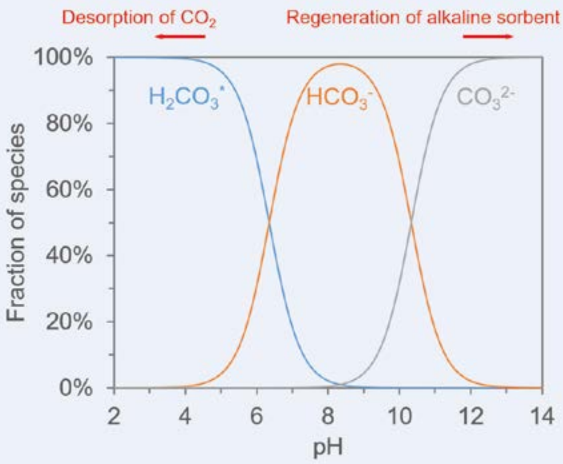

Fig 1. The fractions of different aqueous carbon species at different pH.

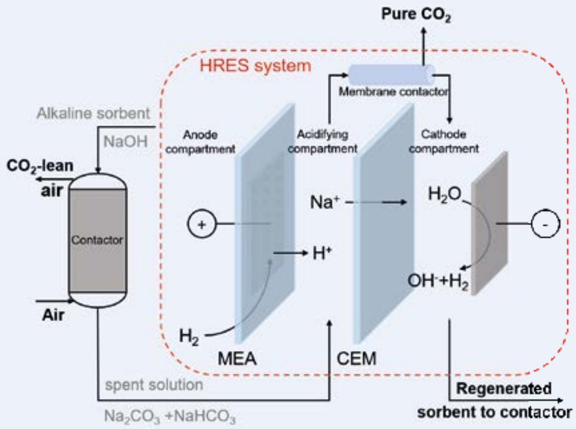

Fig 2. Principle of DAC process using a H_2-recycling electrochemical system (HRES) for CO_2 desorption and regeneration of alkaline sorbent.

The process is based on a H_2-recycling electrochemical system (HRES) which was originally developed for nitrogen recovery from wastewater[2]. Alkaline and acidic conditions are created in two adjacent compartments respectively in HRES, so simultaneous desorption of CO_2 and regeneration of alkaline sorbent could be achieved after the spent solution flows through the electrochemical cell[3].

Research goals

- Developing a novel electrochemical system for CO_2 capture based on the scheme shown in Figure 2
- Investigating the CO_2 capture performance and energy consumption of the system under different conditions
- Studying the performance of the system with different sorbents
- Developing a mathematical model of the system describing the kinetics and transport of different components
- Scaling-up study by integrating pairs of bipolar membranes in the electrochemical cell

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Genomics based water quality monitoring

According to the Dutch Water Act, water companies are required to measure a wide variety of chemical parameters in drinking water (>200) while the number of microbiological parameters required is very limited (<10). Microbiological examination of drinking water is primarily based on classical culturing methods. Over the years this has resulted in extensive knowledge about the presence of possible microbiological threats to public health and knowledge of the microbiological processes during the production of drinking water and transport. However, the application of direct cell counts (microscopic and flow cytometry) has shown that the culturable microorganisms in water are only presenting a fraction of the total microbial population (<1%) and that most of the cells seem to be active. Drinking water sources, treatment and distribution have an enormous impact on the (micro) biological composition/quality of the drinking water produced and distributed. The main question is whether it is possible to predict and control the changes in biological quality and stability of drinking water caused by changes in drinking water processes. Within this theme, the focus will be on generating fingerprints (sometimes called barcoding or barcodes) of the complete microbial population present in (drinking) water based on Next Generation Sequencing (NGS). With this the effect of disturbances on the fingerprint can be examined and indicator organisms/markers can be characterized. The final aim is to develop applications for a precise (online) monitoring/control of water quality and water treatment processes.

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Research projects

- **Fabian Ruhnau**, University of Groningen
  Drinking water quality assessment using Next-Generation Sequencing of bacterial DNA and RNA
- **Antoine Karengera**, Wageningen University
  Developing a HyGenChip for detection of genotoxic potency of hydrophilic contaminants
- **Alicia Borneman**, University of Groningen
  Monitoring chemical and microbial water quality by transcriptome analysis of single-cells **NEW**

Industrial partners

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Academic partners

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Drinking water quality assessment using Next-Generation Sequencing of bacterial DNA and RNA

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Motivation

Water source, treatment scheme and distribution are three factors that influence the water microbial community and their metabolic activities[1,2]. After producing drinking water at the treatment plant, the microbial community is influenced by the materials of the distribution system, residence time, temperature shifts, flow pattern variations, pressure changes and presence of chemical compounds.
Next-Generation Sequencing (NGS) techniques can be employed to gain insights into the microbial community composition of a water sample as well as the respective metabolic activity. This provides detailed information in a short time. Information obtained can be the deoxyribonucleic acid (DNA) or the ribonucleic acid (RNA) content of organisms present. DNA sequences enable characterization of the microbial population as well as the metabolic potential. RNA sequences give information on the metabolic state of the microbial community.
In this project we will investigate whether the microbial drinking water population, determined using NGS technology, can be used to infer chemical water quality (Fig.1).

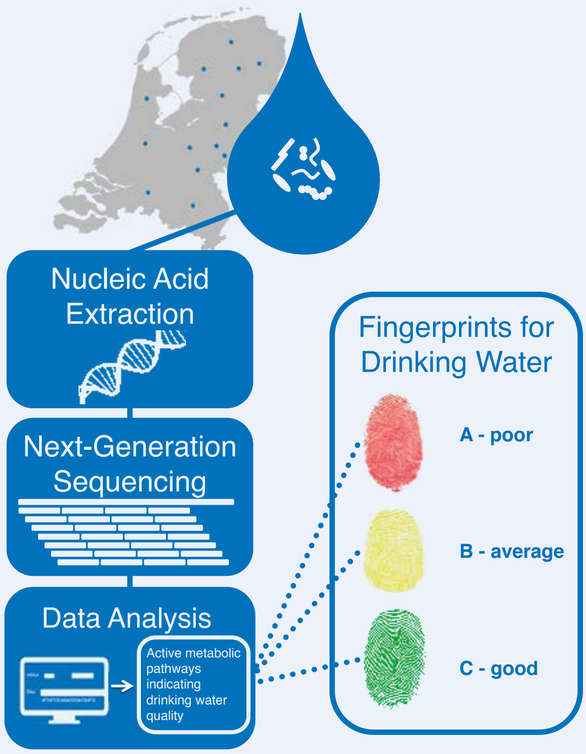

Fig.1 Top left: Map of the Netherlands and potential water source sampling points (blue dots). Samples are represented by the droplet. The analysis workflow on samples consists of nucleic acid extraction, NGS and data analysis. Data analysis results lead to characteristic fingerprints that can indicate (A) poor, (B) average or (C) good microbial and chemical water quality.

Technological challenge

To use the microbial community as a water quality indicator, the initial challenge will be to integrate DNA and RNA data sets in order to understand the metabolic potential and the actual activity of the existing microbial population. Correlating these results in a meaningful way to chemical water quality will be the most important step in the analysis. The final task is to identify key microbial response patterns that can be reliably identified as “fingerprints” describing microbial and chemical drinking water quality.
Analyses of NGS data will be performed using existing bioinformatics tools and statistical methods. The tools will be extended and optimized in order to handle these large NGS data sets in a short time. New software tools predicting the presence of xenobiotics, toxic compounds or critical metabolic by-products in water will be developed.

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[2] Pinto, A. J. et al., Environmental Science & Technology (2012) Bacterial community structure in the drinking water microbiome is governed by filtration processes.

Research goals

- Detect changes in microbial communities and their metabolic activities using NGS technology throughout the drinking water distribution system over time.
- Record comprehensive data sets (from source to tap) that enable to correlate distribution system parameters (e.g. temperature, materials etc.) in relation to chemical (e.g. xenobiotics) and microbiological water quality.
- Identify “fingerprints”, in other words: characteristic genomic and transcriptomic signatures, which can be used to quickly obtain information about water quality.

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university of groningen

genomics based water quality monitoring

Developing a HyGenChip for detection of the genotoxic potency of hydrophilic contaminants

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Motivation

Knowledge gaps related to hydrophilic chemicals in groundwater and surface water are a critical challenge in the management of water quality [1,2]. Currently, there is no existing proper method to concentrate and chemically analyze low concentrations of water soluble pollutants. Most of these contaminants remain unseen, unmeasured, and largely unknown. Despite their low concentrations, these substances present a potential risk to the drinking water chain and environmental water quality (Figure1). This especially is the case for very sensitive endpoints such as genotoxicity and endocrine disruption. This project aims at development of a bioassay to quantify the genotoxic potency of hydrophilic compounds. By exposing very small organisms to water with hydrophilic compounds, the molecular response in the organisms can be used as an indication of the genotoxic potency of compound mixtures in the water (Figure 2).

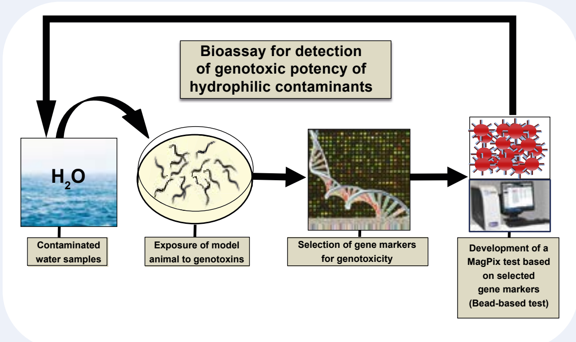

Figure 2. Graphical Abstract of the project

Technological challenge

The challenge is to design an efficient and cheap test that does not require specialists to apply and interpret. The bioassay, HyGenChip, employs very small invertebrate organisms as sentinel species. Hydrophilic compounds, invisible by chemical analyses, will leave their signature in those animals. The focus is on genotoxic contaminants that damage DNA and induce metabolic and DNA repair responses. The most indicative gene expressions for genotoxic effects will be validated with standard single compounds and mixtures. With selected gene markers a MAGPIX assay (Figure 3 & 4) will be developed. The sample preparation needed for the MAGPIX assay is far less time consuming than for classical gene expresion analyses. The assay can then be performed and interpreted in normally equipped laboratories.

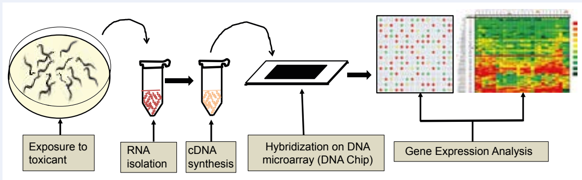

Figure 3. Schematic representation summerizing the concept of a DNA microarray method. This assay provides the possibility to monitor the expression levels of thousands of genes simultaneously [3].

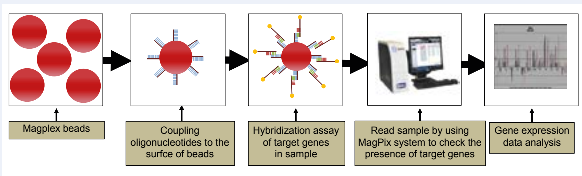

Figure 4. Schematic representation of multiplex assay with the Magpix system for gene expression profing [4] .

Figure 1. Schematic representation of some possible sources of hydrophilic contaminants and their pathways to groundwater and surface water

Research goals

1. Develop an easily applicable method and approach 'HyGenChip' for detection and quantification of the genotoxic potency of hydrophilic pollutants;
2. To assess the genotoxic potency of hydrophilic contaminants in surface water (environmental relevance) and groundwater (source of raw drinking water);
3. Develop a simple and easy procedure to apply and interpret the approach for genotoxicological assessment.

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genomics based water quality monitoring

Monitoring chemical and microbial water quality by transcriptome analysis of single-cells

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Motivation

In the Netherlands, we are fortunate to have good drinking water facilities. The drinking water is of high quality and heavily monitored. It is distributed to households via a large and intricate distribution system. The challenge is to keep drinking water quality the same from where it enters the distribution system until the households. One important aspect is to maintain biological stability throughout the system [1]. In this project, we aim at using the indigenous bacteria in the drinking water as indicators of the water quality. Bacteria respond to their environment by switching certain genes on or off, which will lead to changes in mRNA levels [2]. Subsequently, this mRNA profile, or transcriptome, may be correlated to specific environmental stimuli. For example, the transcriptomic response could indicate biological instability or the presence of a certain compound in the distribution system. This may then, require action from the drinking water company (Figure 1). In other words, we propose to use the bacteria in drinking water as microbial sensors by investigating their transcriptomic response. They should potentially also be able to recognize and signal the presence of unknown impurities, which is not possible with the current standard methods.

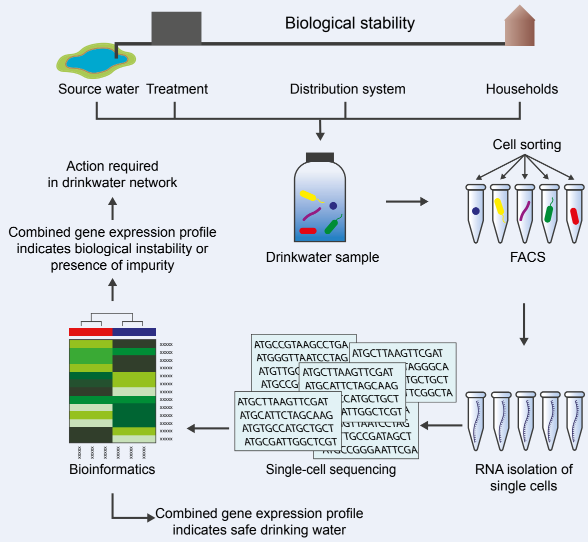

Figure 1: Project overview.

Technological challenge

- Sample preparation. mRNA is very unstable and just present for a short time in the cells. Therefore, sample processing and RNA isolation needs to be performed with care and speed; sample fixation may be necessary [2].
- Distinguishing between microbial subpopulations, such as the active and dormant fraction in drinking water, and sorting those with fluorescence-activated cell sorting (FACS).
- Performing single-cell analysis. We want to perform single-cell analysis to investigate the transcriptomic response in the individual cells instead of the average response of many cells. This is a relatively new and challenging technology, but would greatly improve using the indigenous bacterial cells as biological sensors.
- Data analysis. Analyzing the large amount of data and determining the transcriptomic profiles in relation to specific environmental stimuli will require a lot of bioinformatics and computational power.

Research goals

1. Establish a reliable workflow to distinguish between the microbial subpopulations in drinking water and for single-cell analysis.
2. Investigate what factors influence the biological stability in a full-scale water distribution system, in terms of community composition and bacterial transcriptomes.
3. Determine changes in the transcriptomic profile of microbial subpopulations and single-cells in response to known compounds.
4. Work towards an application that uses the transcriptomic profiles as an indicator for drinking water quality.

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Sensoring

The Sensoring theme of Wetsus focuses on the development of devices for monitoring the quality (composition) of water. The envisioned sensor devices should measure on-line and continuous, be sensitive, reliable, fast and low-cost. Applications can be found in drinking water, industrial (waste) water and surface water.

The motivation to develop reliable water quality sensors is threefold. First, from the point of view of public health, safe drinking water is of utmost importance. Secondly, the quality of discharged industrial waste water is more and more dictated by governmental regulation, implying the need to strictly control its quality. Thirdly, process control might require online measurement of specific compounds to improve the quality of product.

The technology applied within this research theme is very diverse and interdisciplinary. Measurements can be specific, e.g. micropollutants (pesticides / herbicides / pharmaceuticals), ions, bacteria, or other toxins, or measurements can be focused on obtaining a fingerprint of the water quality.

Sensors are more than the measurement principle only. It also involves signal conditioning, the interface and how to interpret data (converting data to information). Networks of sensors make it possible to combine data to increase accuracy, sensitivity, or the number of parameters measured (sensor fusion and soft-sensing), but can provide additional challenges such as the need for self-powering, self-calibrating and self-cleaning sensors. All of this is tackled in the Sensoring theme to achieve improved water quality.

Research projects

- **Edwin Ross**, Wageningen University
  Continuous monitoring of oxychlorides through sensor data fusion **NEW**
- **Rutger Kakes**, Delft University of Technology
  Remote monitoring of hydrocarbons in groundwater through sensor data fusion **NEW**

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Industrial partners

EasyMeasure, Grundfos, Evoqua Water Technologies, Shell

Academic partners

Wageningen University & Research, TU Delft – Delft University of Technology sensoring

Continuous monitoring of oxychlorides through sensor data fusion

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Motivation

Across the globe, chlorination is critical to providing safe water. It prevents and even halts water-borne epidemics (Fig. 1), such as from cholera, typhoid and dysentery [1, 2]. However, hazardous oxychlorides may be formed during this process. These are known to affect the human thyroid gland [3]. The oxychlorides are difficult to measure and costly to remove once formed [4]. Commercial sensors are available for some of the oxychlorides but are expensive and need regular maintenance. There are no sensors for the more hazardous oxychlorides.

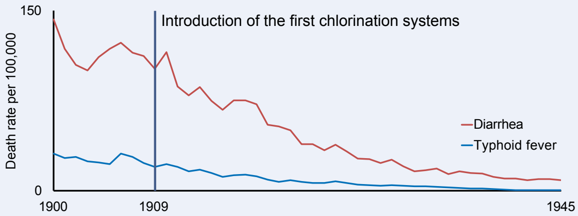

Fig 1. Death rates from water-borne diseases decreased tremendously in the U.S. as access to clean water increased [5, 6]

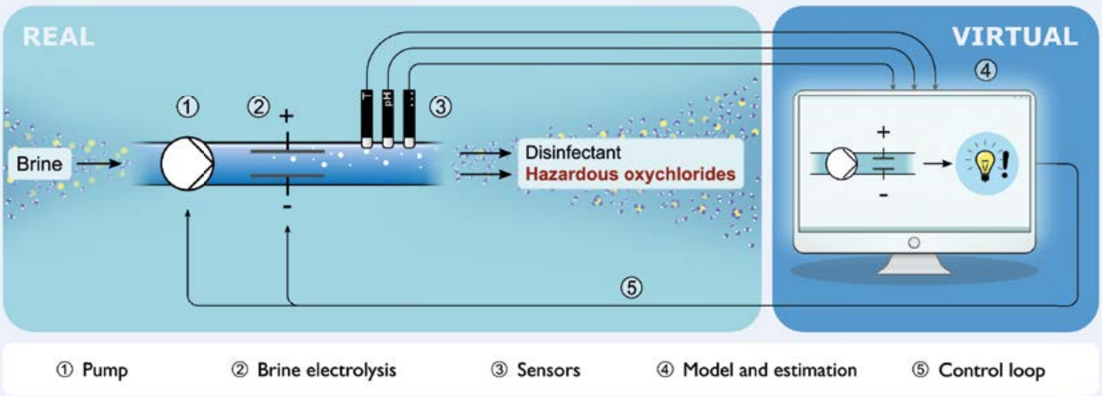

Fig 2. Experimental setup in which a physical disinfectant production process is monitored, modeled, and controlled

Technological challenge

This project aims to overcome the lack of a real-time sensor technology for such oxychloride concentrations by developing sensor technology based on sensor data fusion. In contrast to traditional sensor technology, the concentrations are not measured directly. Instead, **multiple sensors**, such as for temperature, pH and conductivity, are used to give insight into the current state of the chlorine-based disinfectant production process (Fig. 2, 3). These sensors are **widely available**, **affordable** and **robust**. The technological challenge of this project is to deduce oxychloride concentrations from these indirect sensor data, and to do so as accurately as possible.

Three data fusion methods will be investigated, based on:
- A white box model that describes the physics of the process,
- A black box model that uses machine learning for estimation,
- A combination of the two, leading to a new type of soft sensor.

[1] World Health Organization (2011). "Guidelines for Drinking-water Quality", 4th ed.
[2] Childs, C. (1905). *Public Health* **18**, 3, 121 - 150
[3] Stanford, B. D. et al. (2011). *American Water Works Association* **103**, 6
[4] Atwood, J. et al. (2016). *Agriculture and Horticulture Development Board*
[5] United States Public Health Service (1947). "Vital Statistics of the United States, 1945, Part 1"
[6] Gleick, P.H. (2018). *PNAS* **115**, 36, 8863 - 8871
[7]

Research goals

- To develop and test a system for monitoring oxychlorides based on sensor data fusion, including sensor selection, development of algorithms and system control
- To understand the benefits and limits of machine learning for sensor fusion, and how this can supplement a traditional "white box" approach and vice versa
- To learn how uncertainties in the data and model impact the final estimates
- To generalize the sensor data fusion system design methodology to enable wider application

Fig 3. Two examples of commercial electrochlorination systems

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ir. Edwin Ross P.D.Eng., dr.ir. Martijn Wagterveld,
dr.ir. Mateo Mayer, prof.dr.ir. Karel Keesman

sensoring

Remote monitoring of hydrocarbons in groundwater through sensor data fusion

Rutger Kakes

rutger.kakes@wetsus.nl

Motivation

Industrial activities can lead to contamination of groundwater near industrial sites, for example by petroleum hydrocarbons [1]. They can form pollution plumes of which BTEX (Benzene, Toluene, Ethylbenzene, Xylene) compounds are one of the most damaging for public health [2] (figure 1).

Natural attenuation processes are able to decrease hydrocarbon concentrations in groundwater. Microorganisms can aerobically and anaerobically degrade hydrocarbons using a terminal electron-accepting process (TEAP) [3]. Currently hydrocarbon concentrations are measured on a yearly basis by sampling and lab analysis.

Current sensors that can measure BTEX in situ in aqueous conditions need either frequent recalibration or maintanance due to their measuring principles. Instead of monitoring BTEX concentrations directly, water quality indicators that give an indication of the hydrocarbon degradation will be monitored.
The goal is to develop a cheap in situ sensoring method for BTEX in groundwater that is reliable for over a year.

Technological challenge

Instead of measuring BTEX concentrations directly, changing water quality indicators could provide information on BTEX concentrations. It is hypothesized that changes in ORP (Oxidation Reduction Potential), pH and temperature correlate with hydrocarbon concentrations and degradation processes. Finding the correlation between water quality parameters and BTEX concentrations is the biggest challenge.

Furthermore, sensors that will be used for the remote monitoring should be low-cost and reliable for a long time. A degree of autocalibration should be developed in the sensors.

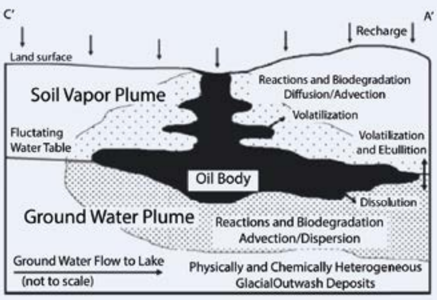

Fig 1. Cross sectional view of multiple natural attenuation processes of light non-aqueous phase liquid (LNAPL) in the subsurface [4]

[1] Contamination of ground water by toxic organic chemicals. 1981
[2] Delin, G. 1998: US Department of the Interior, US Geological Survey.
[3] Haack, S.K. and B.A.J.H.J. Bekins. 2000. Hydrogeology Journal. 8(1): p. 63-76.
[4] Essaid, H.I., et al., 2011. Groundwater. 49(5): p. 706-726.

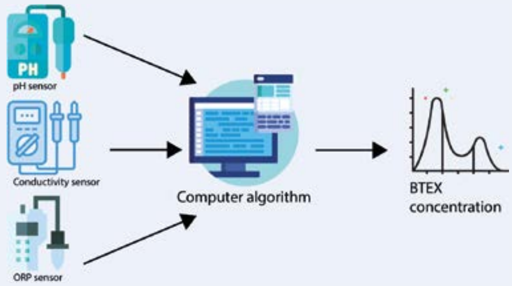

Fig 2. Schematic sensor data fusion through pH, conductivity and temperature to determine BTEX concentration.

Research goals

The goal of the research is to use reliable and low-cost multi-sensor system together with a computational sensor fusion framework to enable remote monitoring of hydrocarbons in groundwater under varying conditions (figure 2). This is done by measuring water quality indicators that are affiliated to the natural attenuation of hydrocarbons in groundwater. To do this, multiple questions need to be answered first (figure 3):

- Which measurable water quality parameters can be correlated to hydrocarbon contamination by analyzing model produced and historical datasets?
- Can sensor drift and stability for low-cost sensors be controlled for an extended period of 1+ years?
- Can the amount of BTEX in a laboratory setup be approximated by using the measurable variables that correlate to the contaminants concentrations?
- Can BTEX concentrations in the field be approximated by using the measurable variables that correlate to BTEX concentrations?

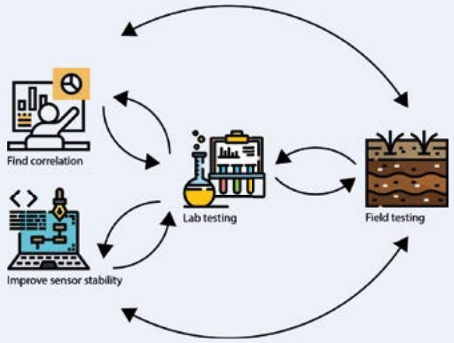

Fig 3. Plan of approach to solve the research goals

The research received funding from Netherlands Organization for Scientific Research (NWO) in the framework of the collaboration programme of NWO with Wetsus on Sustainable Water Technology.

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www.tudelft.nl

R. Kakes, R.M. Wagterveld, L.C. Rietveld, B.M. Van Breukelen

wetsus

european centre of **excellence**
for sustainable **water technology**

European projects

combining scientific excellence with commercial relevance

WaterSEED
Societal entrepreneurs and excelling doctors in water technology

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for sustainable ***water technology***

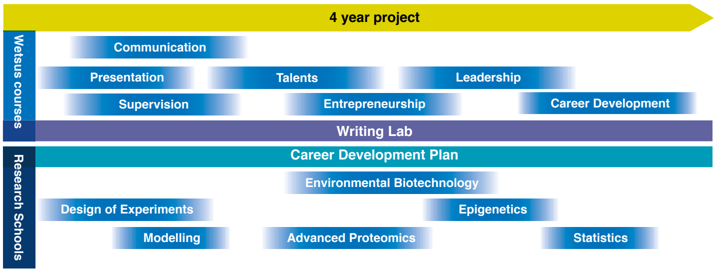
SCOPE

The objective of the WaterSEED project is to provide a doctoral program to excellent early stage researchers (ESRs) that want to develop their skills and contribute to the development of breakthrough technologies for water related challenges. Key elements in the program are the strong focus on interdisciplinary interaction, entrepreneurial skills and societal relevance.

IMPACT

- Stimulate creativity and entrepreneurial mindset
- Enhance career perspectives and employability
- Develop skills needed to solve the societal challenges of Europe

INNOVATIVE PhD TRAINING TRACK



In addition to the research training, Wetsus offers a unique personal development training track in collaboration with coaches and specialized organizations

AT A GLANCE

PROGRAMME:
H2020-MSCA-COFUND-2014

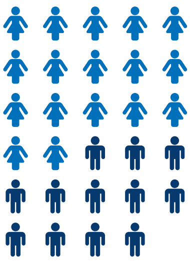
TYPE OF ACTION:
Marie Skłodowska-Curie Actions

DURATION:
60 months
(1 February 2016 – 31 January 2021)

COORDINATOR:
Wetsus | Prashanth Kumar
(prashanth.kumar@wetsus.nl)

OUTCOME 2016-2018 (8 CALLS)

17 female
12 male



29 PhD researchers hired from **17** countries

wetsus
WaterSEED

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 665874

www.phdpositionswetsus.eu

REvivED water

LOW ENERGY SOLUTIONS FOR DRINKING WATER PRODUCTION BY A REVIVAL OF ELECTRODIALYSIS SYSTEMS

INTRODUCTION

The balance between drinking water demand and water availability has reached a critical level in many regions of the world. Factors such as climate change are causing more frequent and severe droughts which exacerbate these adverse conditions. With seawater making up 97.5% of the world's water resources, low energy desalination solutions will be a crucial part of providing sufficient levels of good quality drinking water for a growing world population.

THE REvivED WATER SOLUTION

REvivED water is a European Commission funded innovation project which aims to contribute to overcoming the drinking water challenge by establishing electrodialysis (ED) as the new standard for desalination of seawater. Safe, affordable and cost-competitive drinking water will be produced; with significantly reduced energy consumption compared to state-of-the-art Reverse Osmosis (RO) technology.

FOCUS WILL BE ON THE FOLLOWING SYSTEMS AND APPLICATIONS:

ED system
Applications:
- Brackish water desalination in developing countries (pilot testing in Africa, Asia and Latin America)
- Tap-water softening in Europe (pilot testing in the Netherlands and Germany)

Multistage ED system
Applications:
- Industrial-scale seawater desalination (pilot testing in the Netherlands)

Multistage ED system + Reverse ED (RED)
Applications:
- Further reduction of energy consumption for seawater desalination (pilot testing in the Netherlands)

RO system integrated with RED or ED
Applications:
- Market intrusion ED-RO without the need to replace the extensive RO infrastructures already developed around the world (pilot testing in Spain)

METHODOLOGY

1. Development of ED system based on RED and ED components (membrane, electrodes, stacks).
2. Assessment of pilot systems in a real environment to demonstrate improvements regarding energy consumption, water quality and cost, among others.
3. Study of the economic viability of the different ED desalination systems, their business perspectives and the market strategy to follow.

EXPECTED RESULTS

- Water desalination applications with significant reduction of the energy consumption compared to current state-of-the-art energy technologies.
- More cost efficient seawater and brackish-water desalination as well as tap-water softening.
- Contribution to the sustainable provision of safe and affordable drinking water all over the world, covering applications ranging from large industrialised plants to small, stand-alone systems for developing countries.

Designed and developed by AquaTT

CONTACT US

REvivED water Coordinator
Dr. Natalie Tiggelman
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Fujifilm Manufacturing Europe B.V.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no. 685579. This output reflects the views only of the author(s), and the European Union cannot be held responsible for any use which may be made of the information contained therein.

PARTNERS

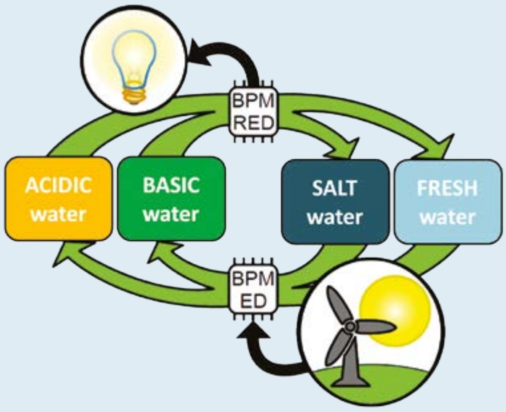
FUJIFILM, ABENGOA, AQUATT, Phaesun, REDstack, DEUKUM, European Desalination Society, Università degli Studi di Palermo, Universiteit Gent, wetsus

THE BAOBAB PROJECT:
SUSTAINABLE ENERGY STORAGE BY REVERSIBLE SALT WATER DISSOCIATION

BAoBaB
BLUE ACID/BASE BATTERY

The energy storage challenge

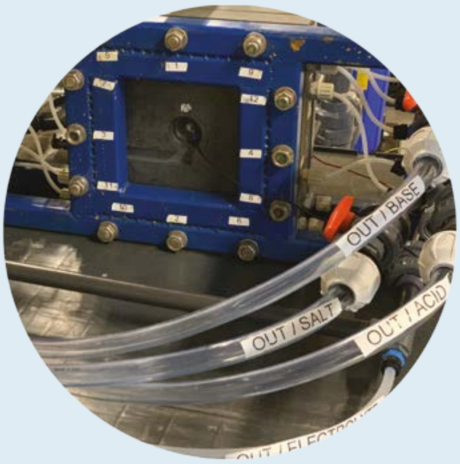
The need of energy storage for our society has drastically increased in the last years, due to the growing share of renewable sources (such as wind and solar) on electricity grids. A new generation of innovative batteries must be developed, to provide safe and sustainable energy storage on large scale.



The BAoBaB solution

The BAoBaB project is EU-funded project that aims to develop and test a **safe, environment-friendly, and cost-competitive battery** for centralized and decentralized energy storage.

The BAoBaB technology is based on **bipolar electrodialysis**, i.e. a membrane process able to generate acid and base from salt solutions. Electric energy is stored by using only salt and water, thus providing a safe and sustainable energy storage system.



Project objectives

- Develop new battery design and optimized monopolar/ bipolar membranes
- Validate the technology on pilot scale (1 kW power, 7 kWh energy storage) under real conditions
- Environmental and economic assessment of the BAoBaB technology
- Develop guidelines for system integration with electrical grids

Expected impact

- Bring to the market a scalable and flexible energy storage system at kWh-MWh scale
- Enlarge the portfolio of available energy storage systems for both centralized and decentralized applications (e.g. islands grids)
- Reduce the energy storage cost compared to current state-of-the-art technologies

PROJECT PARTNERS

wetsus european centre of excellence for sustainable water technology
Università degli Studi di Palermo
circe
FUJIFILM Value from Innovation
AquaBattery
S.MED.E. PANTELLERIA

CONTACT US

Project coordinator: dr. Michele Tedesco
Wetsus, European Centre of Excellence for Sustainable Water Technology
baobab.project@wetsus.nl
www.baobabproject.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731187

MEDUWA VECHT(E)

Antibiotic resistance in the Vecht catchment

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european centre of excellence for sustainable water technology

BACKGROUND

Antibiotic resistant bacteria and antibiotic residues have been detected in Dutch surface waters. This may pose a risk to ecosystems and human health. Human wastewater and run-off from farmland fertilized with animal manure are sources of antibiotic resistance in surface water (see Fig. 1). In this project we use the Vecht river and tributaries as a study area, in order to get a detailed picture of the contribution of different sources and to obtain parameters that would allow the prediction of antibiotic resistant bacteria in surface water.

IMPACT

We aim to establish the fate of antibiotic resistance in a complete, cross-border catchment (The Vecht, see Fig. 2)

Insight in the fate of bacteria in a catchment can aid predicting concentrations of resistant bacteria at locations of human exposure, such as recreational sites or drinking water production, and translation of measurement campaigns to other catchments.

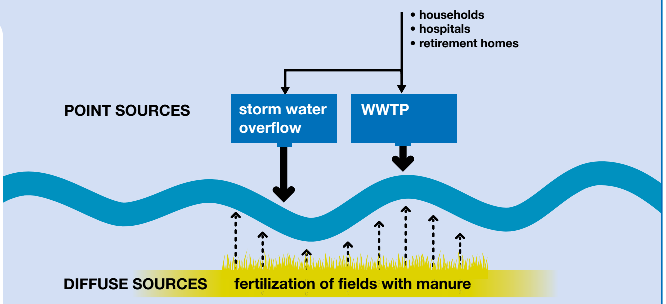

Fig.1 Point and diffuse sources of AMR in surfacewater

PROJECT OBJECTIVES

- 1-year sampling campaign (e.g. detection of ESBL producing E. coli)
- Geographical-based modelling of antibiotic resistant bacteria in the Vecht catchment (models: GREAT-ER, QMRACatch)
- Assess the attribution of different sources (point and diffuse) to antibiotic resistance in surface water
- Assess exposure of humans to antibiotic resistance in surface water

Fig.2 The Vecht catchment (courtesy of Stichting Huize Aarde)

AT A GLANCE

PROGRAMME:
INTERREG V A Deutschland-Nederland

DURATION:
32 months
(11 October 2016 – 30 June 2020)

COORDINATOR:
Wetsus | Eri van Heijnsbergen
(eri.vanHeijnsbergen@wetsus.nl)

PROJECT PARTNERS

The MEDUWA VECHT(E) project consortium consists of 28 partners from 2 EU countries (NL, DE), working on the entire medicine chain in order to avoid the transfer from environmental pharmaceuticals and multi-resistant bacteria to humans and animals.

INTERREG Deutschland Nederland
www.deutschland-nederland.eu
Europäischen Union Europese Unie
MEDUWA

This project is financially supported by the European Union and the INTERREG partners as part of the INTERREG program.

www.meduwa.uni-osnabrueck.de

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RawMatters
Ambassadors at schools

SCOPE

An innovative program to make science education and careers in the Raw Material (RM) sector attractive to youngsters. A consortium of 12 European partners combine their expertise to initiate, promote and assist a wide dissemination action on Raw Materials at schools. Through local networks of Raw Matters Ambassadors supported with hands-on educational toolkits, students (10-19 years) are encouraged to solve future RM-related challenges

IMPACT

- Enhance career perspectives and employability in Raw Materials
- Transferring knowledge on RM to secondary schools students
- Stimulate creativity and entrepreneurial mindset

RAW MATTERS LEARNING TRACK

1. RM Ambassadors @ Schools
2. Education Toolkits
3. Company Visits
4. School Challenge
5. Science Fair

AT A GLANCE

PROGRAMME:
EIT Raw Materials

TYPE OF ACTION:
Wider Society Learning

DURATION:
36 months (Jan. 2018 – Dec. 2020)

COORDINATOR:
Wetsus | Marco de Graaff
(marco.degraaff@wetsus.nl)

OUTCOME 2016-2018

20 toolkits

The tookits are focused on the six Knowledge & Innovation Themes (KIT) identified by EIT Raw Materials:
1| Exploration
2| Mining
3| Metallurgical processes
4| Recycling
5| Substitution of critical materials
6| Circular economy

CONSORTIUM

12 partners

"I hear and I forget. I see and I remember. I do and I understand" | Confucius

eit RawMaterials RM@Schools

This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation. Grant Agreement: No 15098

www.rmschools.isof.cnr.it

ViviMag, a novel magnetic route for phosphorus and iron recovery from sewage sludge

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european centre of **excellence**
for sustainable **water technology**

BACKGROUND

Phosphorus (P) is a limited resource and our agriculture relies on a steady supply. Phosphate rock is mined and processed to produce phosphorus containing fertilizers, like PK-fertilizers. However, exploitable phosphate rock reserves are found in just a few countries. The EU itself has hardly any phosphate rock reserves and depends nearly entirely on the import of this crucial resource; in 2005 the primary P import of the EU-27 was 1.8 Mton. Phosphorus use has to become more sustainable and should include P-recycling from secondary sources (i.e. wastewater). This will not only prevent eutrophication of surface waters, but will also minimize costs for disposal of phosphorus rich wastes.

Phosphorus rich waste streams such as sewage have a high potential for P recovery. Phosphorus has to be eliminated from these wastewaters to prevent environmental damage, like harmful algae blooms. Annually, Europe's Sewage Treatment Plants (STPs) remove about 370 kton P by immobilization in the sewage sludge. The direct use of the sludge as fertilizer is problematic due to its bulky volume, the fixed nutrient ratios and the low bioavailability of a nutrient like phosphate.

Therefore, there is an increasing interest to separate the phosphorus in concentrated form from the bulk sludge for subsequent reuse in the fertilizer industry (Fig. 1). The majority of Europe's STPs apply chemical precipitation with an iron-based coagulant to achieve sufficient phosphorus removal.

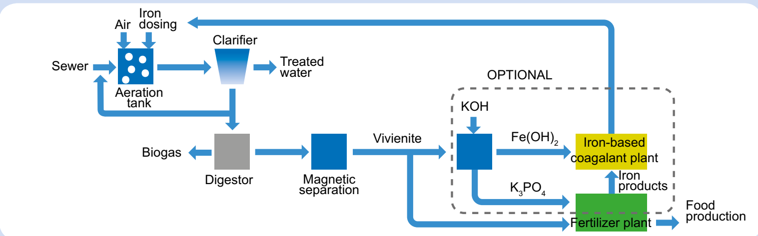

Fig. 1 Simplified scheme representing recovery of vivianite from digested sewage sludge and subsequent processing to fertilizer.

SCOPE

ViviMag will develop and up-scale a magnetic separation process to recover the insoluble iron phosphate mineral vivianite from Sewage Treatment Plants (STPs) that rely on chemical phosphate removal. The separation process will be applied on sewage sludge after anaerobic digestion. Anaerobic digestion reduces the sludge volume and recovers energy in the form of biogas. During anaerobic digestion Fe(III) is reduced to Fe(II), which results in vivianite formation.

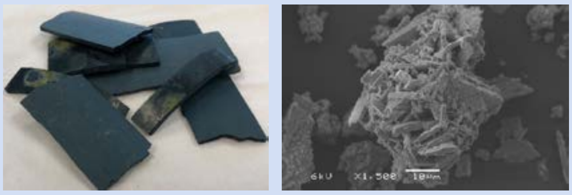

Fig. 2 Image of a vivianite sample from an STP and SEM image of a vivianite particle recovered from digested sludge.

IMPACT

- Phosphate recovery from sewage sludge can cover 20% of the EU-27 phosphate demand.
- Vivianite separation from sewage sludge will create a new phosphate resource and reduce waste disposal costs.
- Production of fertilizer from vivianite will contribute to a sustainable future.

CONSORTIUM

- EIT RawMaterials
- Outotec (Finland) Oy
- Kemira Oyj
- Outotec GmbH & Co. KG
- Wetsus
- TU Delft

CONTACT

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vivimag@wetsus.nl

ViViMAG
eit RawMaterials
Connecting matters

This activity has received funding from the European Institute of Innovation and Technology (EIT). This body of the European Union receives support from the European Union's Horizon 2020 research and innovation programme. Grant Agreement: No 17021.

www.wetsus.nl/vivimag

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LIFE-NEWBIES
Nitrogen Extraction from Water By an Innovative Electrochemical System

MOTIVATION

Our society relies on the application of fertilizer to ensure sufficient crop yield for food production. The production of nitrogen based ammonia fertilizers is responsible for about 1 to 2% of the worldwide energy consumption. A large amount of this reactive nitrogen ends up in the wastewater we produce and needs to be removed to protect sensitive water bodies and to comply with current regulation.

Common practices for nitrogen removal from wastewater are energy intensive and convert reactive nitrogen to inert nitrogen gas (N_2). The production of nitrogen based fertilizers and nitrogen removal from wastewater are thus essential parts of the nitrogen cycle.

The LIFE-NEWBIES project aims to shorten the nitrogen cycle by directly recovering nitrogen (ammonia, NH_3) from wastewater. This way, the energy demand associated with nitrogen removal and production using conventional methods can be reduced.

AT A GLANCE

PROGRAMME:
LIFE

DURATION:
36 Month (1 July 2018 – 30 June 2021)

EU CONTRIBUTION:
747.602,00 €

EMAIL: life-newbies@wetsus.nl

SCOPE

The Life-NEWBIES project will design, build and operate a pilot for ammonia (NH_3) recovery from wastewater.

The objectives are:

- to recover 1 kg nitrogen per day
- to show NH_3 recovery at equal or lower costs, and with a lower environmental burden than conventional technologies
- to produce a useful fertilizer product
- to bind stakeholders for market uptake

CONSORTIUM

wetsus

evides industriewater

W&F TECHNOLOGIES

ICRA Catalan Institute for Water Research

NEWBIES

The LIFE-NEWBIES project (LIFE17 ENV/NL/000408) has received funding from the LIFE Programme of the European Union.

Life

www.life-newbies.eu

wetsus
european centre of excellence for sustainable water technology

SCALIBUR
Scalable technologies for bio-urban waste recovery

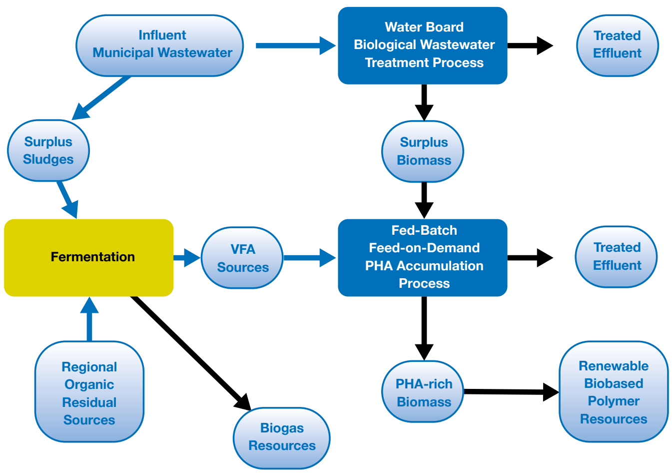
SCOPE

Across the EU, over 100 M tonnes of biowaste are currently produced every year. More than 75% is sent for incineration or landfilling This has environmental impact and it also means that a great part of this organic waste is not valorized. It is irreversibly extracted prematurely from potential and viable material and economic cycles. SCALIBUR aims to cut linear urban biowaste management methods and establish solutions with circular production chains of valuable renewable resources. The figure below is one example.

Within Wetsus, SCALIBUR forms part of the 'Biopolymers from water theme'. Wetsus focusses on the production of biopolymers (PHA) by feeding surplus activated sludge with volatile fatty acids (VFA) from fermented organic municipal waste to produce a PHA rich biomass. The PHA can be recovered to produce a pure and high quality biopolymer with a favorable sustainability profile. PHA has several applications both as an ingredient to biodegradable plastics, and as a platform chemical building block for other materials and services.

OBJECTIVES

Establishing production of, and quality control for, PHA from surplus activated sludge and fermented organic municipal wastes as feedstocks in a pilot system. Supporting next steps towards scaled up industrial applications of the technology methods and processes.



AT A GLANCE

PROGRAMME:
H2020-SFS-2018-2020

TYPE OF ACTION:
Research and innovation

DURATION:
48 months (November 2018 – November 2022)

EXPECTED OUTCOMES

- Commissioning and routine operation of a pilot facility for PHA production and recovery using Dutch urban biowaste streams as feedstocks.
- Implementing ideas and innovations towards securing robust process and production strategies in the expected technology scale up.
- Instilling confidence with the PHA production quality control for all stakeholders.

CONSORTIUM

The SCALIBUR consortium consists of 21 partners from nine EU countries and is coordinated by César Aliaga, ITENE, Spain. Together whole value chains are covered, from production to characterization of the value-added bio-based products.

CONTACT

Project leader Wetsus:
Erik de Vries, erik.devries@wetsus.nl
Biopolymers from water theme coordinator:
Alan Werker, alan.werker@wetsus.nl

SCALIBUR
LEADING A REVOLUTION IN BIOWASTE RECYCLING

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817788.

www.scalibur.eu

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for sustainable water technology

Interreg Europe iWATERMAP

BACKGROUND

The iWATERMAP project focuses on suporting the innovation policies in water technology sector, helping to increase the critical mass of innovation ecosystems in partner regions in this sector. The critical mass in innovation ecosystem approach means that all the necessary elements for innovation ecosystem are identified and put in place stage by stage, such as academia and business cooperation, cross-cluster fertilization, interregional networks and cooperation, science and education, thus ensuring stable and sustainable development of the system.

AIM & RELEVANCE

The Project has selected the water technology sector as a focus area. The importance of the sector lies in its ability to help to address societal challenges related to water resource management - water scarcity, efficiency, use in other industrial sectors, resource recovery from waste water and waste water treatment etc. The sector has a large potential for generating innovative products and services which can be exported, thus also contributing to the creation of growth and jobs in the region.

Fig.1 Project look and feel

OBJECTIVES

Project will address 7 policy instruments by assessments, learning sessions, roadmaps, action plan development, good practice identification and sharing and involvement of regional stakeholder groups. The main output will be a shared action plan, consisiting of concrete steps to improve the critical mass of innovation ecosystems. Improving the impact and efficiency of Water Technology RDI.

AT A GLANCE

PROGRAMME:
INTERREG Europe
DURATION:
(from 1 Jun 2018 to 31 May 2023)
COORDINATOR:
Wetsus | Pawel Roman
(Pawel.Roman@wetsus.nl)

Fig.2 Project partners from iWATERMAP project.

PROJECT PARTNERS

There are 9 partners and 7 regions participating in the Project from NL, LV, PT, ES, EL, RO and CZ, thus combining a leading regions in innovation (NL) with moderate (CZ, LV, ES, PT, EL) and modest (RO) innovators.

iWATERMAP
Interreg Europe

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817788.

www.interregeurope.eu/iwatermap

Wetsus research staff

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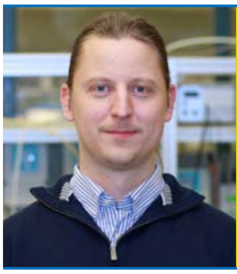
Program director
bert.hamelers@wetsus.nl



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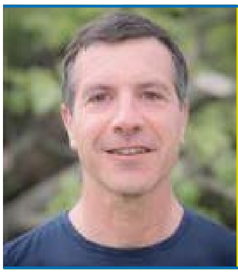

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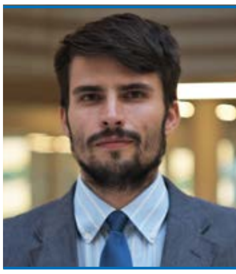

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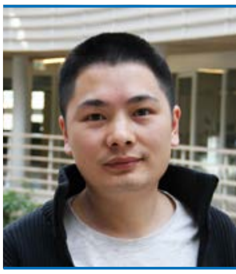

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Wetsus, European centre of excellence for sustainable water technology is a facilitating intermediary for trend-setting know-how development. Wetsus creates a unique environment and strategic cooperation for development of profitable and sustainable state of the art water treatment technology. The inspiring and multidisciplinary collaboration between companies and research institutes in Wetsus results in innovations that contribute significantly to the solution of the global water problems.

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