جامعة الملك عبدالله
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King Abdullah University of
Science and Technology

Water Desalination
and Reuse Center

RESEARCH POSTERS 2023

Message from WDRC Director

The focus of the Water Desalination and Reuse Center (WDRC), since inception, has been in undertaking fundamental and applied research in the water sciences and in advancing the development of relevant water technologies that will deliver innovative solutions to address the challenges of water security and the sustainability of water resources in the Kingdom of Saudi Arabia, the GCC, and the world at large.

Over the years, WDRC have been recognized as a key part of the KAUST research agenda and entrusted with the responsibility of finding effective solutions to global water challenges, while positioned as a veritable vehicle for research translation and impact in the Kingdom.

Our center research activities encompass the following areas:

- To research and develop novel technologies for water desalination and reuse
- To optimize and hybridize desalination and reuse technologies for enhanced performance
- To promote water technologies for sustainable urban, agricultural, and industrial applications
- To research urban and natural hydrologic systems to enable improved water resource understanding and management
- To disseminate knowledge through demonstration, engagement, and technology transfer.

These activities fall within our three main flagship goals:

- Greener Desalination: New approaches to more efficient and affordable desalination
- Water Security: Improving the sustainability and management of water resources.
- Wastewater to Resource: Turning byproducts of desalination and wastewater into a usable and value-adding resource.

This poster booklet highlights a few of the exciting research topics that is being undertaken within the various research groups in WDRC, under our three flagship programs.

I am confident that working together in a healthy, collaborative, and supportive environment in WDRC will continue to inspire great ideas, both in our fundamental and translational research efforts.

HANS VROUWENVELDER, PH.D.
DIRECTOR WDRC

"Let us work together on ***Transforming the Water Cycle***"

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About WDRC

Our Vision

"To play a leading role in delivering a water secure future that will enable social and economic prosperity in the Kingdom and beyond."

Our Mission

"To undertake fundamental and applied research that will deliver innovative solutions to the global challenges of water security, safety, sustainability and supply."

Our Core Values

Innovation
innovations for society

Partnership
inspiring network

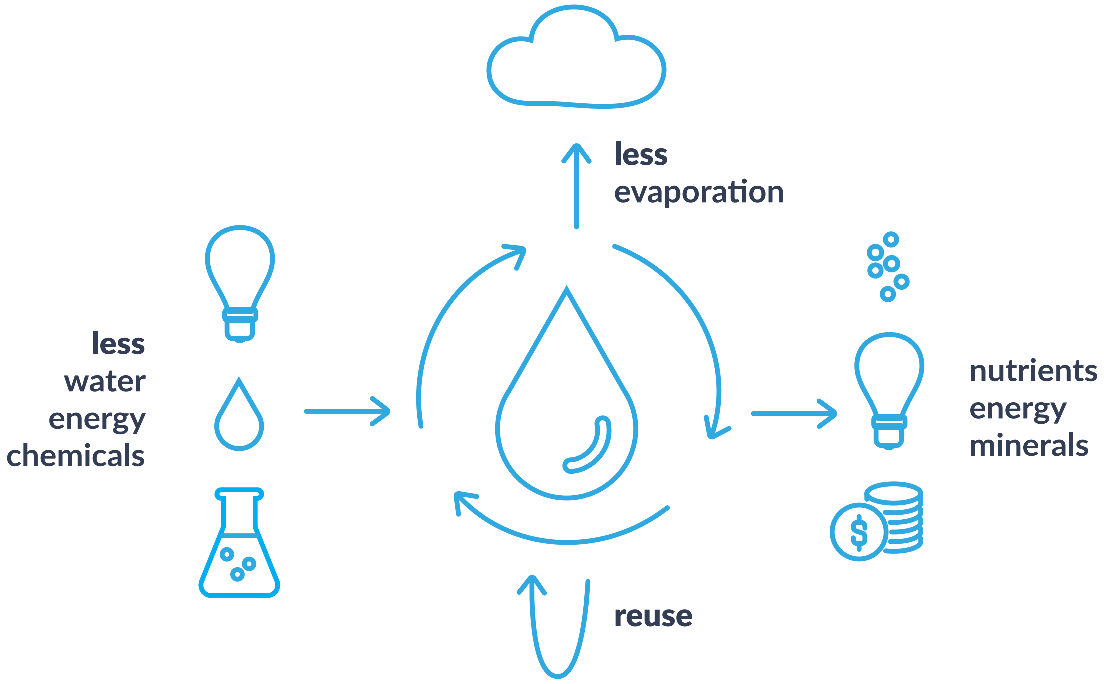
Joy
pleasant atmosphere

Cooperation
open and safe environment

Reliability
keep our promises

Our Purpose

Transform the Water Cycle



"WDRC's purpose is to transform the human water cycle in order to achieve a reduction in the use of energy and chemicals, a reduction of leaks and evaporation and to minimize discharge to the environment while maximizing the harvesting of water, energy, nutrients and minerals."

WDRC Faculty

HANS VROUWENVELDER

PROFESSOR | DIRECTOR

Research Interests: Biofilms and (bio)fouling control; Biological stability in drinking water production and distribution

NOREDDINE GHAFFOUR

PROFESSOR

Research Interests: Sustainable desalination, Membrane distillation, Forward osmosis, Hybrid systems, Membrane fouling and mitigation, Membrane cleaning, Renewable energy

KIM CHOON NG

PROFESSOR

Research Interests: Thermal Desalination, Adsorption Desalination (AD), Energy Efficiency Analysis with Standard Primary Energy (SPE), Direct Spray Evaporation and Condensation (DCSEC), Atmospheric Water Harvester (AWH)

PASCAL SAIKALY

PROFESSOR

Research Interests: Electromicrobiology, Microbial electrochemistry, Anaerobic ammonium oxidation (anammox) process, Aerobic granular sludge, Water reuse, Resource recovery

QIAOQIANG GAN

PROFESSOR

Research Interests: Water and Energy Sustainability, Nanophotonics, Thermal management, Optical Biosensing

GEERT-JAN WITKAMP

PROFESSOR

Research Interests: Crystallization, Thermodynamics, Supercritical carbon dioxide, Natural deep eutectic solvents, Green solvents

CRISTIAN PICIOREANU

PROFESSOR

Research Interests: Numerical modeling, Biofilms, Membrane engineering, Bioreactor engineering, Multi-scale simulations, Water Treatment

MATTHEW MCCABE

PROFESSOR

Research Interests: Remote sensing, Water security, Climate impacts, Precision agriculture, Unmanned aerial vehicles

PEIYING HONG

PROFESSOR

Research Interests: Wastewater multibarrier treatment technologies, Emerging microbial contaminants, Water quality, Water reuse, Anaerobic processes

HIMANSHU MISHRA

ASSOCIATE PROFESSOR

Research Interests: Superhydrophobic insects and plants; Bio-inspired technologies for precision agriculture, coatings, and membranes; Interfacial chemistries; and Nanoconfined liquids

Research Flagship Themes

WDRC has strategically organized its research activities into three flagship themes: Greener Desalination, Water Security, and Waste-to-Resource.

Greener Desalination

This research theme has a paramount focus on reducing the energy and chemical consumption of desalination, a critical issue since seawater desalination is the primary source of drinking water and water for industry. Moreover, the Kingdom is expected to double its total desalination capacity in the next 7 years, which makes this subject matter critical.

- The team has developed an innovative thermal desalination process, Direct Contact Spray Evaporation Condensation (DCSEC), which utilizes low investment cost and low energy consumption, making use of waste heat or solar-generated heat, led by Professor Kim Choon Ng. Furthermore, the team has proposed a new membrane desalination concept that outperforms commercial modules using solar-driven flashed-feed, showerhead, and localized heating modules. The team also proposed a cleaning concept using carbon dioxide (CO_2) gas bubbles to remove impurities from capillary membranes, avoiding the use of harmful chemicals, and unblocking pores through backwashing.
- The research team's notable findings include a highly efficient cleaning method for reverse osmosis membranes, which not only improves membrane performance but also reduces environmental discharge by enabling the recovery and reuse of cleaning agents. Professor Hans Vrouwenvelder led this critical research initiative.
- Moreover, the team has designed an innovative perforated spacer for spiral-wound reverse osmosis and nanofiltration elements that reduces both fouling and concentration polarization in the membrane element, which can lead to improved efficiency and durability of the desalination process, Professor Noreddine Ghaffour leads these research initiative.
- Lastly, our research team, led by Professor Geert-Jan Witkamp, has developed a water refinery for recovering water, salt, and metals, using Eutectic Freeze Crystallization (EFC), minimizing corrosion and safety risks, while reducing energy costs by up to 90% compared to evaporative crystallization and 50% compared to triple stage evaporation. Lastly, our team has unlocked the potential for recovery of valuable trace elements (Li, Rb, Cs) from desalination brine through (ultra-)trace element tracking and recovery.

Waste to Resource

This cutting-edge research theme is dedicated to maximizing the value of water treatment residuals, both from wastewater treatment and desalination brine. The Kingdom's ambitious goal of achieving 100% wastewater treatment and reuse before 2030 makes this theme crucial for sustainable development.

- Our research initiatives have led to groundbreaking discoveries, such as the development of a novel biotechnology for decentralized wastewater treatment and reuse. This approach harnesses an anaerobic electrochemical membrane bioreactor (AnEMBR), which generates electricity that can be stored as methane or hydrogen, resulting in an energy-neutral or positive process for water reuse. Additionally, our team has developed a unique anaerobic process for ammonium removal from N-rich wastewater, without nitrate formation and being energy-neutral. We have also enriched a novel anammox bacterium from the Red Sea to treat saline wastewater, enabling the use of seawater toilet flushing, which represents 25% of household water consumption, Professor Pascal Saikaly leads these research initiative.
- Our team has also developed sustainable approaches to address water scarcity, including the application of an anaerobic membrane bioreactor (AnMBR) for wastewater treatment, resulting in an energy-neutral/positive process that retains nitrogen and phosphorus in the effluent, making it ideal for agricultural irrigation or maintaining green living spaces in urban cities, led by Professor Peiying Hong.

Water Security

This research theme focuses on providing safe and sufficient water to end-users by managing both water quality and quantity, encompassing drinking water, wastewater, and agricultural water.

- Our team, led by Peiying Hong, is monitoring SARS-CoV-2 in wastewater, establishing detection limits and potential wastewater surveillance for predicting future outbreaks of other novel viruses and biological contaminants.
- We have also collaborated with the Ministry of Environment, Water, and Agriculture to implement national-scale water accounting, providing an accurate estimate of agricultural water use and changing agricultural practices, led by Professor Matthew McCabe.
- Our team has also developed an innovative approach, led by Professor Himanshu Mishra, to increase crop yields by up to 70% using Superhydrophobic Sand, which limits evaporation.
- Our research initiatives have yielded significant findings, including the development of a sensitive monitoring method for microbial activity in drinking water networks led by Professor Hans Vrouwenvelder. This method identifies areas that are susceptible to bacterial growth and pathogen proliferation, particularly in water networks that have been in hibernation due to the SARS-CoV-2 situation.

Through these initiatives, we are committed to providing innovative and sustainable solutions for water management, supporting the Kingdom's vision for sustainable development.

Research Posters

The EDS Conference awarded the best poster to Dr. Graciela Gonzalez Gil for her poster entitled "The microbial growth potential of antiscalants used in seawater desalination." Miriam Balaban, a legend of the global desalination community, handed the award.

Greener Desalination

Water Desalination and Reuse Center

Greener **Desalination**

Smart process operation to modulate biofilm development and improve system performance in reverse osmosis and nanofiltration

Kees Theo Huisman

Motivation

Biofilm growth can strongly impair the operational performance of membrane filtration systems for seawater desalination. My research applies recent advances in imaging techniques to unravel the effect of process conditions on biofilm development. Optimization of process conditions can play an important role in controlling biofouling.

Challenge

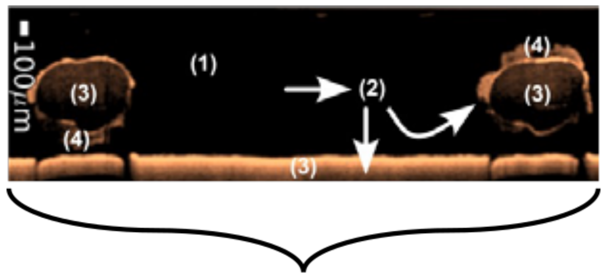
Biofouling results from complex interactions between operational settings, membrane and spacer, and feed water composition. It is not known how these conditions of process operation affect biofouling and operational performance.

(1) Feed water composition
- Microbial community
- Nutrient status
- (In)organics
- Temperature
- Salinity
- pH

(2) Membrane and spacer
- Material
- Geometry
- Morphology
- Permeability

(3) Operational settings
- Crossflow velocity
- Permeate flux
- Cleaning regime

(4) Biofouling
- Time evolution
- Spatial distribution



Operational performance indicators
- Transmembrane pressure
- Feed channel pressure drop
- Salt rejection

Research goals

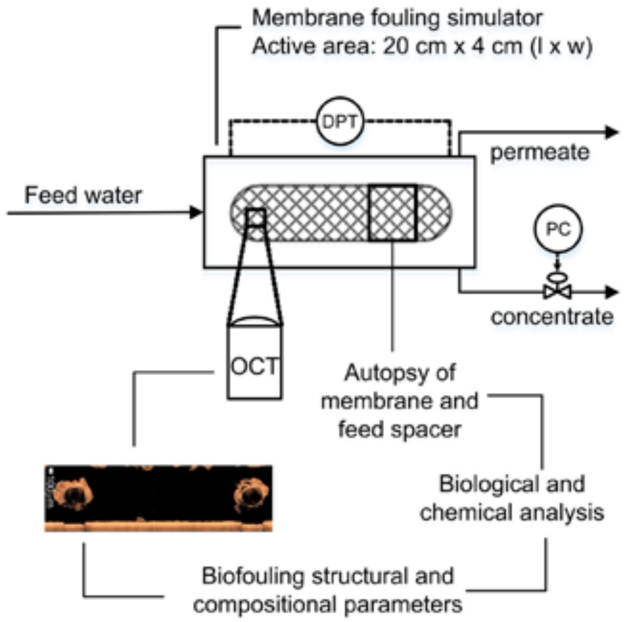


Fig 2: Structural and compositional characterization of biofouling. OCT: optical coherence tomography. DPT: differential pressure transmitter. PC: pressure controller

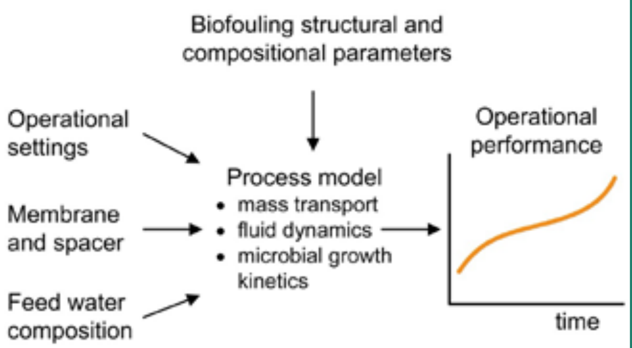


Fig 3: Establishing a predictive link between conditions of process operation and operational performance for biofouling in membrane filtration systems.

PI: Johannes S. Vrouwenvelder

Email: kees.huisman@kaust.edu.sa

Water Desalination and Reuse Center

Greener **Desalination**

Pretreatment selection to control membrane desalination biofouling: method development

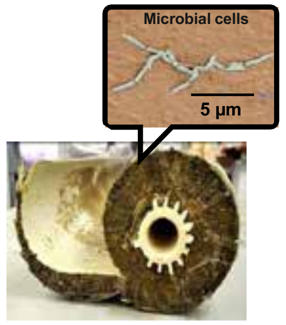
Yasmeen Nadreen

Motivation

Pretreatment of seawater is performed to protect reverse osmosis (RO) membranes.

However, pretreatment in reverse osmosis desalination plants is not optimal.

The consequences:
- Increased (bio)fouling of RO membranes
- Increased membrane replacements and waste generation

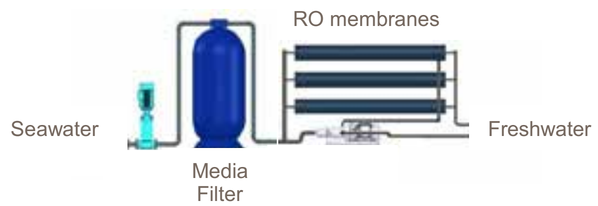


Challenge

Parameters assessing pretreatment efficiency do not include the produced water's microbial/ biofilm growth potential.

How is this a problem?

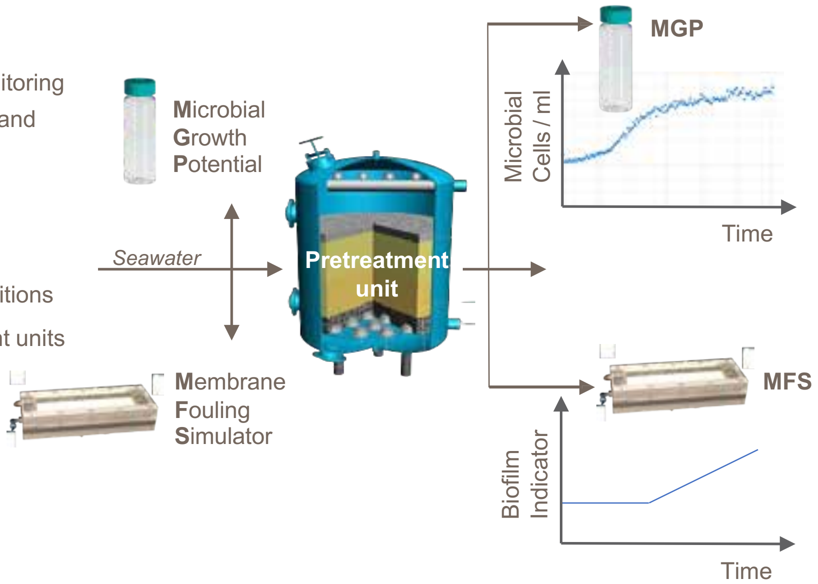
Unchecked microbial growth in membrane systems lead to biofouling and irreversible damage.



Research goals

We are developing a biological based monitoring system to improve seawater pretreatment and minimize biofouling in the RO system.

Our research will aid in:
- Improving pretreatment operating conditions
- Selecting the most optimal pretreatment units
- Extension of RO membrane lifetime



PI: Johannes Vrouwenvelder

Email: yasmeen.nadreen@kaust.edu.sa

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Greener **Desalination**

Early biofouling detection and enhanced cleaning protocols for biofouling control in membrane filtration processes

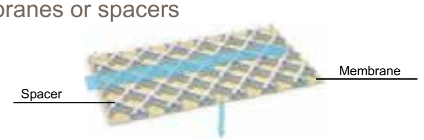
Laura Milena Pulido Beltran

Motivation

Current approaches to control biofouling

1. Improve feed water quality through pre-treatment performance

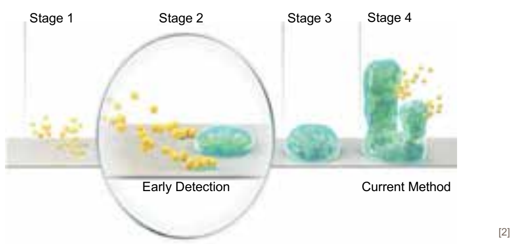
2. Material and geometry modification of the RO membranes or spacers



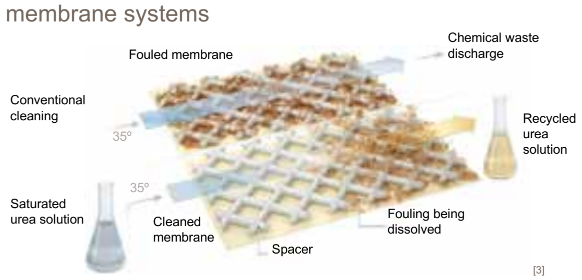
3. Membrane cleaning through chemical or mechanical processes to RO modules

Challenges

- Develop early biofouling detection methods on membrane systems



- Optimized cleaning methods for biofilm removal on membrane systems



Research goals

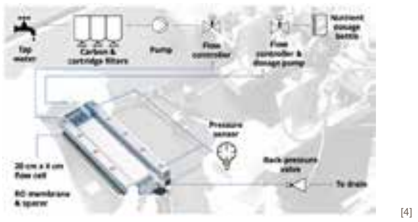
1. Develop strategies that allow early detection of biofouling by monitoring water and understanding biofilm formation in membrane systems.

2. Compare the efficiency of cleaning strategies when applied to different biofilm formation stages analyzing differences in biofilm composition after cleaning.

3. Optimize the duration of physical and chemical cleaning strategies assessing how cleaning efficiency changes with time and how it affects biofilm.

Methods

Membrane Fouling Simulator (MFS)



Online Flow cytometry

Membrane Autopsies

References
[1] Illustration from Shubham Inc.
[2] Khan et al (2019). Enzyme and Microbial Technology 120, 43-51.
[3] H. Sanawar et al (2021). Water Res. 13, 100117.
[4] Javier, L. et al. (2021). Membranes, 11, 928.
[5] Images from KAUST Insights for National Priorities: Sustainable Water Desalination
[6] Illustration from BD Biosciences and OnCyt companies

PI: Johannes Vrouwenvelder

Email: laura.pulidobeltran@kaust.edu.sa

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Greener **Desalination**

Understanding scaling in reverse osmosis membranes: development of a protocol for the acceleration of $CaCO_3$ scaling in membrane fouling simulators (MFS)

Natalia Franco Clavijo

Motivation

The negative environmental impact of brine discharge from reverse osmosis membranes is receiving increasing attention. Approaches like zero liquid discharge and/or chemical-free brine dilution have a great risk of membrane scaling. Therefore, to address the negative impact of brine discharge, a better understanding and control of membrane scaling are needed.

Challenge

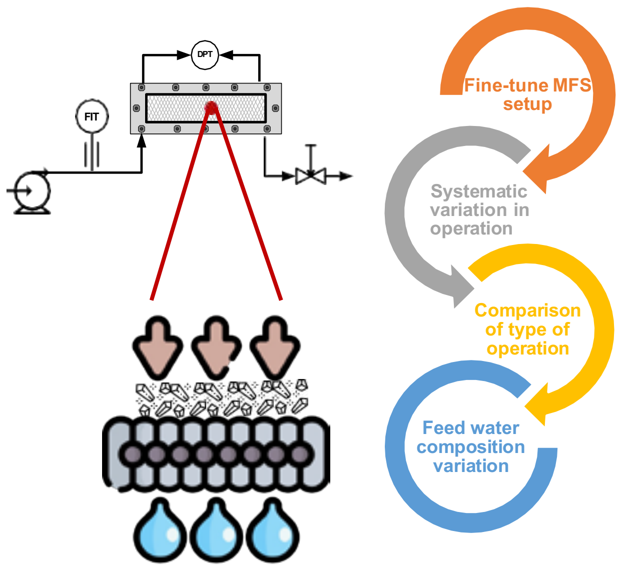
Developing chemical-free scaling control strategies to adopt in industrial practice requires a membrane scaling simulating tool that allows scaling formation to be evaluated precisely and convincingly. Some of the challenges that were identified are mentioned as follows:

- Limited development or application of observation techniques
- The kinetics of heterogeneous crystallization in a spacer-filled membrane channel has yet to be established.
- Measurement methods that can quantitatively and locally measure the composition and amount of scaling.
- Microscale numerical models to predict crystal formation in time from complex solutions in intricate hydrodynamic environments needs to be developed.

There is a real need to develop a simulation tool that comprises controlled/accelerated scaling, observation, and model prediction. Furthermore, the relation with operational performance indicators of RO systems needs to be established.

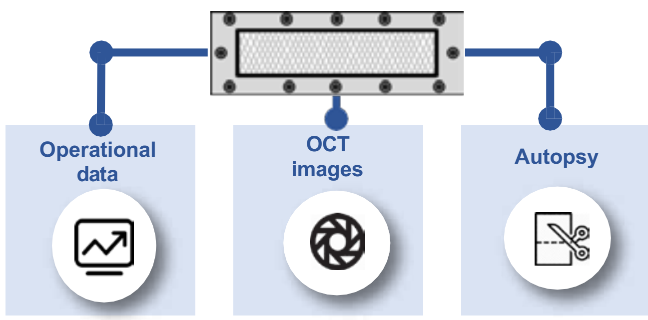
Research goals

Scaling protocol in membrane fouling simulators and in-situ monitoring



Scaling characterization

Scaling parameters determination and its correlation with operational parameters.



PI: Johannes S. Vrouwenvelder

Email: natalia.francoclavijo@kaust.edu.sa

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Greener **Desalination**

From nature to nature: Eco-friendly, bioinspired antibiofouling coatings for greener desalination

Krishnaveni Venkidusamy

Motivation

Biofouling is a critical challenge in seawater desalination systems as it impairs membrane performance, integrity, and its longevity. Biofouling occurs through a cascade of events as illustrated in Fig 1. Antibiofouling (ABF) coatings are a promising strategy to control the impacts of biofilms. My research focuses on interdisciplinary research in microbiology, polymer science, and engineering to develop bio-inspired and eco-friendly ABF coatings for targeted water treatment applications.

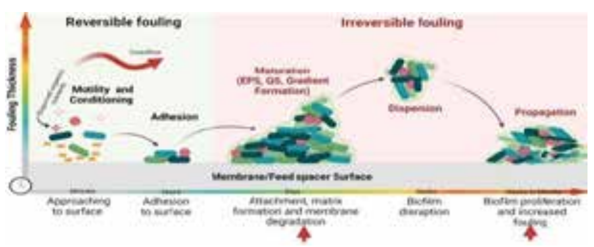

Fig 1: Membrane biofouling processes

Challenge

Biofouling is mainly a feed spacer problem in spacer-filled channels, however, most biofouling control research has focused on membrane modification[1]. Most of these effective modifications used biocidal formulations, but environmental concerns and legislation are driving science and technology towards non-biocidal solutions. Thus, developing greener alternatives with non-biocide-release-based ABF technologies are therefore urgently sought for biofouling control in industrial applications.

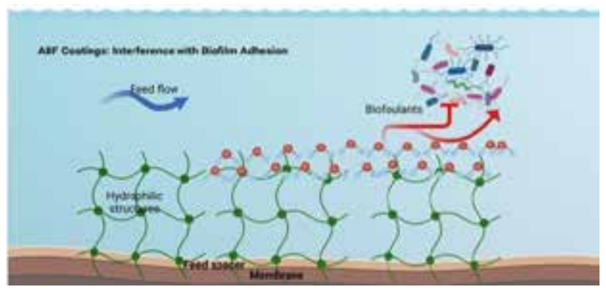

Fig 2: Passive ABF coatings prevent biofilm adhesion

PI: Prof. Johannes S. Vrouwevelder

Email: krishnaveni.vendkidusamy@kaust.edu.sa

Research goals

✓ Develop effective bio-inspired ABF coatings as greener alternatives to combat biofouling in real seawater desalination

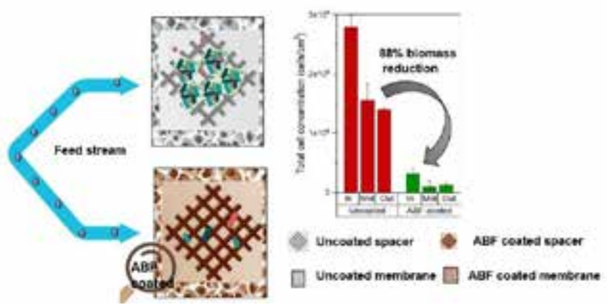

Fig 2: Bioinspired ABF coatings on membrane and spacer

✓ Eco- friendly and applicable to wide variety of materials based on non-toxic, non-biocide-release principles for targeted water treatment applications

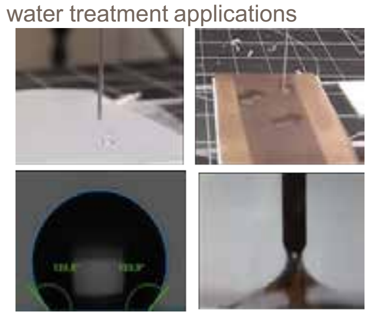

Fig 3: Properties of uncoated and coated feed spacers

✓ Scalable & real-time surface modification within a membrane module for practical applications

Uncoated spacer *ABF coated spacer*

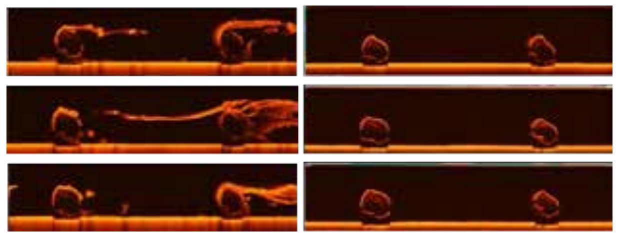

Fig 3: Spatial biofilm distribution on coated and uncoated feed spacer surfaces at the end of study

References

1. 1. Vrouwenvelder, J. S., et al. Water research 43, (2009): 583-594

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Greener **Desalination**

Smarter Antiscalants Choices for Seawater Desalination

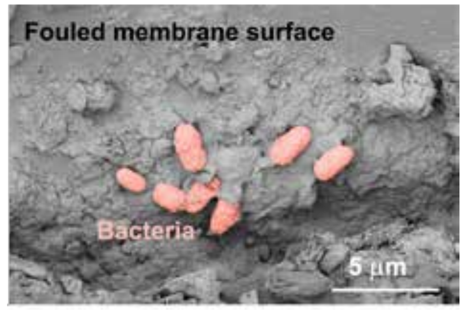
Ghadeer Hasanin

Motivation

Antiscalants are chemicals added to prevent scaling on seawater desalination reverse osmosis (RO) membrane systems

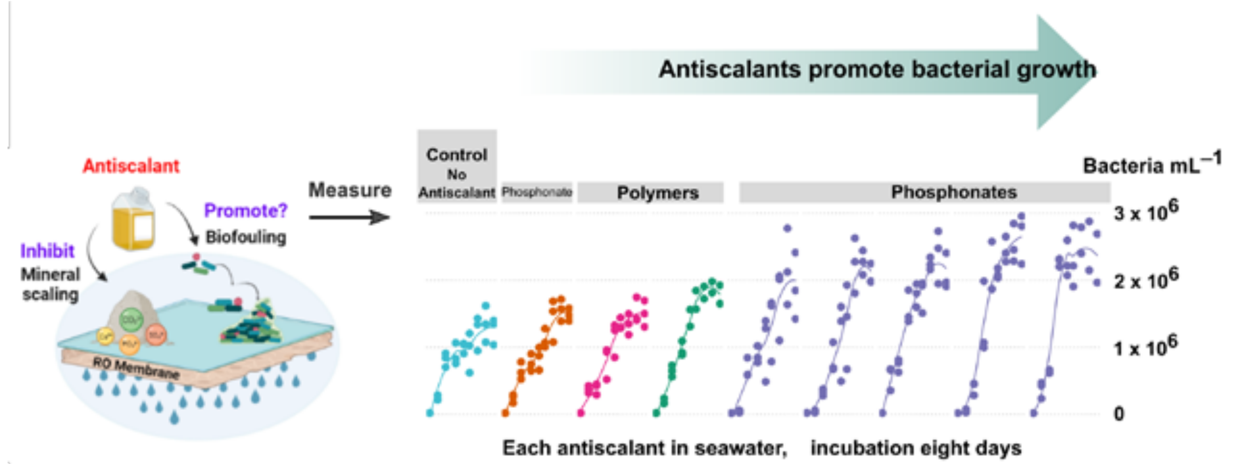
> “Inappropriate antiscalants can promote microbial growth by providing carbon or phosphorus to bacteria, resulting in early membrane blockage”

To improve the selection of antiscalants, we devised a test to measure the microbial growth potential of antiscalants in natural seawater.



Highlights

- Our bacterial growth potential test of antiscalants in natural seawater and native bacterial population as inoculum assists on smarter selection of antiscalants, which improves RO desalination performance.
- Polymers showed no significant increase in bacterial growth.
- Phosphonate-based antiscalants showed a broad range in growth potential under phosphorus limiting conditions..



PI: Johannes S. Vrouwenvelder

Email: graciela.gonzalezgil@kaust.edu.sa

To know more:
Hasanin et al. 2023. The microbial growth potential of antiscalants used in seawater desalination. Water Research. 233:119802.

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Greener **Desalination**

Water treatment by Gravity-Driven Membrane (GDM) filtration: Understanding the role of membrane biofilm on water quality and permeate flux.

Luigi Ranieri

Motivation

SUSTAINABLE DEVELOPMENT GOALS

Gravity-driven membrane (GDM) processes have recently been proposed as a *sustainable alternative* for water treatment presenting several advantages, including (i) low operating energy (ii) and the achievement of a stable permeate flux, allowing long-term reliable operation without any chemical cleaning [1,4].

Challenge

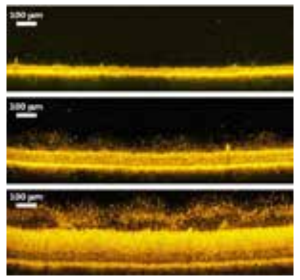


Fig 1.

The stabilized permeate flux and effluent quality are directly linked to the formation of porous biofilm layer on the GDM membrane surface, which is the result of the deposition of organic and non-biodegradable substances, and microorganisms. [1]

However, the impacts of biofilm on membrane performance and water quality, are still not fully understood [1].

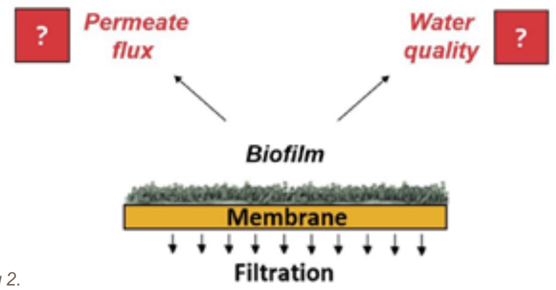


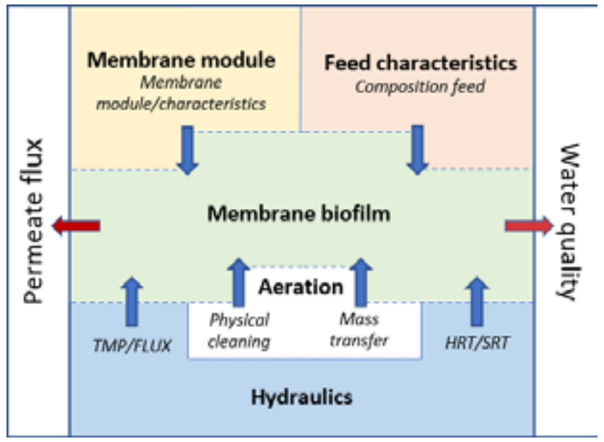
Fig 2.

Fig 1 Membrane biofilm development in GDM.
Fig.2 Schematic drawing of membrane biofilm layer in GDM

Research goals

Understanding the role of membrane biofilm through:

- Evaluation of GDM performance under different process conditions;



- Observation and characterization of biofilm properties (composition and structure).

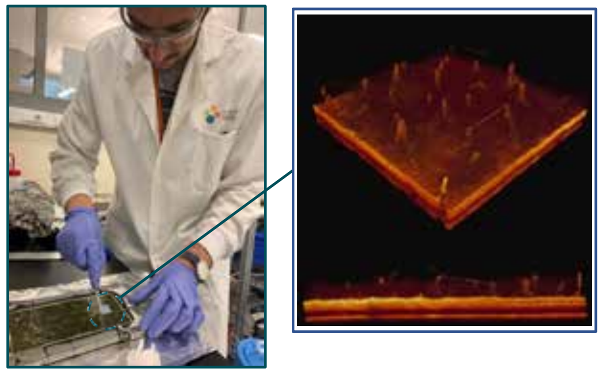


Fig. 3: 3D visualization of OCT scans [3]

References:
1 Ranieri et al. 2022, *Science of the Total Environment, 838, 156340;*
2 Ranieri et al. 2023, *Desalination, 549, 116353*
3 Fortunato, Ranieri et al. 2020, *Journal of Membrane Science, 610, 118261;*
4 Fortunato et al. 2017, Journal of Membrane Science, 521

PI: Johannes S. Vrouwenvelder

Email: luigi.ranieri@kaust.edu.sa

Water Desalination and Reuse Center

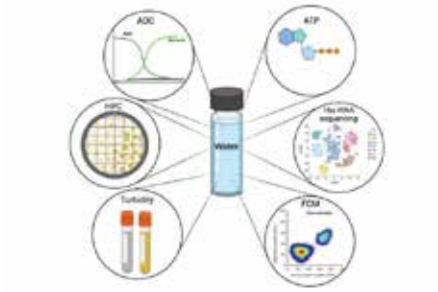
Greener **Desalination**

Assessment of the Bacterial Growth Potential in Reverse Osmosis Produced Chlorinated Drinking Water

Alejandra Ibarra Felix

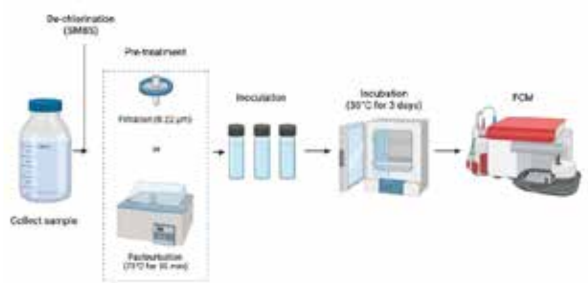
Motivation

Reverse Osmosis (RO) is capable of producing high-quality drinking water with an ultra-low nutrient level. Therefore, a very low bacterial growth potential (BGP). BGP is a key bioassay to evaluate the microbial quality and the biological stability of drinking water. Current methods to assess BGP in drinking water need to be adapted to the wide variety of water types due to the different results that could be obtained from each and consequently, their interpretation.



Scientific Challenge

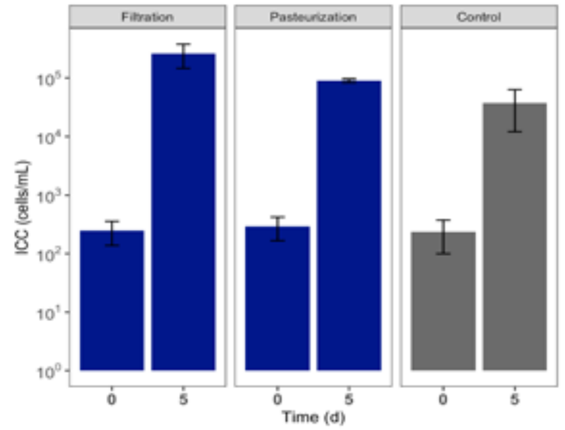
Current BGP methods vary in test conditions such as pre-treatment and inoculum types, quenching agent type, and concentration. Up to date, BGP lacks a standardization for specific types of drinking water



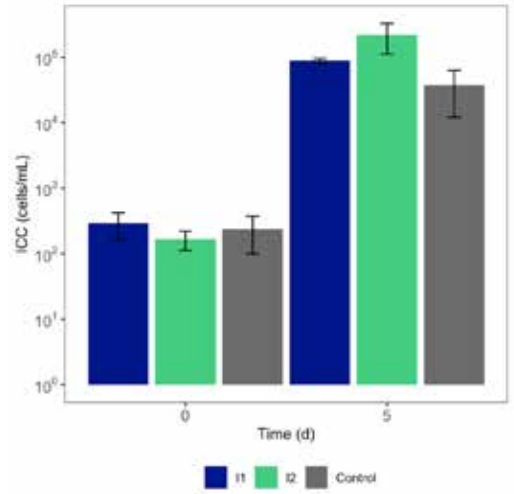
Research goals

Evaluating the application of an FCM-based BGP assay for RO-produced chlorinated drinking water. The approach combines the standardization of a quenching agent concentration, the impact of sample pre-treatment, the effect of inoculum type, and the effect of magnesium addition on BGP.

Effect of sample pre-treatment



Effect of inoculum type



PI: Johannes Vrouwenvelder

Email: Alejandra.ibarrafelix@kaust.edu.sa

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Organic micropollutants removal by biofilm in gravity-driven membrane bioreactor

Yeong Na

Motivation

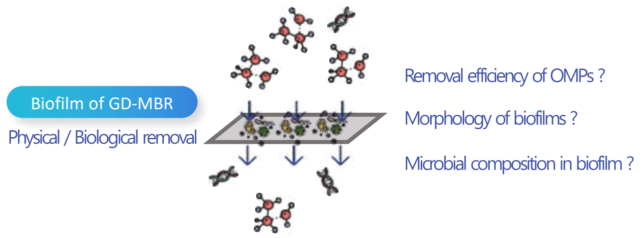
Wastewater contains a variety of micropollutants called emerging contaminants (ECs) that pose environmental and human health risks. Conventional treatment methods are not effective in removing ECs. Gravity-driven Membrane Bioreactors (GD-MBRs), offer a sustainable and low-energy solution for treating organic micropollutants.

GD-MBRs show promise in degrading ECs and can be combined with granular activated carbon (GAC) for enhanced removal. However, further research is needed to fully understand GD-MBRs' degradation capabilities and their contribution to contaminant removal under different conditions.

Challenge

Biofilm plays a key role in the GD-MBR process efficiency, as it contributes to the biological and physical removal of contaminants. The composition and structure of the microbial community within the biofilm are directly associated with the performance of GD-MBRs.

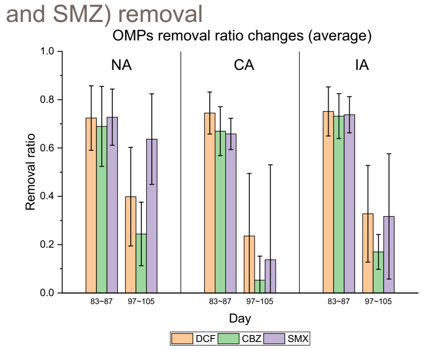
Dissolved Oxygen (DO) is a crucial factor in shaping the microbial community in GD-MBRs. However, the comprehensive understanding of the influence of DO conditions on biofilms within GD-MBRs, as well as their impact on the removal of micropollutants, remains incomplete. Therefore, it is imperative to comprehend the behavior of GD-MBRs under varying DO conditions.



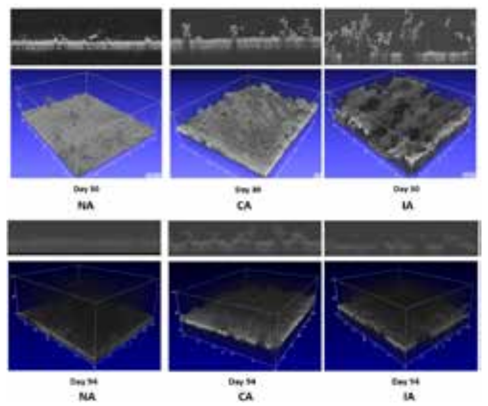
In this study, three different conditions for the GD-MBRs were tested with real wastewater : no-aeration (NA), continuous aeration (CA), and intermittent aeration (IA). Diclofenac (DCF), Carbamazepine (CBZ), and sulfamethoxazole (SMX) have been selected due to their widespread usage. GD-MBR operated without OMPs for 78 days to grow the biofilms, and selected OMPs are dosed for 28 days.

Research goals

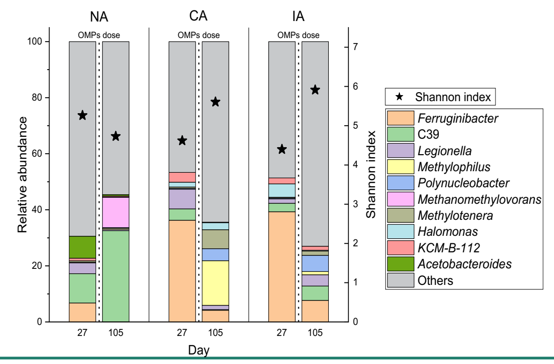
- Evaluate the performance of GD-MBR in different conditions (NA, CA and IA) on selected OMPs (DCF, CBZ and SMZ) removal



- Examine the morphologies of biofilms in each GD-MBR



- Determine the microbial community (bacterial/archaeal) before and after OMPs dosing in each conditions reactors



PI: Johannes S. Vrouwenvelder

Email: yeong.na@kaust.edu.sa

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Micronanobubbles as potential curative and preventive strategies for SWRO biofouling

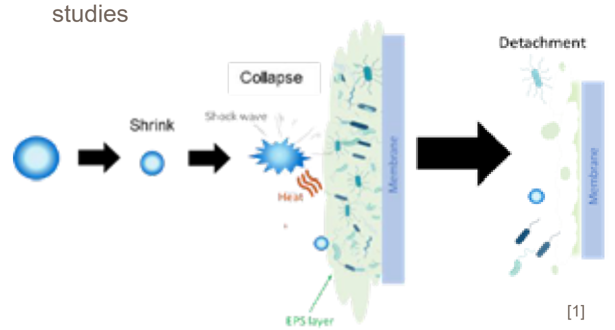
Damaris Alvarez

Motivation

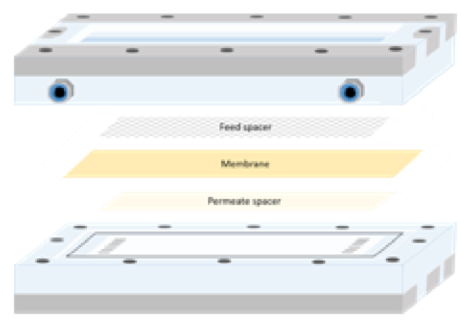
Current industry membrane cleaning practices use chemical treatments to restore membrane performance. However, they result in high costs and a significant environmental impact. Therefore, there is a need for novel effective green cleaning strategies for SWRO to meet the increasing demand while protecting the environment.

Scientific Challenge

- Micronanobubbles (MNBs) have shown to alleviate membrane fouling with synthetic fouling agents or precultured waste/river water biofilms short-term studies



- Test the effectiveness of these methods with real biofouling for longer studies that simulate the operating conditions of a real desalination plant.



Membrane fouling simulator

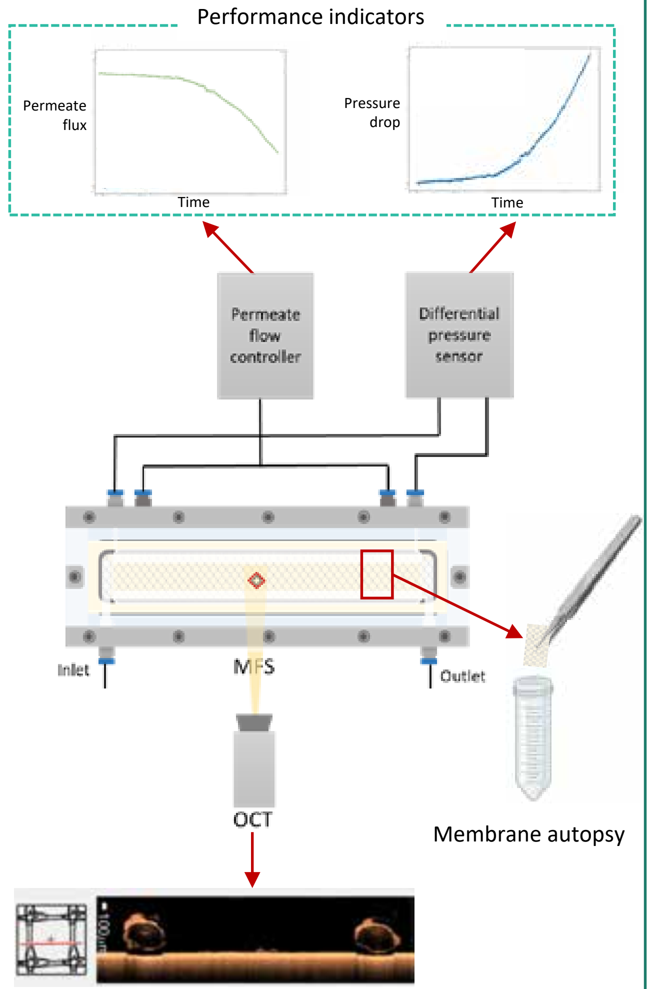
[1] Modified from Agarwal et al. (2012)

Research goals

Evaluate the efficiency of both air-filled micronanobubbles (AMNBs) and CO2 nucleated MNBs as:

1. Curative cleaning-in-place treatments
2. Preventive treatments

For tapwater and seawater biofouling over long-term studies.



PI: Johannes S. Vrouwenvelder

Email: damaris.alvarezsosa@kaust.edu.sa

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Microbial water quality in a reverse osmosis produced drinking water distribution system: Fundamentals and applications

Ratna Putri

Motivation

Significant advancements in membrane-filtration technology have made it possible to produce drinking water from seawater. Reverse osmosis (RO) is the most effective membrane-based filtration method to remove bacteria, viruses, and organic and inorganic contaminants. Only a few studies exist on the biological stability of RO-produced water in full-scale distribution networks. Studies show that bacterial regrowth and biofilm are unavoidable in distribution pipes supplying RO water to consumers. Various operational and physicochemical conditions also affect the bacterial abundance and the dynamics of the bacterial community of RO water, but still underexplored. Information from microbial water quality assessment can serve as operational and surveillance data for improved water quality management

Focus study of biological stability in RO water

Measure/describe change in water quality	Predict change	Methods evaluation and development

Scientific Challenge

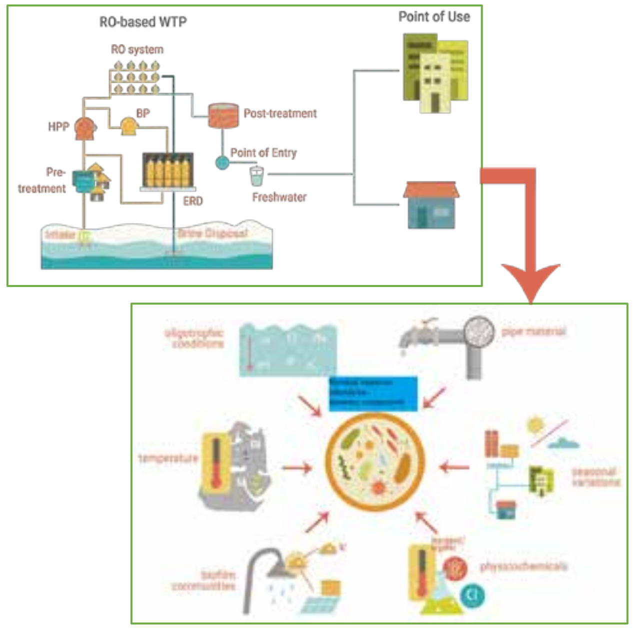
- Chlorinated RO-produced water characterized by low DNA yields. Different schools of thought regarding the analysis of low DNA samples – Low DNA yields challenge the interpretation of results
- The need for sensitive methods and multi-parameter assessment applicable to ultra-pure quality (i.e. low biomass) RO water - Validation of pre-existing methods to ensure reliable data
- RO treatment completely de-mineralizes water; therefore, requiring remineralization before water distribution –The impact of remineralization type on biological stability is not explored
- How do consumers' choices of plumbing materials (i.e. showerhead) affect their outlet water quality?

Research goals

This research aims to

(i) improve the current DNA-based methods applied for drinking water microbiome studies in RO-produced water and,

(ii) disentangle the influence of physicochemical factors and their modifications (i.e. remineralization, water heating), and operational conditions (stagnation, building size/location, temporal/spatial dynamics) to the overall RO water biostability



References:

1. Putri R E, et al. (2021). PLoS ONE., 16(6): e0253799
2. Farhat, N, Kim, L H, et al. (2022). Water Research., 210: 117975

PI: Johannes S. Vrouwenvelder

Email: ratna.putri@kaust.edu.sa

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Solar desalination and salt harvesting using superhydrophobic photothermal membranes

Sarah Almahfoodh

Motivation

Solar desalination is a sustainable desalination method that could satisfy two aspects:

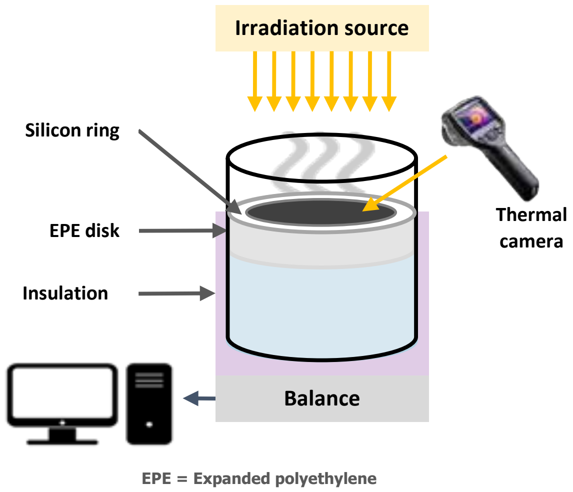
- Desalination of brackish and seawater in remote regions with limited access to electricity
- Brine treatment and salt recovery from conventional desalination plants

Challenge

Photothermal membranes faces several challenges in practice, including:

1. Salt crystallization on the surface of the photothermal membrane due to its hydrophilicity
2. Low vapor production from real streams due to scale formation within the pores of the membrane

In this work, we produce superhydrophobic graphene oxide (SGO) membranes that prevent the formation of salt on the surface. The SGO membranes are assessed in a solar steam generation (SSG) process under 1 sun of illumination.



Experimental apparatus

Research goals

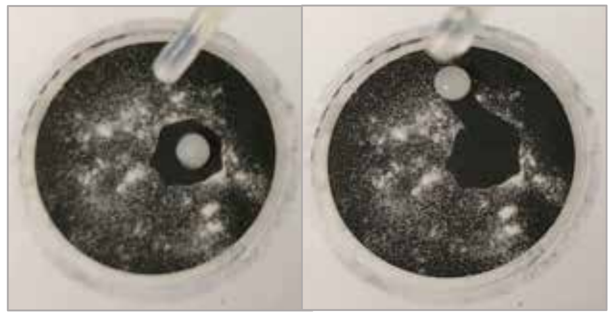
Investigate the photothermal membrane in an 8-hour solar steam generation (SSG) process using:

1. NaCl aqueous solution at 0, 10, 35, and 70 g/L
2. Red Sea water reverse osmosis (SWRO) brine discharge

Results and conclusions

1. Successful salt harvesting (82%) achieved
2. High photothermal efficiency (80%) achieved; corresponding to an evaporation rate of 1.4 LMH
3. High performance maintained in untreated Red Sea water and SWRO, which resulted in slightly lower evaporation rates (1.2 and 1.1 LMH, respectively) due to the presence of scaling ions.

Salt harvesting around the membrane. The photothermal layer remained intact.



Self-cleaning properties of the superhydrophobic photothermal layer

PI: Noreddine Ghaffour

Email: sarah.almahfoodh@kaust.edu.sa

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Investigating the biofilm distribution during direct contact membrane distillation of the Red Sea water

Harun Elcik

Motivation

Membrane distillation (MD), a hybrid thermal-membrane desalination technology, is gaining increased attention for its ability to produce high-quality freshwater from seawater/brine owing to its several distinct advantages, including diminutive dependence on the feed water salinity and very high salt rejection.

Challenge

Membrane biofouling is considered one of the critical challenges faced by seawater desalination today, greatly compromising the efficiency of the desalination processes and increasing the operational expenses. While in mature processes, such as reverse osmosis biofouling is widely investigated, in emerging processes such as membrane distillation (MD), its development is complicated due to the temperature effect that adversely affects the growth of microorganisms. Given the high relevance of MD to regions with abundant warm seawater, it is important to explore the biofouling propensity of microbial communities with higher tolerance to elevated temperature conditions.

Research goals

-Investigation of mechanisms and major factors that influence biofilm formation potential and its effect on process performance and permeate quality during direct contact MD (DCMD) of the Red Sea water.
-Evaluation of the combined spatial and temporal effects of biofilm distribution over the membrane surface, including its structure, morphology, and microbial/organic composition at different feed water temperatures common to the MD process.
-Exploration of biofilm proliferation and its composition on the membrane surface.

Conclusions

-A shift in bacterial diversity was observed with the increase in the feed temperature. A number of thermophilic bacteria colonized the membrane surface.
-Intact cells in biofilms were dominant over the damaged cells.
-Diversity of EPS fluorescence peaks decreased with the increase in feed temperature.
-Biofilm thickness increased along the feed water path due to temperature gradient.

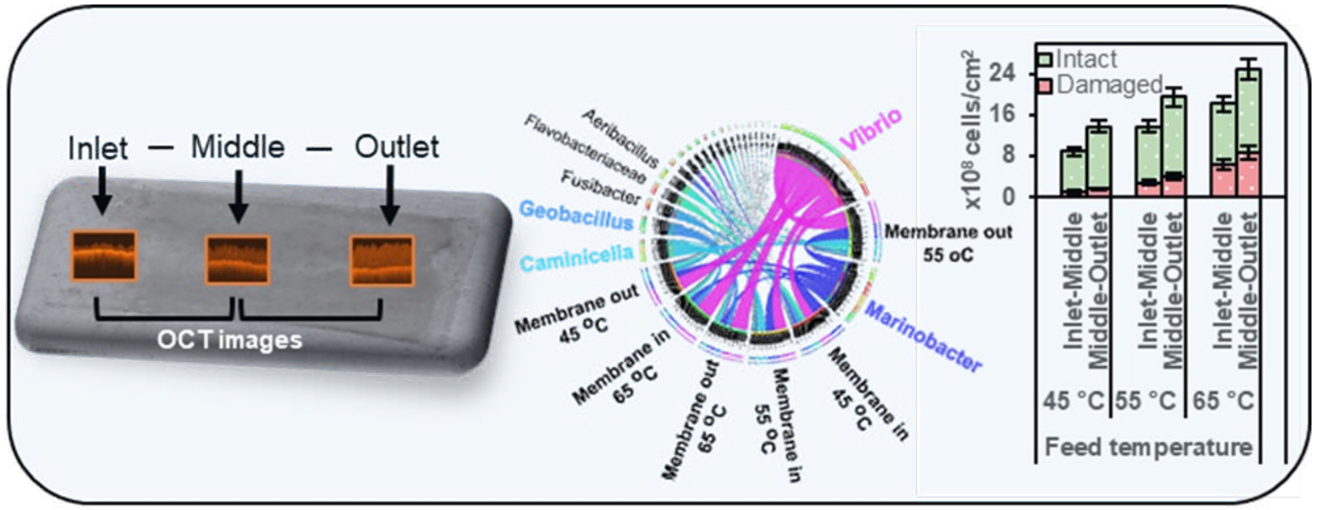

Fig. 1. Analysis of the spatial and temporal biofilm distribution: OCT imaging (left), microbial community analysis (middle), spatial distribution of intact and damaged cells (right) [1].

PI: Noreddine Ghaffour

Email: harun.elcik@kaust.edu.sa

Reference:
[1] Elcik, H., Alpatova, A., Gonzalez-Gil, G., Blankert, B., Farhat, N., Amin, N. A., Vrouwenvelder J.S., Ghaffour, N. (2022). Elucidating biofouling over thermal and spatial gradients in seawater membrane distillation in hot climatic conditions. Water Research, 223, 118983.

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Evaluating the osmotic backwashing cleaning potential for produced water fouled forward osmosis membranes

Muhammad Saqib Nawaz

Motivation

During produced water (PW) treatment with forward osmosis (FO) the membrane gets fouled. Osmotic backwashing (OB) is a unique phenomenon in FO to remove reversible foulants without any hydraulic pressure application. This research optimizes OB protocol for PW fouled FO membranes cleaning.

Challenge

Optimization of OB protocol to produce higher flux recovery and lower reverse solute flux (RSF) in repetitive experiments.
Methodology adopted as per **Figure** 1 and some results are shown in **Figure 2.** The key findings of the study are shown in **Figure 3.**

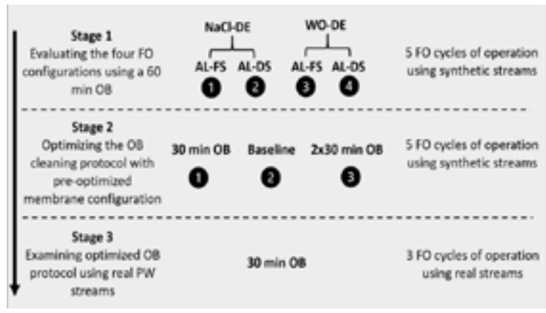

Figure 1: Experimental protocol used in the study

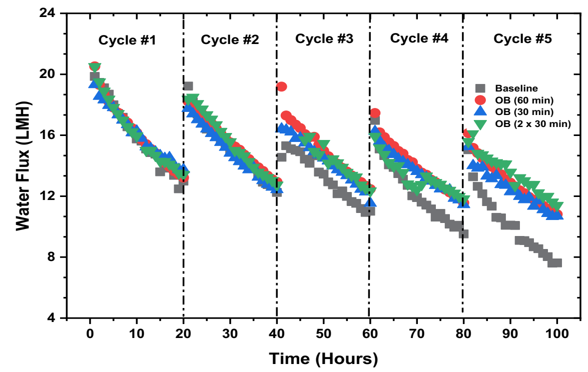

Figure 2: Flux trends under different OB protocols

Research goals

- Explore the potential of OB in long-term repetitive experimental cycles using synthetic and real PW streams.
- Systematic optimization of the OB protocol keeping in view the flux, RSF, membrane integrity, and system availability.

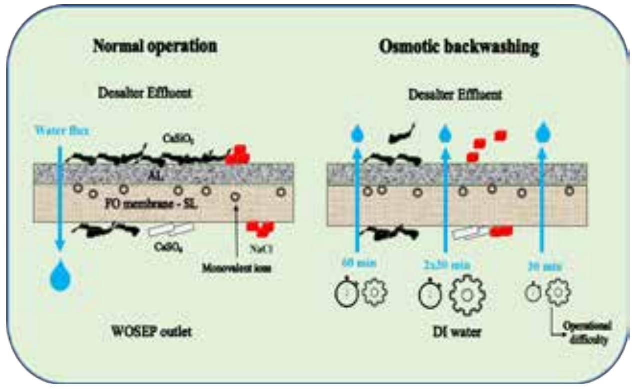

Figure 3: Key findings of the study

Conclusions

- 30 min OB gave highest (96.2%) cumulative system efficiency due to greater system availability (97.6%) and higher effective recovery (98.2%).
- OB with 30 min produced 13% higher flux recovery and 10% lesser SRSF compared to baseline (no OB) scenario.
- Real PW streams gave a 3% higher flux recovery and 46% lower SRSF compared to synthetic streams.
- There were no major changes in the membrane surface roughness and active groups due to OB.
- OB strategy in this study uses same concentrated feed stream instead of a third artificially made stream, making it sustainable and operation friendly.

Reference: (Alamoudi et al., 2022): Optimization of osmotic backwashing cleaning protocol for produced water fouled forward osmosis membranes. Journal of Membrane Science (2022) 663: 121013.

PI: Noreddine Ghaffour

Email: muhammad.nawaz.1@kaust.edu.sa

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Design and scale-up of membrane separation processes

Sofiane Soukane

Motivation

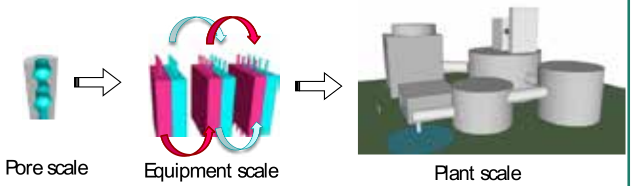
Membrane processes represent a viable alternative to address global water scarcity. In a context of climate-water-energy-food nexus, membrane-based desalination and water treatment processes have to comply to stringent performance and environmental requirements. Therefore, reliable scale-up and optimization strategies are needed to design sustainable processes.

Challenge

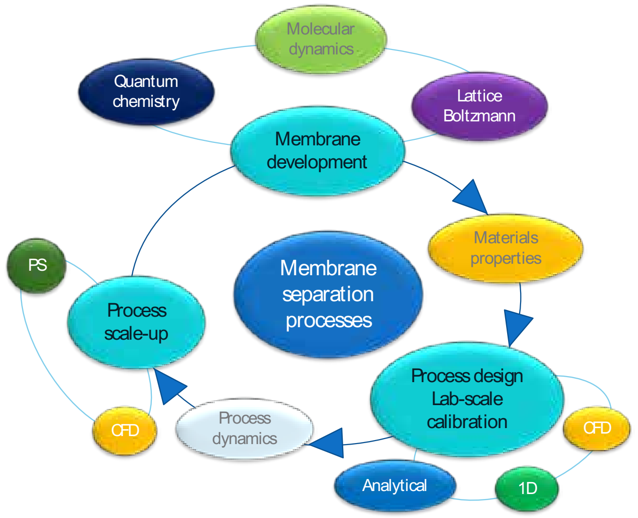
The scale-up design of a chemical process consists of translating a laboratory prototype to a larger scale. This procedure is performed with the purpose of increasing the system productivity, which in case of membrane separation processes such as membrane distillation or forward osmosis, is represented by the quantities of valuable fluids (water) or compounds (minerals) transferred through or retained by the membranes. Therefore, the scale-up procedure is associated with the size of the membrane active area offered by the system. Ideally, an increase of the membrane area would lead to the same increase ratio of the productivity. Unfortunately, this linear relationship is seldom observed as strong non-linearity prevails in real life. Although separation occurs at the membrane interface, momentum, heat and mass transfer, which strongly depend on equipment design, can limit the system performance. In order to minimize trial and error at the design and scale-up stages, both experimental and modeling developments are key to assess how systems behave. Models, which couple momentum, heat and mass transfer to species transport across membranes, if well calibrated with targeted experimental results could help identifying the required adjustments to sustain productivity by virtually designing and increasing the equipment size.

Research goals

- Establish reliable procedures to scale-up membrane separation processes.



- Use mixed experimental and advanced modeling strategies to build reliable models for process design and scale-up.



PI: Noreddine Ghaffour

Email: sofiane.soukane@kaust.edu.sa

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In situ conductive spacers for early pore wetting detection in membrane distillation

Alla Alpatova

Motivation

Membrane distillation (MD) could aid in effective seawater desalination and brine management due to its lower reliance on feed water osmotic pressure. In MD, the water vapor is stratified from the heated saline stream by hydrophobic membrane and condensed on the permeate side which has lower temperature.

Challenge

The quality of product water in MD process is superior dye to hydrophobic properties of membrane that prevent liquid from passing through its pores. However, as MD process evolves, a condition called *"pore wetting"* is developed that causes water protrusion to permeate side and deterioration of permeate quality.

To achieve stable MD performance, we propose to utilize **electrically-conductive Pt-coated spacers** placed inside the feed and coolant channels with **a dual purpose of maximizing permeate flux** and **instantaneous wetting detection once first membrane pores are compromised**.

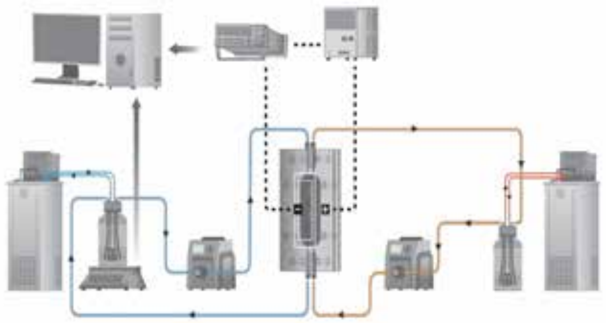

Fig.1. A schematic of the DCMD system operated in a counter-current mode that was tested in our study.

The solid lines represent the MD loop, and dashed lines represent the electrical loop. The conductive spacers are connected to a power source and multimeter to measure generated electrical current.

Research goals

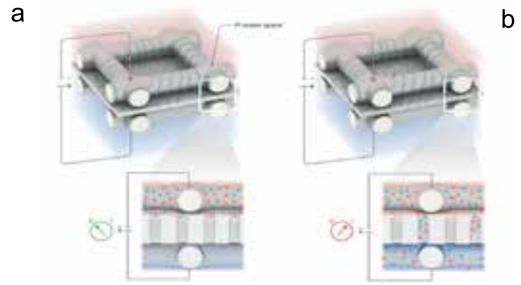

Fig. 2. Electrical current detection in DCMD process without pore wetting (a), and with wetted membrane pores (b).

No electrical current is detected in a normal DCMD operation (absence of wetting). In a compromised DCMD operation, the feed water that contains salts, protruded to permeate side initiating electrochemical reaction and electrical current production.

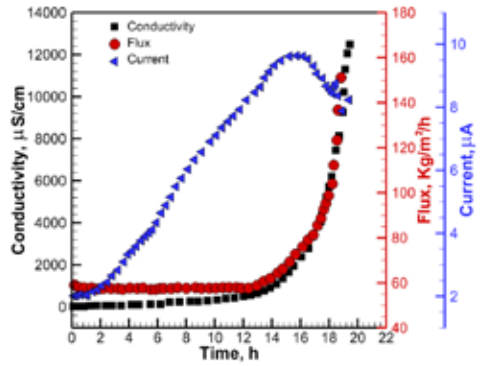

Fig. 3. Changes in DCMD parameters pore wetting induced by a 200 mg/L of sodium dodecyl sulfate.

The electrically-based wetting detection can be applied in any technological application that involves water transport and in which dielectric fluid is in a contact with the surface/bulk material.

More details: Sep. Purif. Technol., 294, 121162, 2022.

PI: Noreddine Ghaffour

Email: alla.alpatova@kaust.edu.sa

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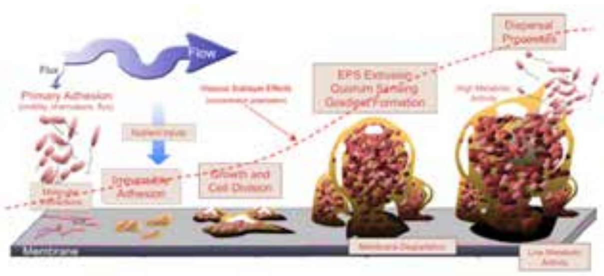
Artificial Intelligent Framework for Early Decision-Making and Preventive Controls

Najat A. Amin

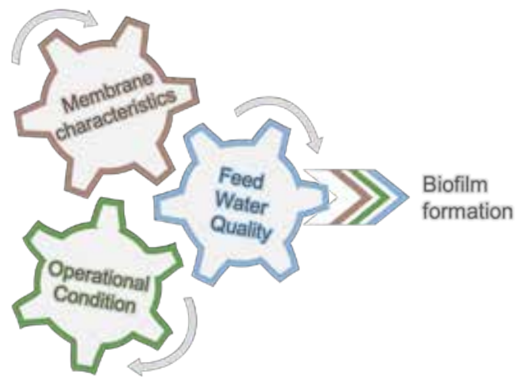
Motivation

Membrane biofouling remains the predominant challenge related to the operation of reverse osmosis (RO) systems. This phenomenon significantly reduces the performance and efficiency of RO membranes, leading to an increase in energy consumption and operating costs. Therefore, the development of biofouling monitoring strategies with early detection of biofilm formation on membrane systems is critically required.



Challenge

Several input parameters can affect the biofouling propensity in RO systems and influence its performance, including:

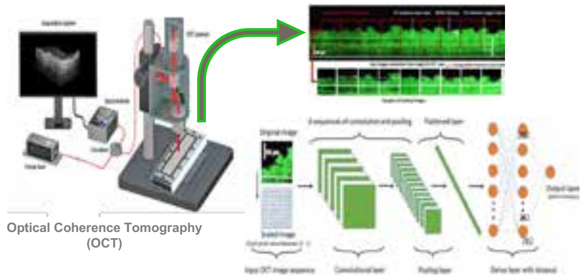


These variations in the input parameters significantly affect permeate water quality and process efficiency.

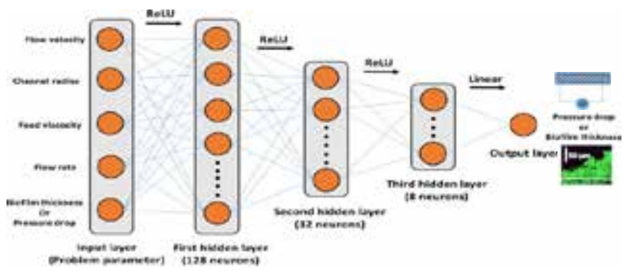
Research goal

Developing a toolbox that can automatically correlate biofouling formation with hydrodynamic parameters in a lab device adjacent to the large-scale modules in order to establish a control strategy in an AI framework, in which:

- Convolutional Neural Network (CNN) is trained by using databases of biofilm images generated from an in-situ Optical Coherence Tomography (OCT) scan of biofouling development in a membrane fouling simulator (MFS) to predict the thickness of biofilm in RO system.



- Non-Linear Regression-Deep Neural Network (NLR-DNN) is also trained in order to predict the non-linear relationship between hydrodynamic parameters and associate it with growing biofilm thicknesses in the filtration process.



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Hoek, E. M., Weigand, T. M., & Edalat, A. (2022). Reverse osmosis membrane biofouling: causes, consequences and countermeasures. npj Clean Water, 5(1).
Qamar, A., Kerdi, S., Amin, N., Zhang, X., Vrouwenvelder, J., & Ghaffour, N. (2022). A deep neural networks framework for in-situ biofilm thickness detection and hydrodynamics tracing for filtration systems. Separation and Purification Technology, 301, 121959.

PI: Noreddine Ghaffour

Email: Najat.amin@kaust.edu.sa

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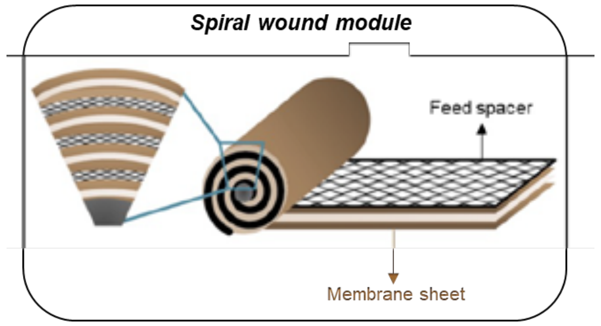
Novel spacer designs for enhanced filtration performance and (bio)fouling mitigation in filtration systems

Sarah Kerdi

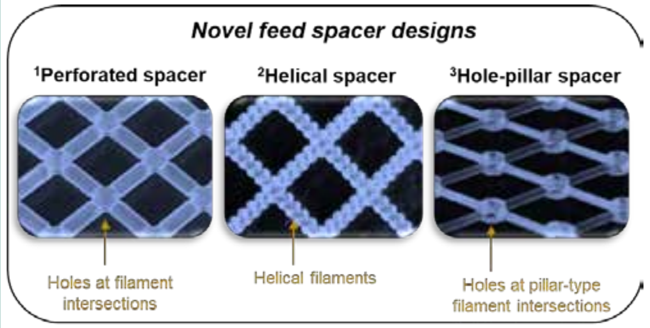
Motivation

Membrane filtration technologies have thrived rapidly to compensate for freshwater scarcity. Besides its mechanical support to the membrane, the feed spacer in spiral wound modules (SWM) helps to enhance the fluid mixing and promote unsteadiness resulting in improving water production and minimizing (bio)fouling development. Thus, the control of hydrodynamics in the filtration channel by optimal spacer design is required for efficient SWM.



Challenge

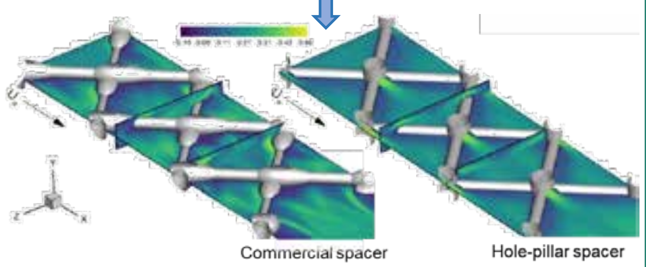
The commercial spacer design creates a low channel porosity, local dead zones, and asymmetrical shear stress/velocity distribution. These limitations tarnish the filtration performance, favor biofouling growth, and raise operating costs. We propose novel 3D-printed feed spacer designs enabled to overcome the intricate hydrodynamics nature of the commercial design.



[1]Kerdi et al., Water Research 140 (2018) 211-219, [2]Kerdi et al., Desalination, 484 (2020) 114454, [3]Qamar et al., Scientific Report, 11 (2021) 6979.

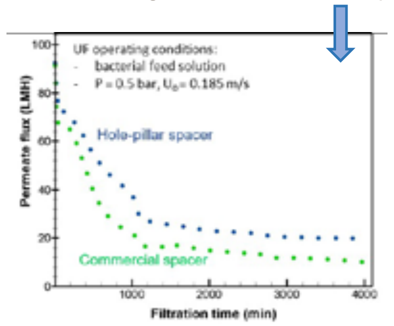
Research goals

- The novel spacers were designed and in-house fabricated by 3D-printer technology.
- As per Direct numerical simulations (DNS), higher localized velocity/unsteadiness was demonstrated using our novel spacers compared to the commercial spacer.

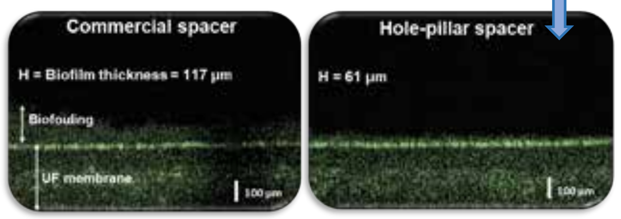


- Utilizing our novel spacers, ultrafiltration (UF) experiments revealed:

✓ Higher permeate flux production with a percentage increase reaching 75% in case of hole-pillar spacer.



✓ Anti-biofouling potential as characterized by optical coherence tomography at 67h of UF.



PI: Noreddine Ghaffour

Email: sarah.kerdi@kaust.edu.sa

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Fabrication of high-performance PAN-supported thin film composite membrane for forward osmosis application

Mohamed Obaid Awad

Motivation

Globally, the interdependency between the water and energy is getting more and more attention from academia, industrial, as well as the general public. It is essential to an in-depth understanding of the water-energy nexus to provide an optimum and practical solution for the water and energy scarcity, simultaneously. Thus, developing a cost-effect, simple, scalable, efficient membrane, or modification of the existing membranes to treat and desalinate wastewater and seawater, respectively, is highly recommended to provide fresh water as well as decrease the energy required for the process.

In this work, we fabricated a novel thin-film composite (TFC) forward osmosis membrane using PAN nanofiber as a low-tortuous, highly porous, and hydrophilic substrate.

Scientific Challenge

Current FO membranes frequently encounter the challenge of internal concentration polarization (ICP) inside the porous substrate, which can reduce effective osmosis driving force and subsequently deteriorate membrane performance with severe flux loss. To decrease the ICP effect, the substrate should be thin, highly porous, and hydrophilic.

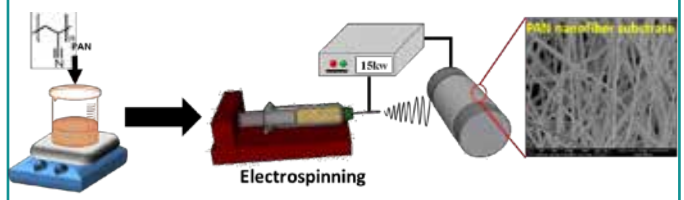


Fig. 1. The fabrication process of PAN nanofiber substrate by electrospinning technique..

Research goals

1- Fabrication of TFC-FO membrane

The electrospinning method was initially used to fabricate a highly porous, hydrophilic, and very thin PAN nanofiber substrate (Fig. 1). After the PAN nanofiber substrate was ready, a layer of polyamide (PA) was synthesized on top of it via an interfacial polymerization method (Fig. 2).

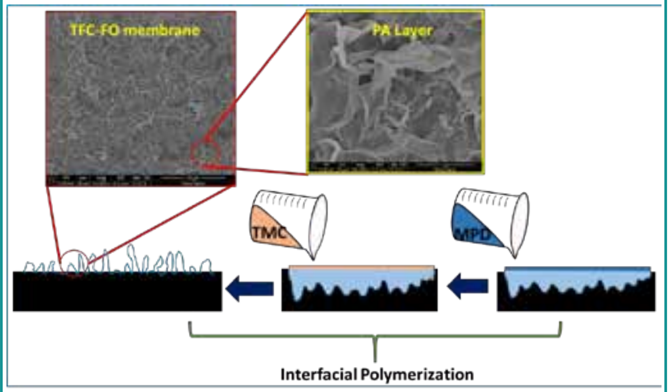


Fig. 2. Fabrication of polyamide (PA) layer on the as-prepared PAN nanofiber substrate using interfacial polymerization.

2- FO performance test

The performance of as-prepared TFC-FO membrane was evaluated using a lab-scale cross-flow FO system. The membrane performance in terms of water flux and reverse salt flux is presented in Fig. 3.

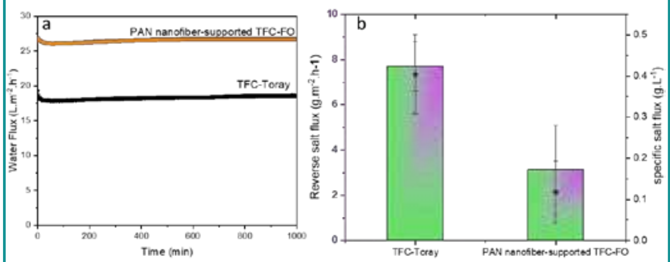


Fig. 3. Performance comparison of the as-prepared TFC-FO membrane and commercial membrane (TFC-Toray) (a) Water flux and (b) reverse salt flux and specific salt flux. AL-FS mode, Draw solution and feed solution are 0.5M NaCl and DI, respectively.

PI: Noreddine Ghaffour

Email: mohammed.awad@kaust.edu.sa

King Abdullah University of Science and Technology | Water Desalination and Reuse Center

Greener **Desalination**

Measurement of elemental (ultra-)traces in water and solids

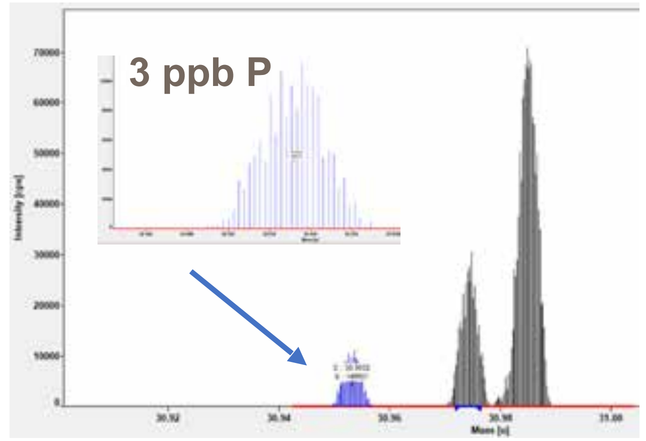
Geert-Jan Witkamp

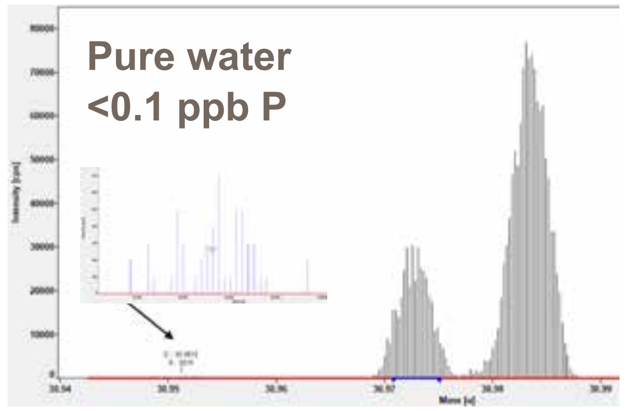
Motivation

At ultralow concentration levels, the fate of elements is largely unknown. Limitations or excess amounts of trace elements can critically determine life processes. In geology, archeology, paleontology, chemical industry, mining, the processes are often understood through elemental concentrations and isotopic ratios.

In the KAUST research statement (Witkamp, 2017) the purchase of a sector field high resolution inductively coupled plasma spectrometer with an ablation laser was proposed which is now running in a beautiful semi-cleanroom at Core Labs. They are an Thermo Element XR and an Applied Spectra J200. More importantly, the lab is continually serviced by two highly competent analytical chemists who develop new methods, provide instructions, and keep the instruments in excellent condition.

Left peak and insert: 3 ppb phosphorus in water (150 k counts).
Right: probably 15N16O and 14N16OH





Challenges

Tackling contamination at pg/g level.

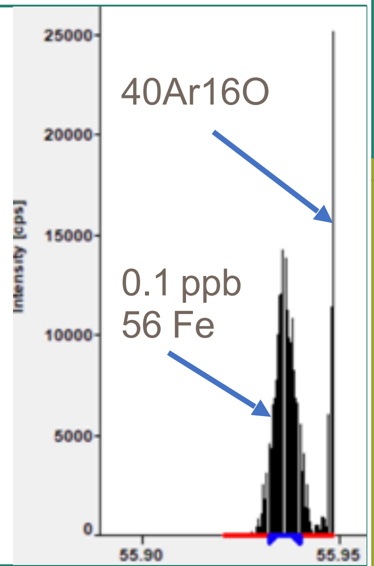
In the argon plasma, thousands of short-lived complexes between the traces and hydrogen, argon, oxygen, nitrogen and other bulk elements create interferences.

Carry over or memory effects caused by minute amounts of compound sticking somewhere in the sample introduction system.

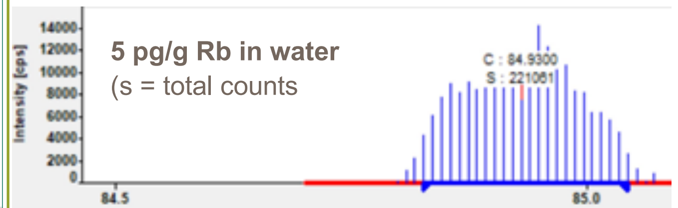
Fluctuations in the plasma at % level cause uncertainties in signal.

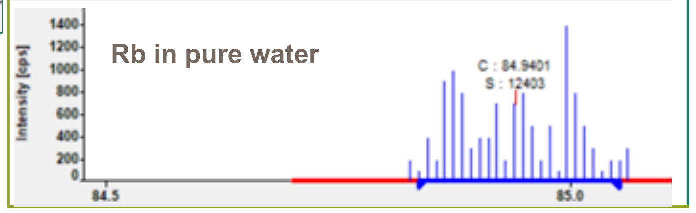
Examples

Separation of 56Fe signal from 40Ar16O interference



5 ppt (5 pg/g) rubidium in MQ
and <300 ppq (fg/g) Rb in pure MQ





Email: geertjan.witkamp@kaust.edu.sa

Water Desalination and Reuse Center

Greener Desalination

Development of liquid membranes for the recovery of trace elements

Andreia Farinha

Motivation

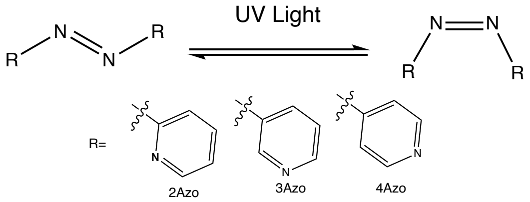
Water contamination is one of the most critical environmental hazards. The pollutants in water are responsible for diseases, affecting its quality and availability worldwide.

We aim to develop liquid membranes for water treatment which will guarantee access to clean water and will recover valuable raw materials. Our research aligns with three of the Sustainable Development Goals; 6 – Clean water and sanitation, 11 – Sustainable cities and communities, and 12 – Responsible consumption and production.

Challenge

- Design and prepare stable molecular carriers for liquid membranes:

1. Photoswitch carriers: by action of UV light these compounds can be converted from E to Z form improving their ability to interact with metals.



2. Hydrophobic NADES – H-NADES are green solvents formed by supramolecular interactions between two or more natural products. One or two of the components are hydrophobic, which makes the solvent immiscible with water.

- Characterize the carriers (stability, ability to bind metals, and experimental conditions to release the metals)
- Find selective materials for the elements targeted for specific industrial waste.

Research goals

Develop liquid membranes for trace elements recovery from different waste streams.

Results

- **Photosiwtch's compounds**

2Azo, 3Azo, and 4Azo, in E and Z form, were placed in contact with a multielement solution (10 ppb). The compound (Z)3Azo showed a significant capability to extract lanthanides from the starting solution.

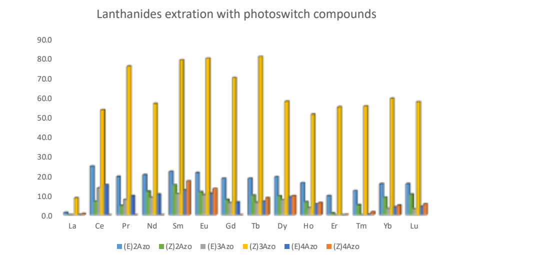


Figure: Percentage of Lanthanides extracted from a aqueous solution using the azo compounds.

- **Hydrophobic Natural Deep Eutectic Solvents**

H-NADES composed of menthol and organic acids showed an extraordinary capacity for removing trace elements from freshwater spiked with a multielement solution (100 ppb concentration). Similar tests with a starting multielement solution of 10 ppb, showed that Menthol:Lactic Acid (M:LA) is able to remove most of the elements. Nevertheless, Menthol:Acetic Acid (M:A) is no longer able to remove the elements from the water.

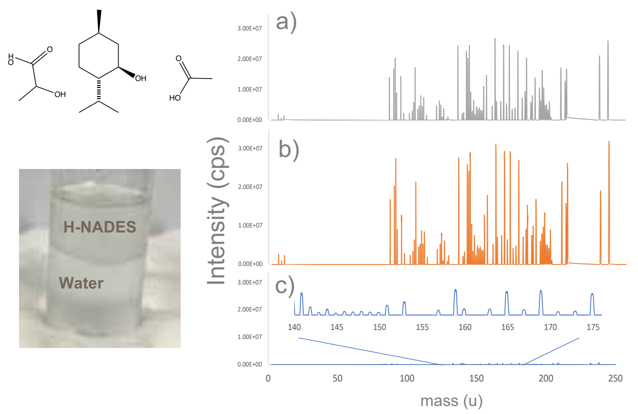


Figure: left H-NADES components, and H-NADES:WATERS two phase solution; rigth: HR-ICP-MS spectrum of a multielement solution with a concentration of 10 ppm before contact with H-NADES (a), after contact with H-NADES M:A(b) and M:LA(c).

PI: Geert-Jan Witkamp

Email: andreia.farinha@kaust.edu.sa

Water Desalination and Reuse Center

Greener Desalination

Bulk, trace, and rare-earth metal removal and recovery using Eutectic Freeze Crystallization (EFC)

Ana Rousseva

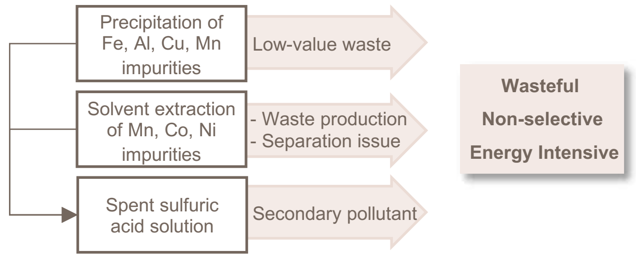
Motivation

Traditional Mining	vs. Urban Mining
- Linear economy	- Circular economy
- Unsustainable	- High sustainability potential
- Difficult and limited extraction	- Highly available and diverse
- **Low** metal concentration per mass of ore	- **High** metal concentration per mass of E-waste[1]

Industrial Need
Effective, efficient, low-waste recovery of valuable metals from E-waste, especially batteries, PCBs, and magnets.

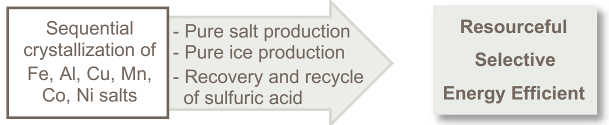
Example: Li-ion batteries

Current Li-ion battery recycling



vs.

Proposed Li-ion battery recycling **with EFC**



Challenges

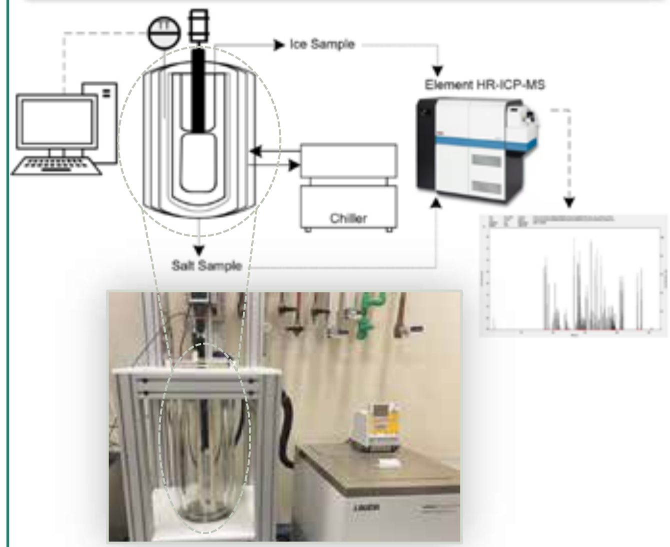
- Minimization of scaling on the inner reactor wall.
- Determination of eutectic and optimal operating points for multicomponent solutions.

PI: Geert-Jan Witkamp

Email: ana.rousseva@kaust.edu.sa

Experimental Plan

1. - Conduct EFC with bulk salt solutions spiked with trace/rare-earth metals.
   - Quantify trace/rare earth metal distribution among ice, mother liquor, and salt crystal phases via HR-ICP-MS.
2. - Conduct EFC to determine eutectic points of salts in a complex aqueous solution (e.g. acidic strip solution from Li-ion battery recycling).
   - Sequentially crystallize salts and determine their purity via HR-ICP-MS analysis.
3. - Conduct EFC to determine eutectic points and crystallize trace/rare earth metal salts.
   - Determine salt purities via HR-ICP-MS analysis.



Eutectic Freeze Crystallizer

- Triple-walled glass vessel with scraper attachment. No mixing issues or high local supersaturation.
- High precision PT100 monitoring of mother liquid.
- Upscalable: 1, 2, 5, 10, and 20 L glass crystallizers available. SS316 demonstrated in industry to be suitable for EFC.

[1] P. Ghisellini, A. Ncube, M. Casazza, and R. Passaro, "Toward circular and socially just urban mining in global societies and cities: Present state and future perspectives," *Frontiers in Sustainable Cities*, vol. 4, Sep. 2022, doi: 10.3389/frsc.2022.930061.

Water Desalination and Reuse Center

Greener **Desalination**

Trace element adsorption and recovery from the Red Sea and industrial streams

Victor Manuel Torres Serrano

Motivation

The trackability of trace elements arouses great interest due to their role in the expected transition toward *greener* energy sources (Figure 1) [1]. Its relevance is also related to their presence in oceans, since they give insights about geochemical and biological processes occurrence [2].

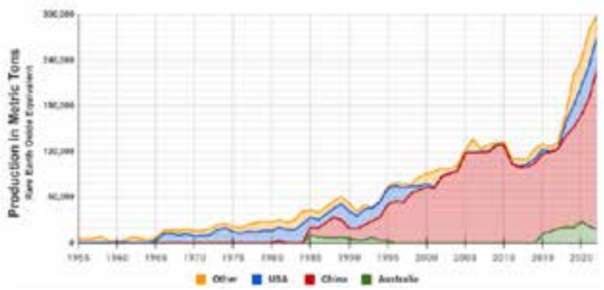


Figure 1: The world demand for trace and rare earth elements has increased from 100% to 150% between 2015 and 2020 [1].

Figure 2: Trace metals are found in oceans playing important role in geochemical and biological processes [2].

Challenges

The detection of these elements becomes challenging in natural water bodies (like seawater) due to their low concentrations (ultra-trace level).

It is possible to preconcentrate and recover trace elements by adsorption and subsequent adsorbent regeneration. However, traditional techniques include undesirable treatments at high and/or low pH.

Research goals

This research aims for:

1. Quantifying trace in particular areas in the Read Sea for tacking biological and geochemical phenomena by using High-Resolution Inductively Coupled Plasma Mass Spectrometry (**HR ICP-MS**) technique.
2. Preconcentrating trace elements by adsorption. Preliminary results with iron-based adsorbents (Figure 3) already showed 80-95% removal of elements at trace concentrations. The study will be extended to include Metallic Organic Frameworks (MOF's).
3. Testing the regeneration capabilities of Natural Deep Eutectic Solvents (**NADES**) (Figure 4) [4] to recover trace elements from water, avoiding treatments at extreme pH.
4. Apply the acquired knowledge to treat industrial effluents containing trace elements.

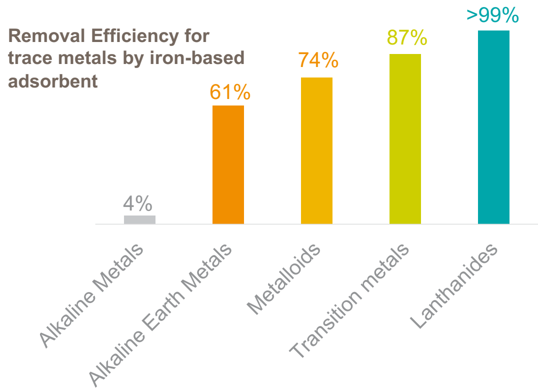


Figure 3: The iron-based adsorbents showed good performance for the removal of Lanthanides, Metalloids and Transition Metals at trace concentrations.

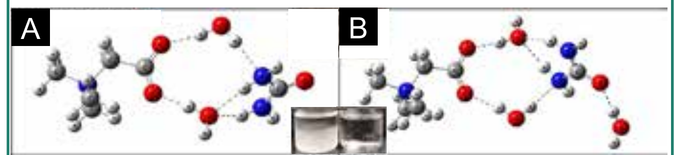


Figure 4: Molecular simulation of the NADES Betaine:Urea:Water (NADES example) in molar proportions (A) 1:1:2 and (B) 1:1:3 [4].

PI: Geert-Jan Witkamp

Email: victormanuel.torresserrano@kaust.edu.sa

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[1] https://geology.com/articles/rare-earth-elements/
[2] https://www.geomar.de/en/research/irf/metals-in-the-ocean
[3] Henderson GM. Ocean trace element cycles. Philos Trans A Math Phys Eng Sci. 2016 Nov 28;374(2081):20150300
[4] Maria F. Nava-Ocampo, Lamya Al Fuhaid, Adriano Santana, Szilárd S. Bucs, Robert Verpoorte, Young Hae Choi, Geert J. Witkamp, Johannes S. Vrouwenvelder, Andreia S.F. Farinha, Structural properties and stability of the Betaine-Urea natural deep eutectic solvent, Journal of Molecular Liquids, Volume 343, 2021

Water Desalination and Reuse Center

Greener **Desalination**

Natural deep eutectic solvents: Structure, Properties, Applications, and involvement in Biology

Lamya Al Fuhaid

Motivation

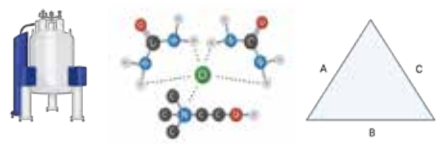
Natural deep eutectic solvents (NADES) represent a new class of green solvents formed from food-grade, inexpensive materials such as sugars and amino acids. NADES are involved in a wide range of applications, including the solubilization, stabilization and extraction of biomolecules. For example, previous work in our laboratory showed that NADES was able to dissolve the components of biofilms, providing a green solution for biofouling in reverse osmosis water desalination membranes.

Research Goals

1. Study NADES structure, physicochemical properties, supramolecular organization, and thermodynamics.
2. Understand the involvement of NADES in cellular metabolism and stress response in organisms.
3. Explore potential applications of NADES, specifically, in the fields of biomolecule stability and extraction.

NADES Structure and Stability

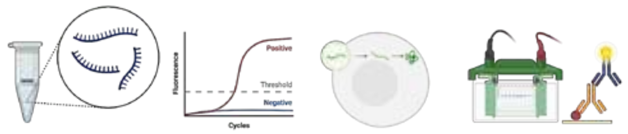
Studying NADES Supramolecular structure and developing methods to identify eutectic ratios of metabolites resulting in NADES immensely improve their synthesis and application.



Team: Andreia Farinha, Szilard Bucs

NADES for Biomolecule Stability

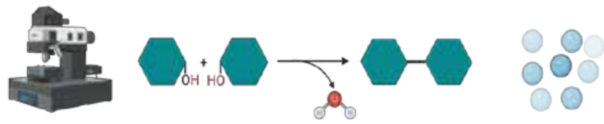
The superior stabilization capacity of NADES can be utilized for the long-term storage of highly unstable biomolecules, including RNA, at room temperature. The ability to stabilize RNA molecules facilitates RNA-related research and applications.



Team: Arwa Alghuneim, Andreia Farinha, Shahryar Khattak, Sergio Di Marco, and Imed Gallouzi

NADES in Biology

The components of NADES are abundantly present in plant and animal cells. Thus, studying NADES can contribute to understanding cellular metabolism, plant response to environmental stresses, and how multi-component osmolytes affect protein structure.



Team: Nischal Maharjan, Muhammad Ghifari Ridwan, Himanshu Mishra, and Salim Al-Babili

NADES for the Extraction of High-Value Compounds

NADES can be tailored for the selective extraction of high-value metabolites such as carotenoids, contributing to the food and pharmaceutical industries.

Team: Luca Fortunato, Najeh Kharbatia, Andreia Farinha, Gordon Wellman, Kyle Lauersen, Shanshan Song, and Salim Al-Babili

PI: Geert-Jan Witkamp

Email: lamya.fuhaid@kaust.edu.sa

Water Desalination and Reuse Center

Greener Desalination

Development of methodologies for trace metal quantification and recovery

Fernanda Tavares

Motivation

- Trace metals are non-biodegradable, and can bioaccumulate causing great damages to the environment, therefore methodologies for detection and removal of trace metals are necessary. Furthermore, the presence of some valuable elements, as rare earth elements (REE), gives great commercial value for these trace metals, making the recovery advantageous.
- Natural Deep Eutectic Solvents (**NADES**), are a class of solvents obtained by mixing natural solid compounds, which are promising metal extractors and suitable alternatives to avoid traditional techniques that involve high costs for separation [1]. However, the mechanisms underlying the ion binding of metal complexes are still to be understood [2,3], and research aiming the development of recovery methodologies with new medium is necessary.

Challenge

- The detection of such elements becomes challenging in natural water bodies (like seawater) due to their low concentrations (ultra-trace level). However, the High-Resolution Inductively Coupled Plasma Mass Spectrometry (**HR ICP-MS**) technique can detect and quantify ultra-trace concentrations.
- Find green alternatives as extraction medium for trace metals. First Experimental results showed the good performance of 3 NADES compounds, composed of menthol and lactic acid (1:1 and 1:2) and menthol and acetic acid (1:1), where the extraction was up to 98% (Figure 2) from solutions containing 10 ppb of multi elements.
- The extraction mechanisms involving the metal binding on the NADES solvents needs to be studied, as we see in Figure 3, the recovery is also affected by the initial pH of the 10 ppb contaminated solution, when employing the NADES of menthol and lactic acid (1:1), which also affects the mixture solution pH (final pH ~3).

Research goals

This research aims for:

1. Evaluation of different NADES composition for higher recovery of trace elements and REE.
2. Study of trace metal extraction mechanisms and how it is affected by the mixture pH and components solubility and hydrophobicity.
3. Kinetic study of trace metals recovery and application on marine environments.

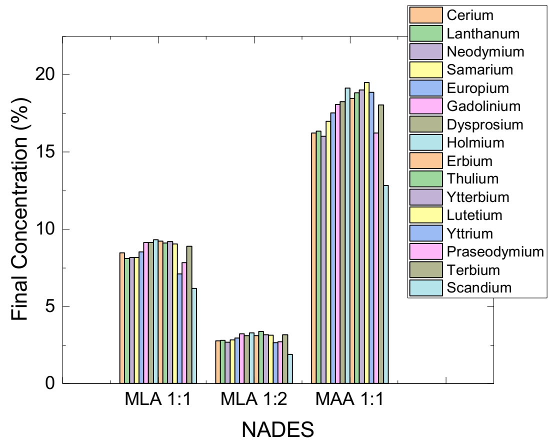


Figure 1: Final concentration of REE, detected by HR ICP-MS, on fresh water after extraction with different NADES at initial pH 2. MLA: Menthol/ Lactic acid. MAA: Menthol/ Acetic Acid.

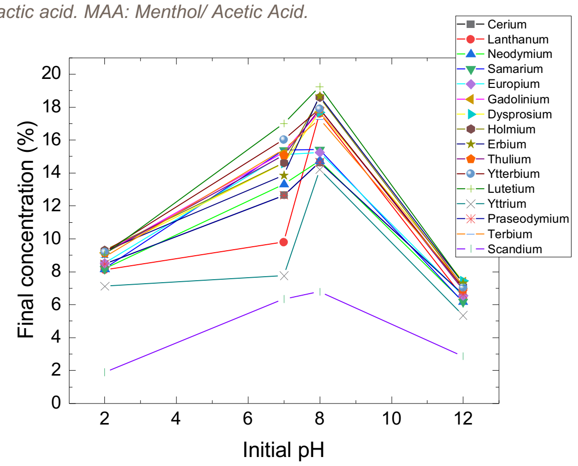


Figure 2: Final concentration of REE, detected by HR ICP-MS, on fresh water after extraction with NADES at different pHs

PI: Geert-Jan Witkamp

Email: fernanda.tavares@kaust.edu.sa

References

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[2] Osowska, N. and Ruzik, L., 2019. New potentials in the extraction of trace metal using natural deep eutectic solvents (NADES). Food Analytical Methods, 12, pp.926-935.
[3] Castro-Muñoz, R., Can Karaça, A., Saeed Kharazmi, M., Boczkaj, G., Hernández-Pinto, F.J., Anusha Siddiqui, S. and Jafari, S.M., 2023. Deep eutectic solvents for the food industry: extraction, processing, analysis, and packaging applications–a review. Critical Reviews in Food Science and Nutrition, pp.1-17.

Water Desalination and Reuse Center

Greener Desalination

Hydrophobic NADESs for Trace Metal Removal from Water

Mariana Rodrigues

Motivation

- Water contamination by trace levels of toxic heavy metals is a severe threat to human health and the environment;

- The use of H-NADESs (Hydrophobic Natural Deep Eutectic Solvents) is a promising and environmentally friendly option for recovering trace metals from aqueous solutions by inducing the selective transport of metal ions.

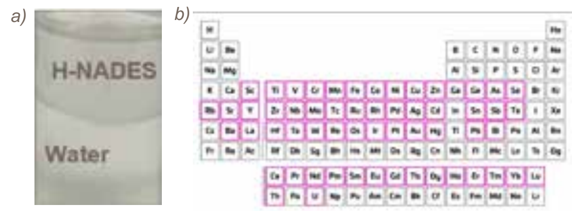


Figure 1: a) Phase separation between H-NADES in water; b) Elements present in multi-element standard.

Challenge

- High-Resolution Inductively Coupled Plasma Mass Spectrometry (HR ICP-MS) is applied to detect and quantify ultra-trace concentrations;
- Element stability can vary with pH, affecting removal efficiency;
- It is necessary to assess the amount of the NADES going into the aqueous phase;
- Ensuring successful extractions and preventing metal precipitation at specific pH levels is crucial;
- Example: Menthol:Lactic acid (1:2) effectively removed > 90% of metals in a 10 ppb solution (Fig 2);
- Figure 3: Improved performance of H-NADES with solutions at initial pHs of 8 (93%) and 12 (97%) (the final pH of the mix was within the range 2-4).

Research goals

1. Find optimal H-NADES for trace metal removal, depending on the matrix and its pH;
2. Find the optimal form (liquid, eutectogels) in which the H-NADES should be to perform the extractions.

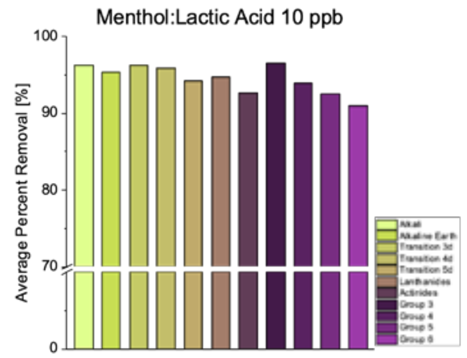


Figure 2: Removal efficiency of Menthol:Lactic Acid (MLA) (1:2) applied to a 10 ppb initial metal solution across all element groups.

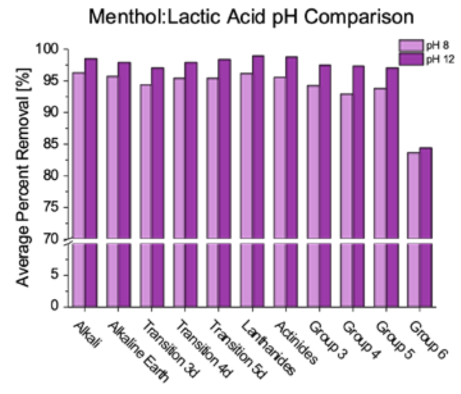


Figure 3: Increased efficiency for higher pHs.

PI: Geert-Jan Witkamp

Email: mariana.rodrigues@kaust.edu.sa

Water Desalination and Reuse Center

Greener Desalination

(Ultra-)trace profiling of stable isotopes

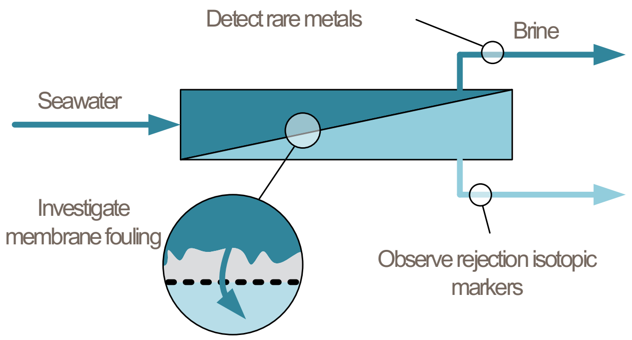
Filipa Simoes

Motivation

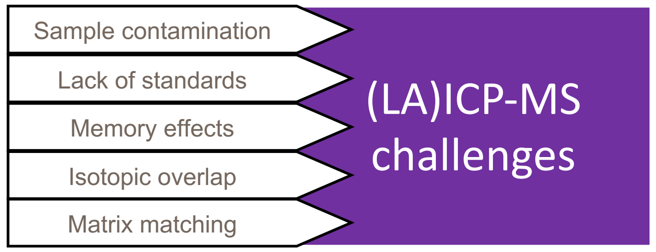
Following the fate of inorganic trace compounds during processes in desalination, in biological systems, mineral processing etc.,it is not only directly relevant for metal recovery, but also contributes to understanding underlying mechanisms.

i) Investigation of such compounds such as heavy metal pollutants or potentially valuable rare metals, in seawater, and wastewater - although challenging due to the clogging and the need of speciation;

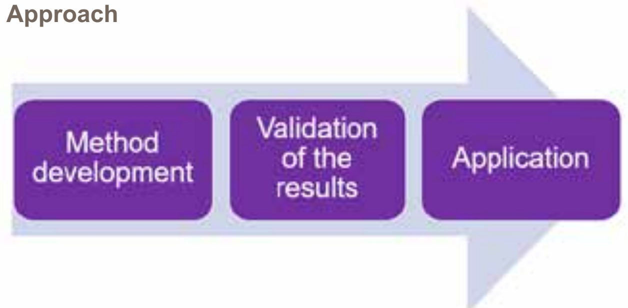
i) Such as fundamental research towards transport phenomena and fouling in membrane applications.



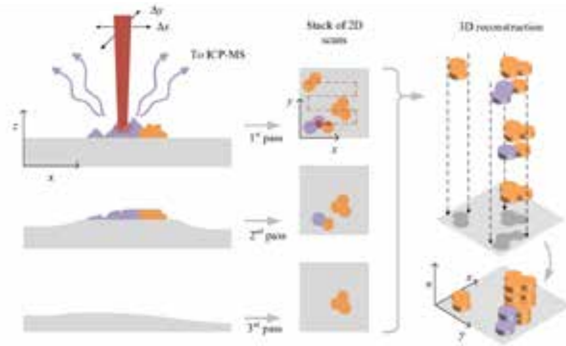
Technological and Scientific Challenge



Approach



The Element XR HR-ICP-MS coupled ASI J200 Femto QX Tandem laser ablation is able to resolve all of mass overlaps and it can provide lateral resolution of 2 microns.



Quantitative 3D reconstruction of membrane scaling.

Remarks

LA-ICP-MS is a promising analytical tool with several important applications in the field of desalination and wastewater reuse.

PI: Geert-Jan Witkamp

Email: Filipa.fernandessimoes@kaust.edu.sa

Water Desalination and Reuse Center

Greener Desalination

Multidimensional models of ion transport in composite membranes active layers with TEM-scanned morphology

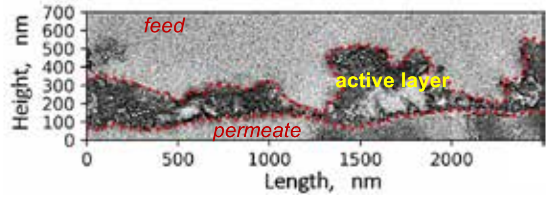
Fernan D. Martinez

Motivation

Current numerical models of ion transport through the active layers of reverse osmosis and nanofiltration membranes are *one-dimensional*, while advanced microscopy clearly shows a *three-dimensional* structure. We want to investigate the effects considering the more realistic 2D/3D geometries on permeation properties, compared with the simple 1D approaches.

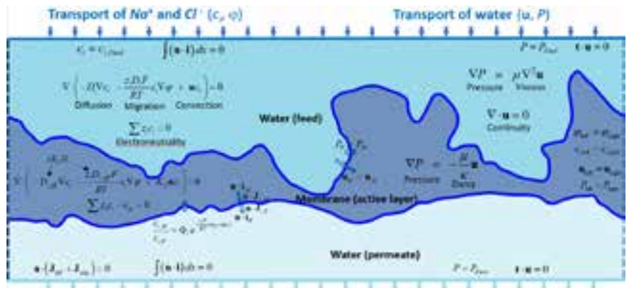
Challenges

- Obtain representative two- and three-dimensional polyamide active layer structures, usable as input geometries in the numerical models. These require sophisticated and laborious microscopy techniques (e.g. Transmission Electron Microscopy).



Example of polyamide active layer geometry obtained by TEM. The layer thickness is very irregular, thus a 1D representation is not suitable.

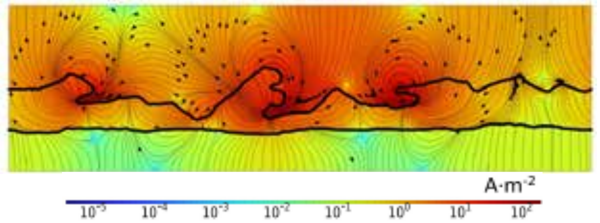
- Solving the mathematical representation of ion transport in the membrane by diffusion, electromigration and convection in conjunction with partition equilibria at the membrane-water interface (Donnan, steric, dielectric) is challenging numerically due to the gradients occurring at nanometer scale. Further complications include the representation of acid-base equilibria, ion-association, pH effects and non-uniform charge in the membrane. Water transport raises additional theoretical and numerical problems.



Physics of ion and water transport through the active layers.

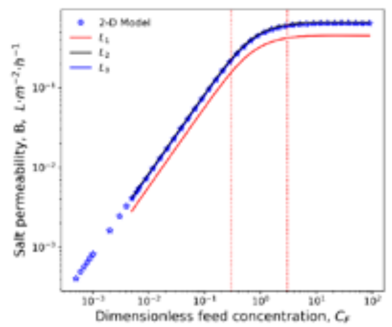
Research goals

- Investigate ion and water transport through two- and three-dimensional polyamide active layers of composite reverse osmosis membranes, with geometry extracted from microscopy images.
- Explain new phenomena, which may arise only in 2D/3D systems. For example, our models revealed the possible existence of weak circular ionic currents inside and in the water surrounding the active layer.



Ionic currents in a charged membrane, as streamlines with direction arrows. Color scale represents the magnitude of ionic current density on a logarithmic scale.

- Obtain a suitable parameter that allows reduction of the multidimensional models to much simpler 1D representations. The parameter should be computed from images of membrane active layer. We have shown that the response of a 2D model to variations in flux and salinity can be very similar to the response of a 1D model, providing that the 1D model uses a correct equivalent membrane thickness.



Active layer salt permeability *B*, function of a dimensionless feed salinity C_F, computed with the 2D model (blue stars) and with the 1D model using three methods to express equivalent thicknesses.

Martinez-Jimenez F.D., Musteata V.E., Cespedes-Zuluaga S., Blankert B., Picioreanu C. (2023) *Desalination* **565**,116876.

PI: Cristian Picioreanu

Email: fernan.martinez@kaust.edu.sa

Water Desalination and Reuse Center — Greener Desalination

Role of pH equilibria in boron separation by reverse osmosis

Felipe Salto

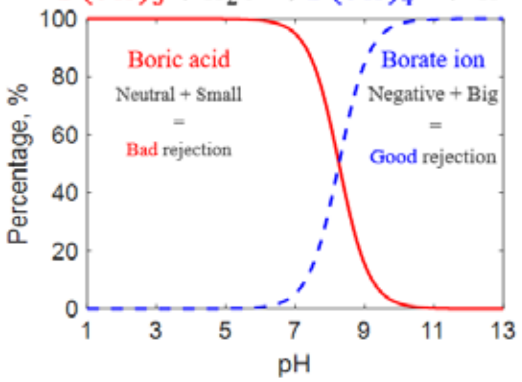
Motivation

- Boron removal with reverse osmosis is needed to meet environmental and health requirements.
- Mathematical models are required to develop desalination in industrial scale.

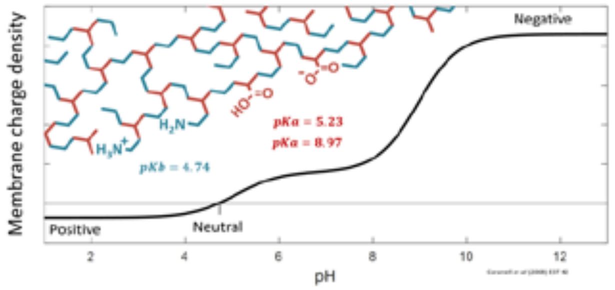
Challenge

- Boron removal depends on the acid-base equilibrium of boric acid, function of pH.

$$B(OH)_3 + H_2O \leftrightharpoons B(OH)_4^{\ -} + H^+$$

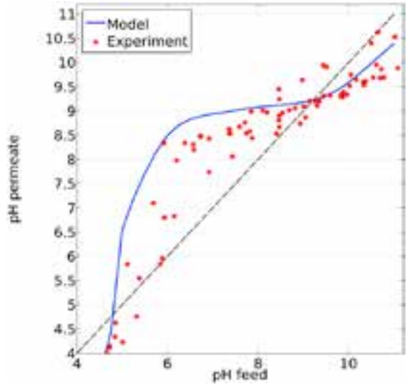


- Also, local pH is affected by reactions of acid-base equilibria, concentration-polarization, membrane equilibria and membrane charge.

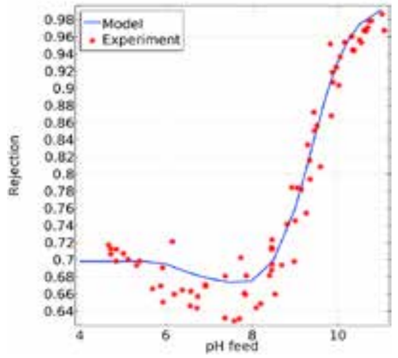


Research goals

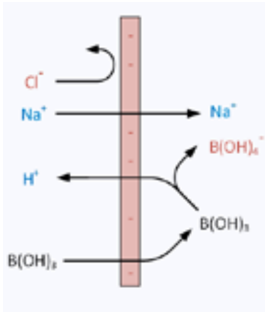
- To describe how the permeate pH changes after feedwater pH variations.



- To create a model that represents the boron rejection in function of pH



- To explain the mechanisms of transport of boron in desalination.



PI: Cristian Picioreanu

Email: felipe.saltoquintana@kaust.edu.sa

Water Desalination and Reuse Center — Greener Desalination

Modelling Biocorrosion


Raúl Dávalos   Luis Rosa

Motivation

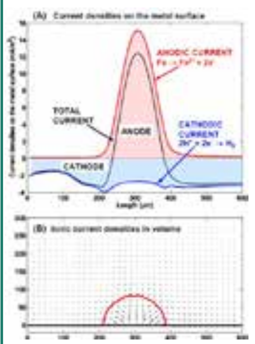
- Uncontrolled microbial activity, with the consequent corrosion enhancement (biocorrosion or microbially influenced corrosion - MIC), is one of the leading causes of pipeline failure in oil/gas and water treatment industries worldwide.
- Corrosion issues are estimated to cost Saudi Aramco $1.75 billion annually, with approximately 20% of this amount to be caused by biocorrosion.

Damaged steel pipeline due to biocorrosion

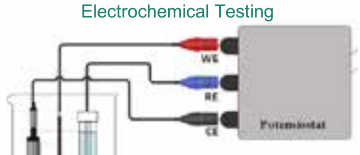
Technological Challenge

- Biocorrosion is a complex phenomenon that has been investigated for more than 50 years. Still, there is only limited understanding of its fundamental mechanisms.
- Our challenge is the creation of a reliable modelling approach to simulate and predict biocorrosion. This would be used to develop strategies to minimize the occurrence of biocorrosion and potential pipe failure.
- The target is to generate positive impact on asset integrity, operation continuity and maintenance costs of the pipelines in industry.

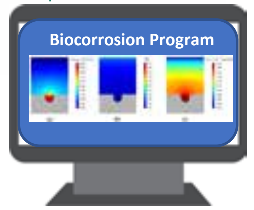
Modelling & Simulation



Electrochemical Testing



Computational Corrosion Tool

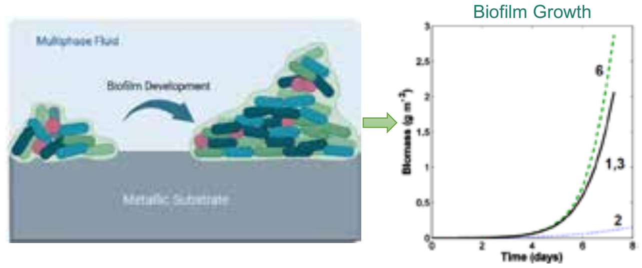


Research Goals

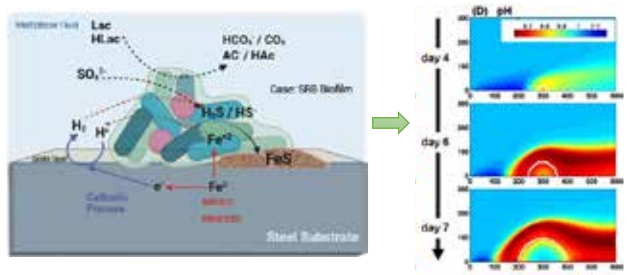
The main project goal is to develop computational tools for biocorrosion, based on coupled chemical, electrochemical and microbiological models. These will be backed up by electrochemical corrosion experimental data.

1. **Produce a biofilm development model**

Biofilm Growth

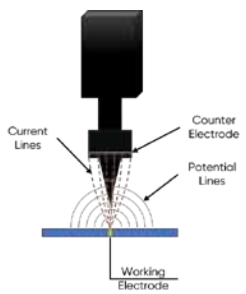


2. **Produce a microbiologically induced corrosion model**

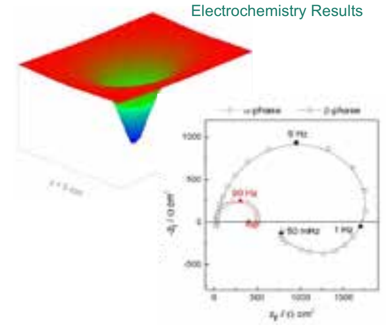


3. **Model compared with time-dependent experimental data obtained with Local Electrochemical Impedance Spectroscopy (LEIS)**

LEIS Working Principle



Electrochemistry Results



PI: Cristian Picioreanu

Industry sponsor: Saudi Aramco

Email: raulleandro.davalosmonteiro@kaust.edu.sa, luis.rosa@kaust.edu.sa

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Greener Desalination

Three-dimensional modeling flow, mass transfer and reaction in spacer-filled channels of membrane separation processes

Santiago Céspedes-Zuluaga

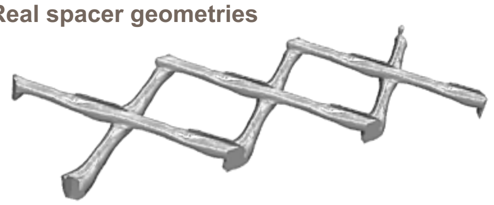
Motivation

Concentration polarization affects the membrane separation processes by increasing the transmembrane pressure and the potential for salt precipitation. My research focuses on understanding, through numerical simulation, the interaction between ions and the effect of different conditions inside the concentration polarization layer. This can lead to better membrane desalination process design, with reduced costs and less environmental impact.

Challenges

Predicting the performance of membrane separation processes requires better understanding of the phenomena involved. Thus, numerical simulations must consider more realistic conditions and intricate physical-chemical interactions.

1. Real spacer geometries



We compute with accurate 3D geometries taken from CT scans

2. Coupled interactions

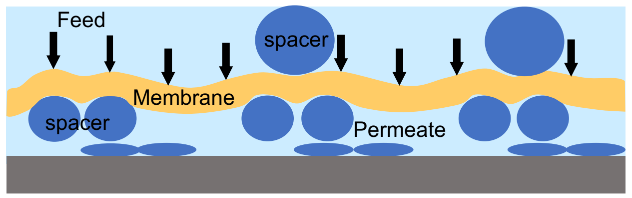
Fluid dynamics: laminar/turbulent, stationary/transient flow

Mass transfer: convection, diffusion, electromigration of solutes

Precipitation: homogeneous and heterogeneous reactions

Solid mechanics: elastic vs. plastic deformations

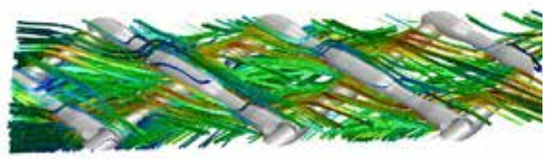
3. Feed/permeate spacer and membrane mechanics



Deformation of feed/permeate spacers and membrane can affect the process performance

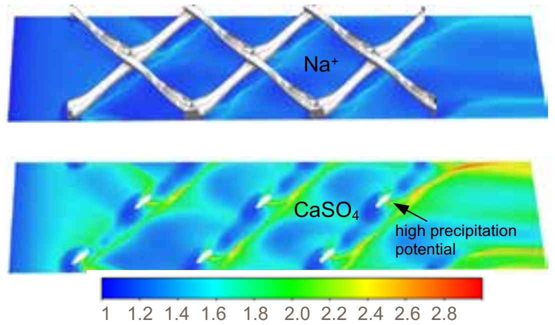
Research goals

1. Evaluate effects of realistic spacer geometry on the performance of membrane separation processes



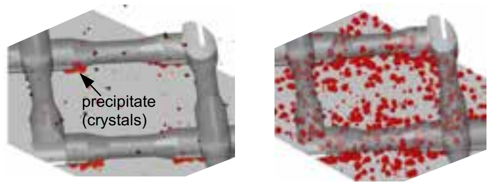
Flow patterns in the feed and permeate channels

2. Understand effects of coupled interactions in concentration polarization layers



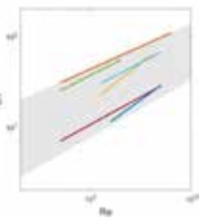
Concentration polarization moduli on membrane

3. Predict localized precipitation and scaling



4. Develop engineering mass transfer correlations based on numerical simulation of 3D multicomponent systems

$$Sh = f\left(Re, Sc, \frac{TMP}{\Delta\Pi}, \frac{B}{A \cdot TMP}, \ldots, \frac{h}{L}, \ldots\right)$$



5. Evaluate effects of deformation due to mechanical stresses
Pore blockage, more pressure drop, more salt passage.

PI: Cristian Picioreanu

Email: santiago.cespedeszuluaga@kaust.edu.sa

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Greener Desalination

Understanding the evolution of organic fouling in membrane distillation

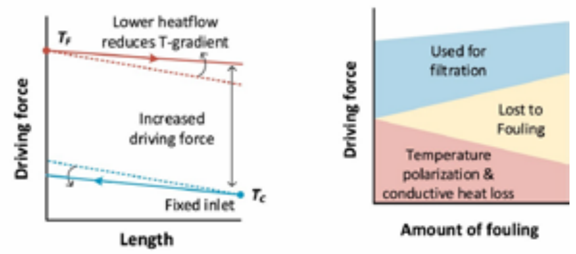
Francesco Ricceri

Motivation

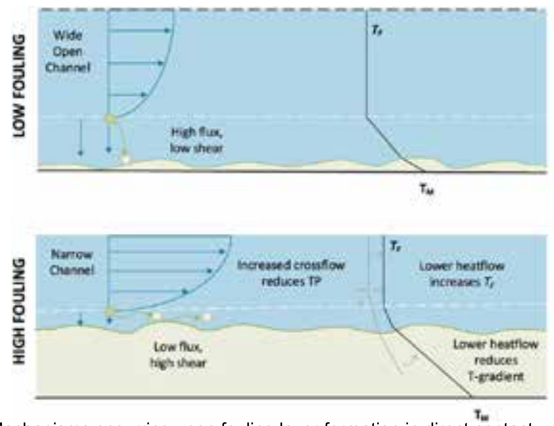
Fouling is one of the main issues hampering the implementation of thermally-driven membrane distillation. While the mutual influence of driving force and fouling deposition has been critically assessed in pressure- and osmotically-driven processes, fouling mechanisms have not been systematically investigated in membrane distillation.

Challenge

Our recent investigations showed that the driving force and the resistance increase during fouling in membrane distillation. Both these factors determine foulant deposition in time.



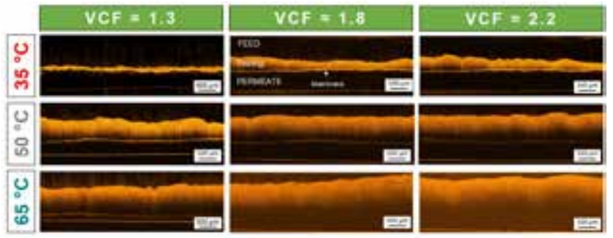
Further investigations are necessary to optimize the design and minimize fouling in larger scale applications.



Mechanisms occurring upon fouling layer formation in direct contact membrane distillation: influence of hydrodynamics, temperature profiles and driving forces. Top: clean membrane; Bottom: after cake layer formation.

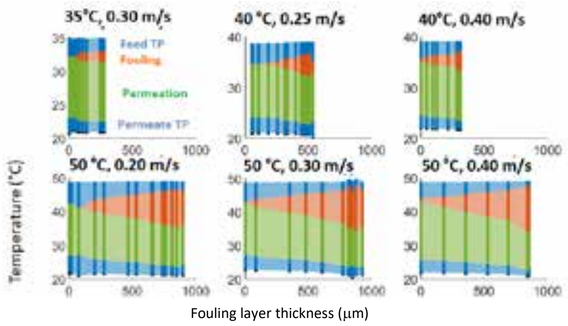
Research goals

- Design a new up-scaled membrane distillation flow-cell compatible with the optical coherence tomography (OCT) microscope to monitor fouling in time and space.
- Analyze the fouling evolution through the new system by using simple feed solution composed by one single contaminant.



Cross-sectional OCT scans of the fouling layer on the membrane, at three Volume Concentration Factors with different inlet feed temperatures.

- Develop a numerical model to describe quantitatively how temperature and cross-flow velocity correlate with the fouling deposition and vice-versa.
- Apply and test the model predictions of fouling in the upscaled system with different feed compositions and various operational conditions.



Contributions of each heat transfer resistance in the overall temperature loss, during growing fouling layer thickness. Blue: feed/permeate temperature polarization (top/bottom); Red: temperature drop in fouling layer; Green: temperature drop over the membrane (water vapor flux).

PI: Cristian Picioreanu

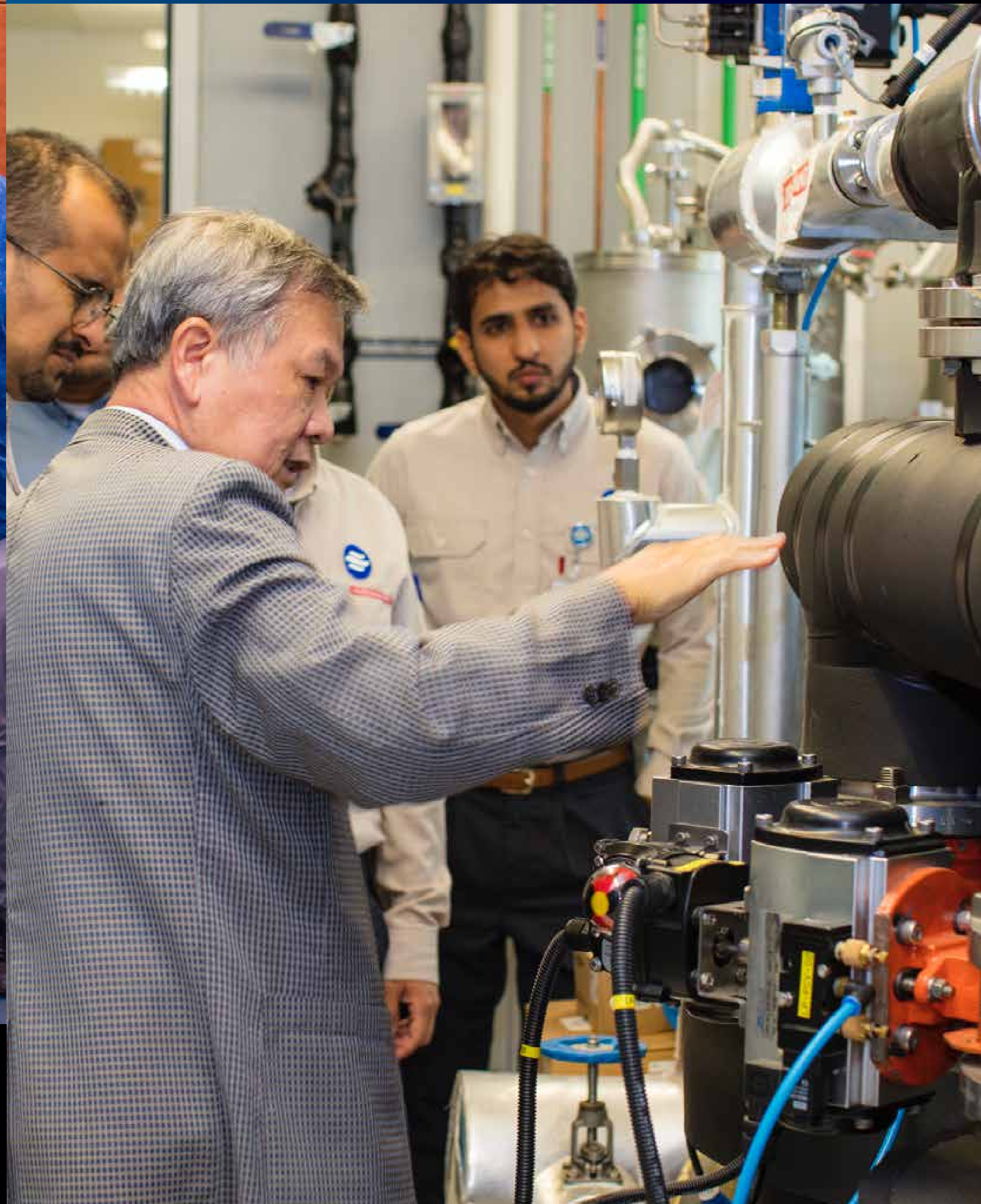
Email: francesco.ricceri@kaust.edu.sa

References

Francesco Ricceri, Bastiaan Blankert, Luigi Ranieri, Cristian Picioreanu, Noreddine Ghaffour, Johannes S. Vrouwenvelder, Alberto Tiraferri, Luca Fortunato (2023) Understanding the evolution of organic fouling in membrane distillation through driving force and resistance analysis. Journal of Membrane Science 686, 121993.

At the KAUST Research Opening Week 2023, Professor Hans Vrouwenvelder's team presented cutting-edge advancements in fouling monitoring for desalination using reverse osmosis membranes.

Researchers from SWCC visited WDRC; during the visit, Professor Kim Choon showcased his pilot plant. Collaboration between WDRC and SWCC is set on pioneering sustainability within the desalination industry and bolstering water supply security in the Kingdom.



Waste to Resource

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology | Water Desalination and Reuse Center

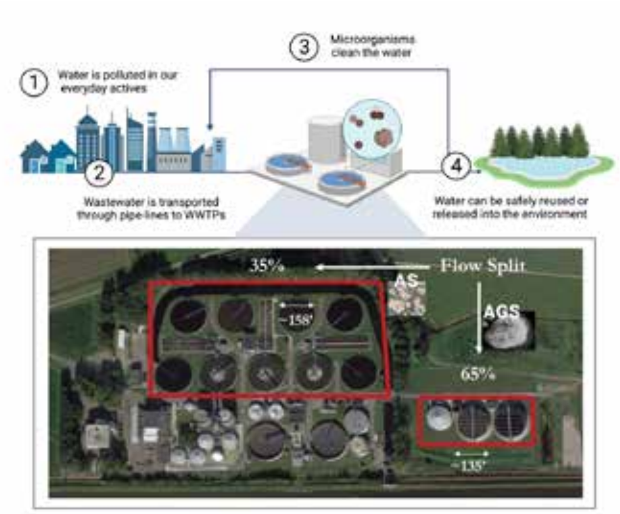
Waste to **Resource**

Factors influencing global diversity, composition, and function of AGS WWTPs

Lucia Ruiz Haddad

Motivation

More than 350 Km³ of wastewater (W)is produced globally per year (Wu et al., 2019), and only 50% of this wastewater is treated before being discharged or reused. Currently, the most widely used biological process for wastewater treatment is the activated sludge (AS) process. However, AS process is energy intensive and requires a large footprint. In contrast, biological processes based on the aerobic granular sludge (AGS) process have several advantages compared to AS process. For example, in AGS, 80% reduction in land space, 50% reduction in energy, and significant reduction in operational and capital cost can be achieved. Further, removal of organics, nitrogen (N), and phosphorous (P) occurs in a single reactor. Based on these advantages, it is anticipated that the AGS process will become the standard biotechnology for wastewater treatment, with more than 100 full-scale AGS WW treatment plants (WWTPs) already in operation in more than 20 countries.



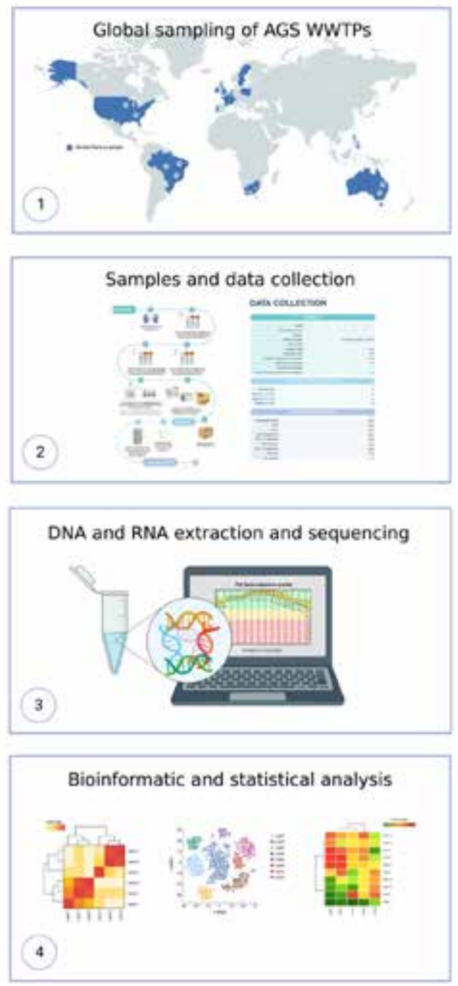
Scientific Challenge

Although AGS technology is already gaining momentum worldwide as the next-generation technology for wastewater treatment, the factors (deterministic and/or stochastic) responsible for shaping the microbial communities of different sized granules are still unclear. Understanding this information is essential for establishing design strategies that optimize AGS treatment to achieve stable Nutrient removal performance.

Research goals

A sampling of full-scale AGS WWTPs will be conducted to address the below aims:

1. Elucidate the global core community in AGS WWTPs.
2. Understand the distribution and function of microbial communities in different-sized aggregates.
3. Identify the microorganisms responsible for the stability and removal of organics and nutrients.
4. Evaluate the response of the microorganisms to regional, stochastic, and operational parameters.
5. Identify the seasonal patterns and reproducibility of microbial communities in AGS WWTPs.



PI: Pascal Saikaly

Email: Lucia.ruizhaddad@kaust.edu.sa

Water Desalination and Reuse Center

Waste to Resource

Marine anammox bacteria: energy-efficient treatment of saline wastewater

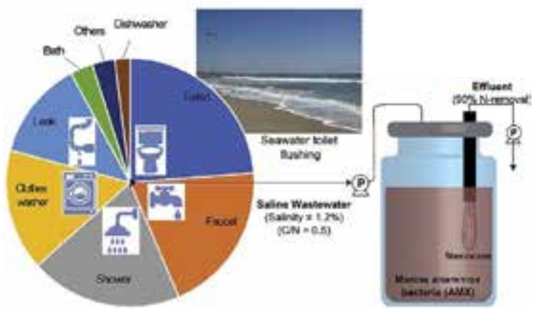
Julian Tobon-Gonzalez

Motivation

Freshwater scarcity
As the demand on freshwater resources for potable and non-potable uses increases due to the rapidly growing human population, the per capita availability of freshwater in many regions is likely to decrease.

Seawater is a resource
Over 50% of the world's population resides within 60 km of the coast, and seawater can be directly utilized for non-potable uses such as toilet flushing to reduce the demand on freshwater resources.

Anammox as energy-efficient nitrogen removal process
Anaerobic ammonium oxidation (anammox) is regarded as one of the most energy-efficient process for nitrogen removal from waste streams. Anammox can save more than 60% of the energy used in aeration systems and 100% of carbon source demand when compared with conventional nitrogen removal with nitrification/denitrification process.



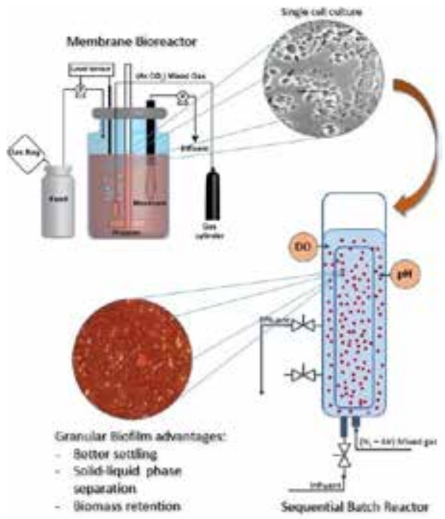
Challenge

- ✓ Anammox process is a prerequisite for achieving a cost-effective and energy-efficient treatment of nitrogen in wastewater. However, saline wastewater produce hyperosmotic stress to freshwater species of anammox bacteria, affecting their performance.
- ✓ Marine anammox bacteria are better suited for nitrogen-rich saline wastewater treatment compared to freshwater anammox bacteria due to their intrinsic tolerance to salinity[1]. However, attempts should be made to demonstrate the application of marine anammox bacteria in granular biofilm systems. Also, nitrite supply or partial nitritation is required to drive the anammox reaction.

Research goals

My research focuses on the development of a granular partial nitritation/marine anammox system for the treatment of saline wastewater.

1. Development of granular marine anammox system



2. Development of a single-stage partial nitritation/anammox process
3. Analysis of microbial community ecology

4. Adaptation of granular partial nitritation/marine anammox system to domestic wastewater conditions

Increase of organics

Pre-treated real wastewater

References

1. Ali, M., Shaw, D. R., and Saikaly, P. E. (2020). Application of an enrichment culture of the marine anammox bacterium "Ca. Scalindua sp. AMX11" for nitrogen removal under moderate salinity and in the presence of organic carbon. *Water Res.* 170, 115345.

PI: Pascal Saikaly

Email: julian.tobongonzalez@kaust.edu.sa

Water Desalination and Reuse Center

Waste to Resource

Synthesis of biohybrid catalyst using the electroactive bacteria *Geobacter sulfurreducens*

Rodrigo Jimenez Sandoval

Motivation

Climate change is a direct consequence of human activities that require the burn of fossil fuels that generates green house gases. To prevent climate change, alternative energy sources are been developed and implemented. Green hydrogen is the best alternative energy source as the electrochemical synthesis process only uses water and its use does not generate carbon emissions. However, catalysts are needed to produce green hydrogen. The best catalyst are made of noble metals which are expensive, scarce, and difficult to extract. An alternative type of catalysts are needed that are as efficient as traditional catalysts but that are also environmentally friendly Biohybrid catalyst are excellent candidates to substitute traditional catalysts. Biohybrid catalysts are a type of material that consists on two components: a biological component that can be a biomolecule or a entire cell and an abiotic component that can be an inorganic polymer, minerals, or metals, among others.

Figure 1. Biohybrid catalyst made with *G. sulfurreducens* and manganese oxide

Challenge

The challenge is to produce catalysts that are as efficient as traditional materials but that are cheaper, simpler, and environmentally friendly. Electroactive bacteria are great candidates for the synthesis of biohybrid materials as they naturally interact with metals and other inorganic materials through their extracellular electron transfer capabilities (EET).

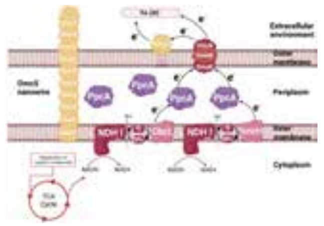


Figure 2. Extracellular electron transfer process

Research goals

1. Synthesize biohybrid materials with *G. sulfurreducens* as the biological component and metallic single atoms, nanoclusters and nanoparticles as the abiotic component.
2. To analyze the physical and chemical characteristics of the biohybrid materials.
3. Test the biohybrid materials as electrocatalysts for the electrochemical water splitting reactions: the hydrogen evolution reaction and the oxygen evolution reaction .

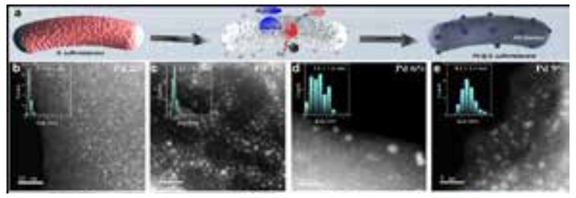


Figure 3. Palladium nanoclusters in the surface of *G. sulfurreducens.*

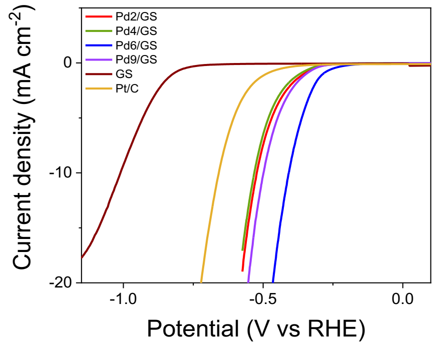


Figure 4. Hydrogen evolution reaction activity of Pd nanoclusters hybridized with *G. sulfurreducens.*

References

1. Kalathil et al (2021). Green chemistry.

2. Jimenez-Sandoval et al (2023). Sustainable chemistry and engineering.

PI: Pascal Saikaly

Email: rodrigo.jimenezsandoval@kaust.edu.sa

Water Desalination and Reuse Center

Waste to **Resource**

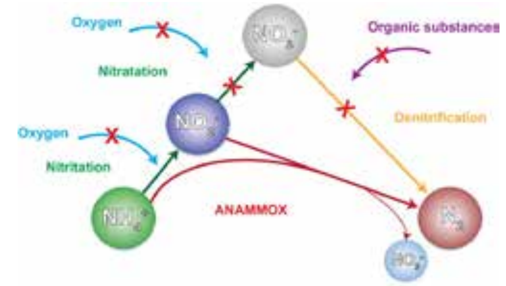
Anaerobic ammonium oxidation (Anammox) for energy-efficient treatment of ammonium and resource recovery from wastewater

Darío Rangel Shaw

Motivation

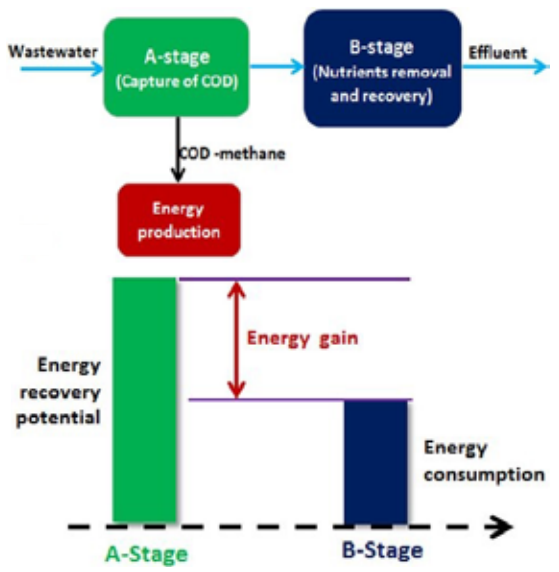
Anaerobic ammonium oxidation (**Anammox**) is a sustainable and efficient process for treating ammonium from wastewater. Compared to conventional nitrification/denitrification processes, anammox offer several advantages:

- ✓ 100% decrease in carbon source demand
- ✓ 60% decrease in oxygen demand (60% less energy)
- ✓ 75% reduction in biosolids
- ✓ Less/no N_2O (GHG) emission



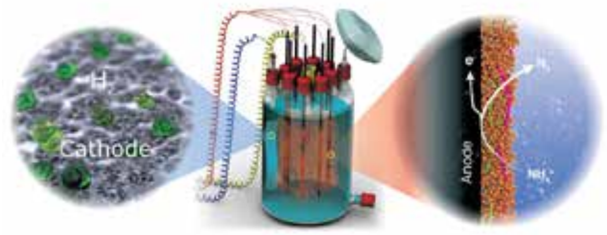
Challenge

- ✓ Integrate electro-anammox process into stage B of an A-B process to achieve energy-neutral or positive wastewater treatment.

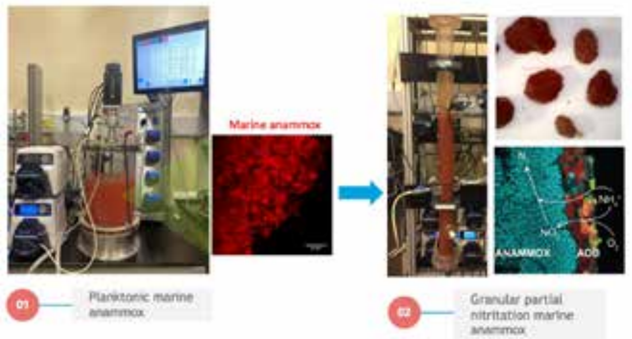


Research goals

1. Application of Electro-anammox, a novel anaerobic process for the oxidation of ammonium with recovery of energy from wastewater. Marine and freshwater species of anammox bacteria couple the oxidation of ammonium with the transfer of electrons to electrodes poised at a certain potential in microbial electrolysis cells (MECs). The process does not accumulate nitrite, nitrate or produce the greenhouse gas (GHG) N_2O. Also, the energy released from ammonium oxidation can be captured in the form of energy-rich hydrogen gas (H_2) at the cathode.



2. Application of novel marine anammox to treat high salinity wastewater. Over 50% of the world's population resides within 60 km of the coast, and seawater can be directly utilized for non-potable uses such as toilet flushing (~30% of the total domestic water demand) to reduce the demand on freshwater resources and energy intensive processes such as desalination. Therefore, it is necessary to develop future technologies that can operate effectively with high salinity levels.



3. Exploring the diversity and physiology of novel microorganisms and pathways for niche specific applications. Through the study of novel microorganisms and metabolic pathways, we can gain a deeper understanding of the microbial world, including the roles that microorganisms perform in ecological processes, as well as their potential applications in biotechnology.

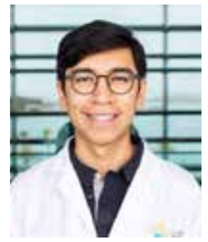
PI: Pascal Saikaly

Email: dario.rangelshaw@kaust.edu.sa

Water Desalination and Reuse Center

Waste to **Resource**

Exploiting anaerobic ammonium oxidation (Anammox) coupled with extracellular electron transfer for energy-neutral ammonium removal from wastewater.



Carlos Bibiano G.

Motivation

The anaerobic ammonium oxidation (anammox) process by anammox bacteria plays a significant role in achieving energy-efficient wastewater treatment (WWT). In the anammox process, ammonium (NH_4^+) is directly oxidized to dinitrogen (N_2) gas using nitrite (NO_2^-) as the electron acceptor.

Recently, our research group discovered that anammox bacteria are electroactive and can transfer the electrons generated from the oxidation of ammonium to the anode through extracellular electron transfer (EET) process. This novel process of ammonium oxidation by anammox bacteria where insoluble and electrically conductive material functions as the electron acceptor is called Electro-anammox[1] (Figure 1).

In electro-anammox process, it is possible to remove NH_4^+ anaerobically, without NO_2^- requirement.

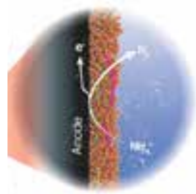


Figure 1. Electro-anammox process, where anammox bacteria oxidize NH_4^+ to N_2 gas and transfer the electrons to the anode.

Challenge

For electro-anammox to become a viable process for ammonium removal from wastewater, the rates of ammonium removal should be comparable to conventional processes such as nitrification and denitrification. To optimize the rates of ammonium removal through the electro-anammox process, we will investigate different anode materials and reactor configurations, and study the interaction of anammox bacteria with different insoluble and electrically conductive electron acceptors.

Research goals

Optimize the ammonium removal rates of electro-anammox process to develop a scalable bioprocess for the energy-neutral removal of ammonium from wastewater.

The research objectives are:

1. Study the interaction of anammox bacteria with semiconductive minerals.

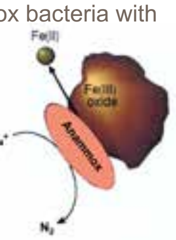


Figure 2. Proposed interaction of anammox bacteria with insoluble minerals.

2. Explore and develop novel anode materials that allow better colonization of anammox bacteria.

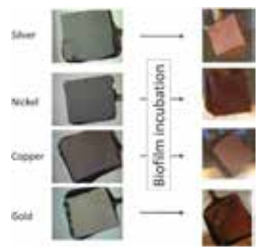


Figure 3. Examples of metals used for modifying anodes.

3. Design and test different bioelectrochemical reactor configurations in order to enhance the ammonium removal rates.

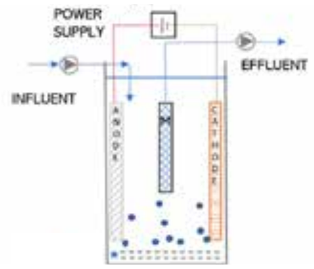


Figure 4. Scheme of a bioelectrochemical reactor configuration for this study.

References

[1]Shaw DR, Ali M, Katuri KP, et al. Extracellular electron transfer-dependent anaerobic oxidation of ammonium by anammox bacteria. Nat Commun. 2020;11(1):1-12. doi:10.1038/s41467-020-16016-y

PI: Pascal Saikaly

Email: carlos.bibianoguadarrama@kaust.edu.sa

Water Desalination and Reuse Center

King Abdullah University of Science and Technology

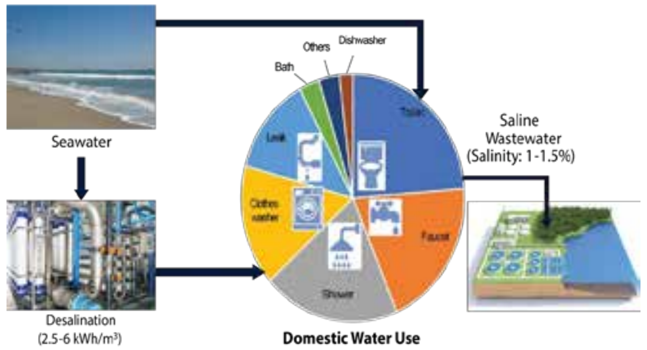
Waste to **Resource**

Aerobic Granular Sludge (AGS) Process for Energy-efficient Treatment of Saline Wastewater

Mohammed Alomari

Motivation

Over 50% of the world's population reside within a total of 60 km of coastline, where seawater can be directly used for toilet flushing to reduce dependence on freshwater resources and desalination process. It is also predicted that by the year 2100, the sea levels will increase by at least one meter. The rise in sea level will have a significant effect on low-lying countries and coastal cities. Therefore, it will increase seawater intrusion into the water lines and end up in the wastewater treatment systems. To build a more resilient wastewater treatment process, we want to study the effect of seawater on the Aerobic Granule Sludge (AGS) process. Understanding metabolic processes and genetic activity in AGS can elucidate key factors responsible for its robustness under saline conditions.

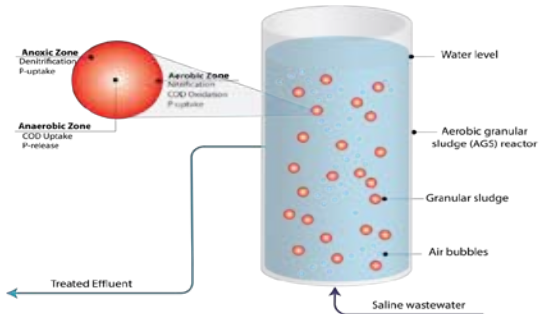


(Technological or Scientific) Challenge

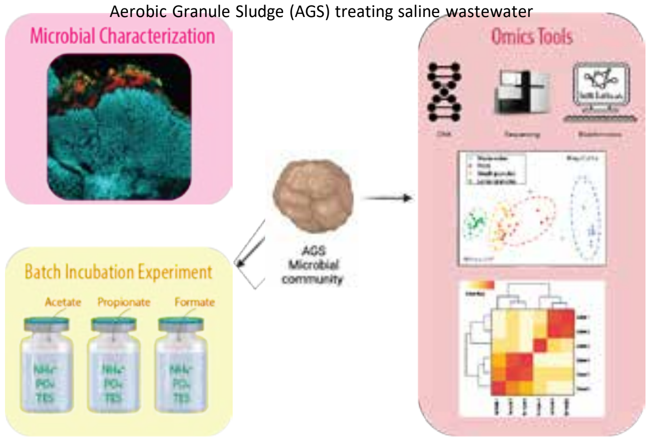
AGS system can treat wastewater rich in NH_4^+ and PO_4^- very efficiently compared to conventional processes. Osmotic stress produced by the increased salinity levels in domestic wastewater streams can negatively affect biological processes involved in nutrient (N, P) removal. Therefore, it is imperative to understand the response of key functional groups involved in N and P removal in AGS systems treating saline wastewaters.

Research goals

Our goal is to understand the physiological response of key functional groups in AGS system treating saline wastewater. This goal will be achieved through a combination of batch testing, biokinetics modeling, and Omics tools such as meta-genomics and meta-transcriptomics.



Aerobic Granule Sludge (AGS) treating saline wastewater



Elucidating microbial community of Aerobic Granule Sludge (AGS) treating saline wastewater

References

1. Wang, Z., van Loosdrecht, M. C. M., and Saikaly, P.E. (2017). "Gradual adaptation to salt and dissolved oxygen: strategies to minimize adverse effect of salinity on aerobic granular sludge." *Water Research*, 124, 702-712.

PI: Pascal Saikaly

Email: mohammed.alomari@kaust.edu.sa

In a groundbreaking discovery led by Professor Pascal Saikaly, anammox bacteria from the Red Sea were identified as a means for energy-efficient wastewater treatment. This method not only removes nitrogen from salty wastewater but also reduces energy consumption and cuts down on greenhouse gas emissions.

At the Plant Science Night, a PhD student from Professor Pascal Saikaly's group, demonstrates how to make bioplastics from potato starch to young learners. This event showcases engaging, hands-on activities for kids, highlighting the importance of sustainability, biodiversity, and restoring desert landscapes.

Water **Security**

Water Desalination and Reuse Center

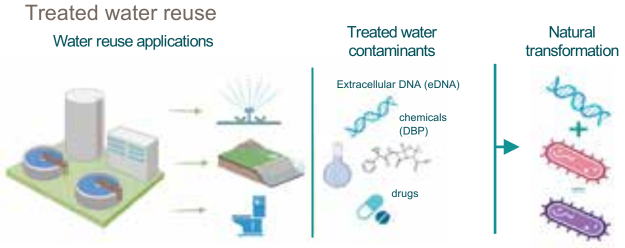
Water Security

Accumulation of stressors present in chlorinated water and their potential impact on horizontal gene transfer among soil bacteria

Bothayna Al-Gashgari

Background

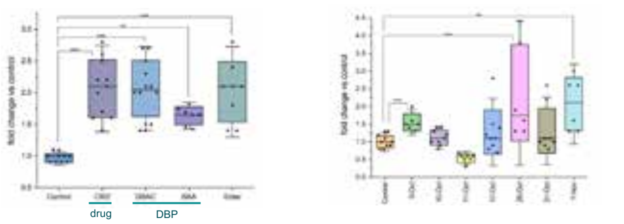
Treated water reuse



Chlorinated water contaminants can increase natural transformation *in vitro*

Natural transformation in *Acinetobacter baylyi* increased upon exposure to treated water contaminants and sunlight

Chlorinated effluent increased natural transformation in *Acinetobacter baylyi*



Objectives and approach

Objective

This work aims to verify the impact of the accumulation of contaminants that exist in treated water due to its use for plant irrigation In this study, we are using a soil system that is irrigated by chlorinated treated wastewater (CE) to analyze the natural transformation frequency in *Acinetobacter baylyi* ADP1 (*A. baylyi* ADP1) reporter that are inoculated in both sterilized and non-sterilized soil, and with/without plant growth

Approach

Short-term experimental design (18 days experiment, sterilized soil, and no plant growth)

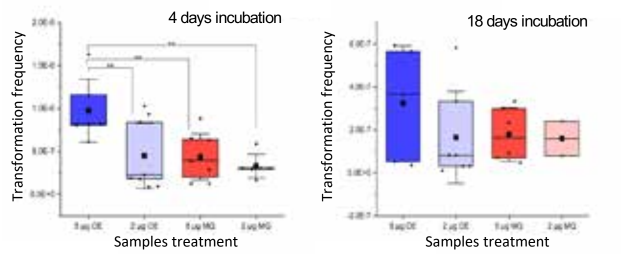
Samples are exposed to :
-16 hours of daylight
-Spiked with dDNA /4 days
-Watered with 50X chlorinated effluent or MQ
Temperature 22 C- 20 C

5 samples are collected over the course of 18 days

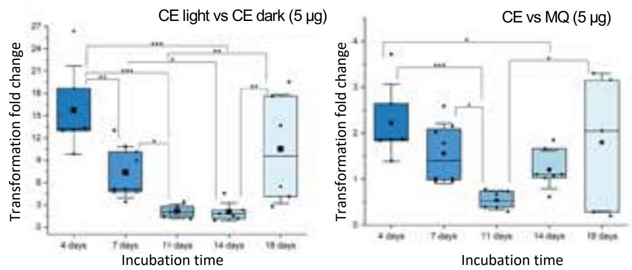
Based on the sensitivity to spectinomycin, transformants are counted and transformation frequency is determined

Preliminary results

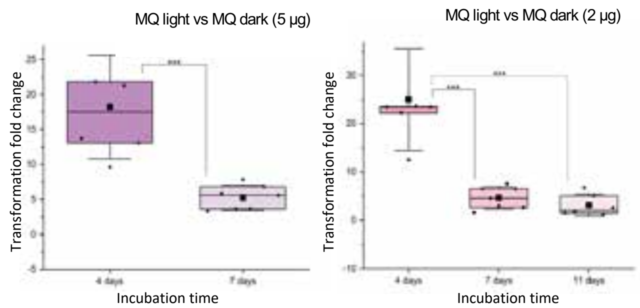
Observed an initial spike in natural transformation frequency in *A. baylyi* inoculated in soil, and that the frequency decreases or becomes more variable with time.



Both sunlight exposure and chlorinated effluent (CE) irrigation have a significant impact on natural transformation frequency when compared to samples incubated in dark and irrigated with milliQ water.



Only when samples were treated with (50X) CE or exposed to sunlight, a positive trend in natural transformation frequency was observed during the incubation period of 18 days.



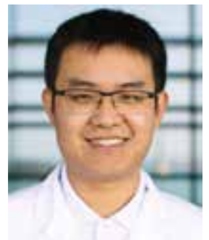
PI: Peiying Hong

Email: bothayna.gashgari.1@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Investigation of antibiotic resistome in hospital wastewater during the COVID-19 pandemic: Is the initial phase of pandemic contributing to antimicrobial resistance?

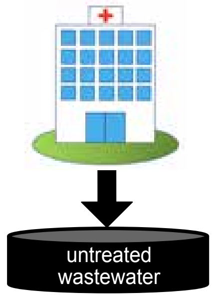


Changzhi Wang

Motivation

• Since the COVID-19 pandemic started, there has been much speculation about how COVID-19 and AMR may be interconnected.

• Many studies reported increased antibiotic usage in hospitals, raising concern of hospitals contributing to subsequent waves of AMR through its wastewater streams as a result of the pandemic.



Scientific Challenge

• COVID-19 patients are often prescribed antibiotics to prevent secondary bacterial infections. The extent to which such a practice can impact antibiotic resistome needs to be elucidated.

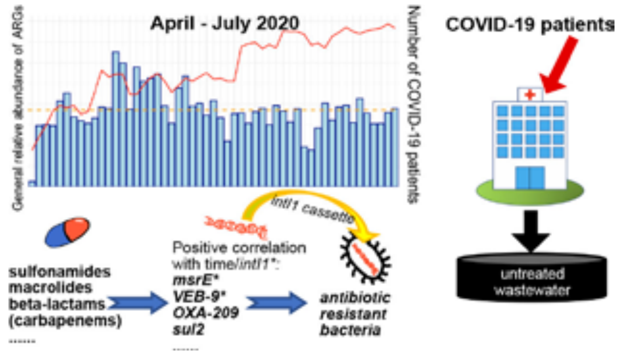
• A metagenomic investigation on the wastewater generated from a hospital providing treatment to only COVID-19 patients during the initial phase of the pandemic would provide insights into the extent at which treatment offered to COVID-19 patients can drive threats of antimicrobial resistance.

Research goals

In this study, we aim to answer following questions:

1. Does the antibiotic treatment contribute to AMR?
2. Which ARG could be affected during the pandemic?
3. Any transmission of ARG happen in hospital wastewater?

To address these questions, two hospitals located in Saudi Arabia were investigated: Hospital A provided treatment to COVID-19 patients in Jeddah, Saudi Arabia, during the first wave of the COVID-19 pandemic (April until July 2020). Hospital B did not receive permission from Saudi MOH to receive any COVID-19 patients. Discharged untreated wastewater were collected during the first wave of the pandemic from April 2020 until July 2020. Samples were brought back to the lab for filtration and DNA extraction, metagenomic sequencing and analysis.



Metagenomics was performed to investigate the relative abundance and diversity of ARGs and to determine the correlation of the relative abundance of ARGs with time/incidence of COVID-19.

References

Wang, C., Mantilla-Calderon, D., Xiong, Y., Alkahtani, M., Bashawri, Y. M., Al Qarni, H., & Hong, P. Y. (2022). Investigation of Antibiotic Resistome in Hospital Wastewater during the COVID-19 Pandemic: Is the Initial Phase of the Pandemic Contributing to Antimicrobial Resistance?. Environmental Science & Technology, 56(21), 15007-15018.

PI: Peiying Hong

Email: changzhi.wang@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Evaluation of Protein Extraction Methods to Facilitate Meta-Proteomics Analysis of Treated Wastewater Biofilms

Fatimah Almulhim

Motivation

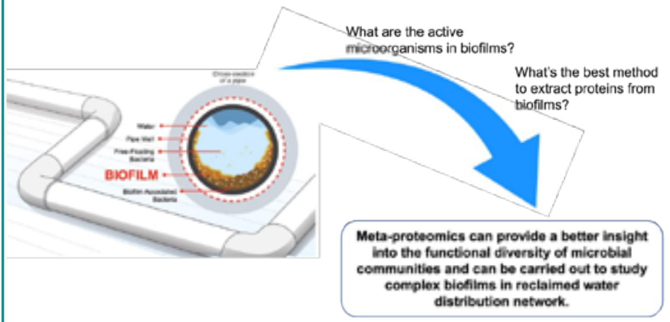
Reclaimed wastewater is used as an alternative freshwater resource to address water demand in arid and water-scarce countries. However, biofilm formation in the treated wastewater distribution systems can detrimentally impact water quality at the points-of-use. To ensure an optimal network treatment, the microbial populations that regrow and persist within the reclaimed wastewater distribution network should be better characterized for their functional activities.

For this, metaproteomics is an emerging "omics" technology that bridges the gap of metagenomics and metatranscriptomics by providing a better insight into the functional diversity of microbial communities and can be carried out to study complex biofilms in reclaimed water distribution network.

Scientific Challenge

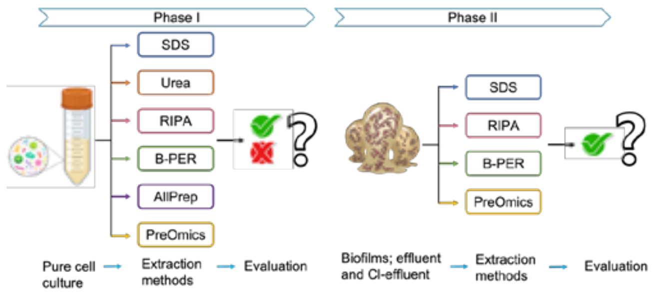
Metaproteomics approach poses some challenges due to the complexity of reclaimed wastewater matrices. Thus far, the identified microbial proteins in the wastewater are only around 1% of the expected protein component based on the average environmental microbial genome size of 3 Mbp.

Moreover, different protein extraction methods lead to variations in protein recovery and introduce bias when analyzing the microbial communities.



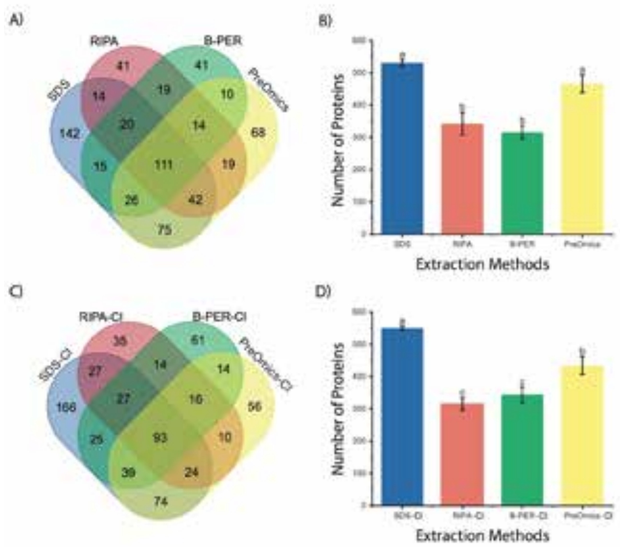
Research goals

Evaluate different protein extraction methods suitable for treated wastewater biofilm by testing their ability to extract high number and amount of proteins in a minimally biased manner.



Results

Number of proteins extracted from highly selected methods using biofilm samples. The number of proteins resulting in the order of decreasing performance is listed as SDS > PreOmics > RIPA > B-PER.



PI: Peiying Hong

Email: Fatimah.almulhim@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Effect of decreasing hydraulic retention time in bacterial pathogens removal performance of anaerobic membrane bioreactor

Julie Sanchez

Motivation

Water reclamation and reuse has been proposed as an alternative to provide additional supply for increased water demand. However, before applying this strategy it is necessary to understand the underlying microbial risks.

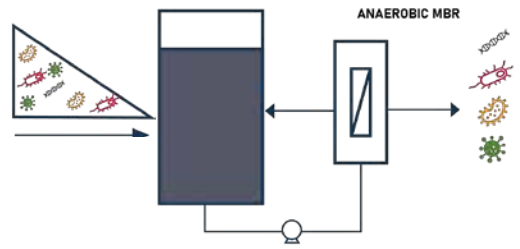
Anaerobic Membrane bioreactor or AnMBR is an emerging technology for wastewater treatment that has smaller footprint and lower energy cost and solid waste disposal requirement than aerobic membrane systems.

However, before implementation it is paramount to ensure the treated water or effluent from the AnMBR is safe for reuse.

Scientific Challenge

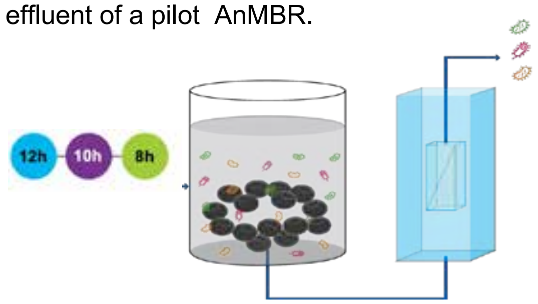
Hydraulic retention time (HRT) or the residence time of the water in the reactor is a parameter that needs to be optimized to ensure the stability of the process and the removal of the contaminants in the wastewater.

Few studies have evaluated the removal of bacterial pathogens and the persistence of emerging contaminants by the AnMBR (1) as well as the influence of operational parameters such as the HRT in the fate of microbial contaminants.



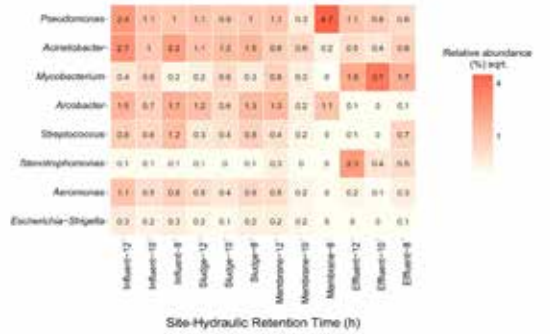
Research goals

Assess the effect of different Hydraulic Retention Times (HRT) in the performance of the reactor and in the persistence of potential bacterial pathogens and antibiotic resistant bacteria in the effluent of a pilot AnMBR.



- 3 HRT evaluated
- Analysis of reactor performance and microbial community (from influent, sludge and effluent)

Current results



- AnMBR is effective in the removal of *Acinetobacter* and *Arcobacter* spp. but *Mycobacterium* spp. is persistent in the effluent across all HRT
- *Mycobacterium franklinii* was assembled from effluent at 8h HRT and is likely a opportunistic pathogen with virulence factors

References

1. Harb, M., & Hong, P. Y. (2017). Molecular-based detection of potentially pathogenic bacteria in membrane bioreactor (MBR) systems treating municipal wastewater: a case study. Environ. Sci. Pollut. Res, 24(6), 5370-5380.

PI: Peiying Hong

Email: Julie.sanchezmedina@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Utilizing flow cytometry for rapid virus-like particle quantification and pathogen prediction in different wastewater matrices

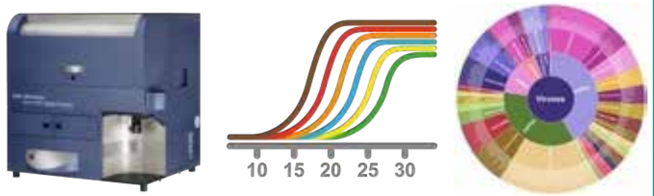
Yevhen Myshkevych

Motivation

Water scarcity is considered one of the largest global risks that can bring detrimental impact on humanity development within the near future. In order to alleviate this issue and improve water security, alternative water sources like seawater, brackish water and treated wastewater (WW) are considered as water sources for potable and non-potable use. To ensure safe reuse, viral pathogens require additional attention due to their small particle size, high resistance to environmental stresses and high infectivity. The state-of-art technology allows viral pathogen concentration determination within 1-2 days from sampling, which in the case of WWTP failure, would mean inability to react swiftly and prevent massive community outbreak. Therefore, there is a need for a prompt and accurate method of viral pathogen concentration prediction.

Scientific Challenge

State of art virus particle isolation and quantification procedures are considered labor-intensive and time-consuming (up to 2 days), and consequently are unsuitable for time-critical applications such as wastewater monitoring. Flow cytometry (FCM), in turn, has the potential for small particle detection and quantification. In previous studies [1,2,3], FCM potential for virus particle detection and quantification has been shown. Nevertheless, pathogenic virus particles, due to their small size (20-100 nm), might be below the FCM detection limit. Therefore, there is a need to verify FCM reads with well-established virus quantification techniques.



References

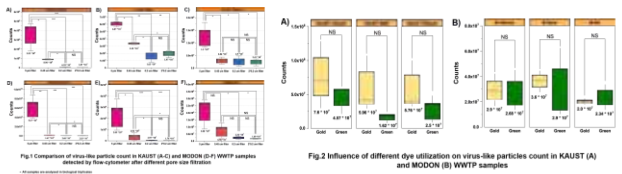
1. Lippé, R. (2018). Journal of Virology **92**(3): e01765-01717.
2. Ma, L., et al. (2013). Water Sci Technol **68**(8): 1763-1769.
3. Brussaard Corina, P. D. (2004). Applied and Environmental Microbiology **70**(3): 1506-1513.

Research goals

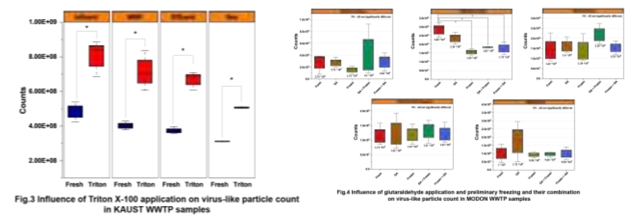
1. Optimize FCM protocol for WW matrices.
2. Perform qPCR and FCM for a large set of samples to check whether FCM might be used for pathogen prediction.
3. Perform quantitative metagenomics to check whether FCM reads correlate with any other virus family or class.

Preliminary results

1. It has been found that consecutive filtration with 5 um, 0.45 um and 0.2 um filters is removing most of the bacterial cells. Subsequent additional filtration with 0.2 um filter showed no effect on counts number. Bacterial cells presence has been tested with heterotrophic plate count technique to ensure purity of sample from bacterial cells. (Fig.1)



2. No difference was detected among two dyes from SYBR family, which was reported as the most efficient for virus particles staining (Brussaard et al., 2004) (Fig. 2).
3. Additionally, no significant improvement has been detected with the use of fixative (glutaraldehyde) (Fig. 4).
4. Surfactant (Triton X-100) improved staining in all samples when added before filtration (Fig. 3).
5. Sample freezing prior to staining and processing hasn't shown a decline in counts number, which suggests that virus-like particles counts are not much affected by one-time freeze-thawing. (Fig. 4)



PI: Peiying Hong

Email: yevhen.myshkevych@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Revamping our wastewater treatment process with anaerobic membrane bioreactor (AnMBR) and advanced oxidation disinfection

Shuo Zhang

Motivation

- ✓ More sustainable wastewater treatment alternatives are needed to produce high quality reclaimed water, hence addressing both water scarcity and climate change simultaneously.
- ✓ In order to convince stakeholders to switch to AnMBR, we need to perform techno-economic analysis of the AnMBR treatment plant and compare against that of conventional wastewater treatment plant.
- ✓ Techno-economic analysis will involve parameters such as water quality, energy costs, chemical costs, greenhouse gas emissions.

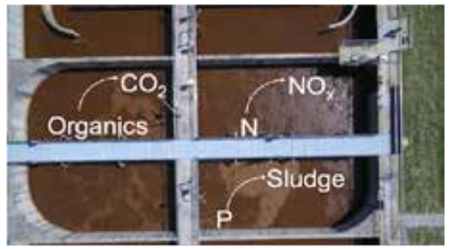


Figure 1. Scheme of conventional activated sludge wastewater treatment plant

Scientific Challenge

- ✓ Membrane fouling should be mitigated to ensure the system steady performance. The influence of membrane cleaning on biological tank should be minimized.
- ✓ Sulfide in the anaerobic effluent should be removed to decrease the effect on UV oxidation disinfection and toxicity to plants.

Research goals

Sustainable and resilient wastewater reuse:

- ✓ Recovery energy from wastewater
- ✓ Low greenhouse footprint
- ✓ High quality reuse water with liquid fertilizer
- ✓ Low sludge disposal
- ✓ Low economic investment

Figure 2. Conception of reimaging the new way we clean wastewater

Successful set-up of decentralized demo plant

Figure 3. Demo-scale wastewater treatment plant successfully in Jeddah, Saudi Arabia

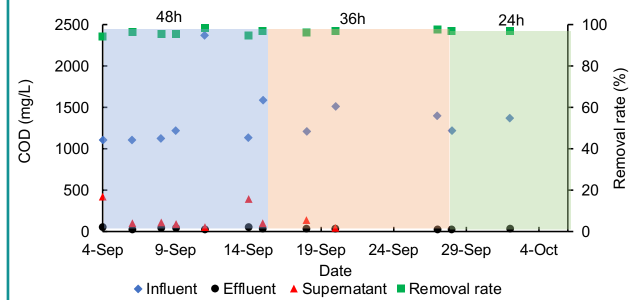


Figure 4. COD removal performance of demo-scale wastewater treatment plant

PI: Peiying Hong

Email: shuo.zhang@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

Applying a nature-based biofiltration system to achieve sustainable urban greening

Yanghui Xiong

Motivation

Most countries in the Middle East region face severe physical water scarcity issues.

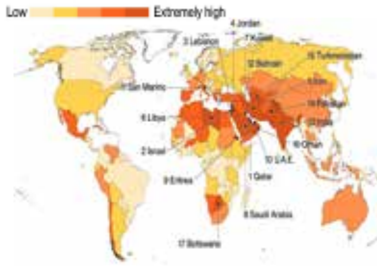


Fig.1 Water Crisis in the world

However, there is increasing water demand from all sectors. One of the most recent water demand comes from the Saudi Green Initative (SGI) to plant 10 billion trees. Treated wastewater, such as the permeate from aerobic and anaerobic membrane bioreactors (AeMBR and AnMBR), can be used as a sustainable water source for greening urban landscapes.

Scientific Challenges

We can use treated wastewater as alternative water sources to support landscaping efforts. However, we still face these challenges:

1) Treated wastewater still contains remnant nutrients, organic micropollutants and microorganisms which can be disseminated into the environment
2) Evaporation loss of water – the traditional way of irrigating landscapes lead to large losses of water which cannot be recovered back for subsequent reuse.
3) Treated wastewater can impose potential detrimental effect on the growth of plants.

Proposed Solution

We will employ a nature-based biofiltration (Fig. 2) to establish the plants in a columns. The advantages are:

1) Additional removal of nutrients and contaminants by the plants and the sand column
2) Excess filtered water can be collected for other reuse purposes
3) Minimize evaporation loss of water due to contained system

Research goals

We will demonstrate the nature-based biofiltration based on the below study aims:

1) Assess the water quality for removal of nutrients, chemical and microbial contaminants. We aim to understand the co-effect of microbes and plants on the removal of contaminants with different treated wastewater.
2) Establish different plants in the columns, which are then irrigated with different types of treated wastewaters, with and without biochar. We can determine the effect of different treated water on plant growth
3) Utilize SandX in the system and monitor for its effect in minimizing water loss

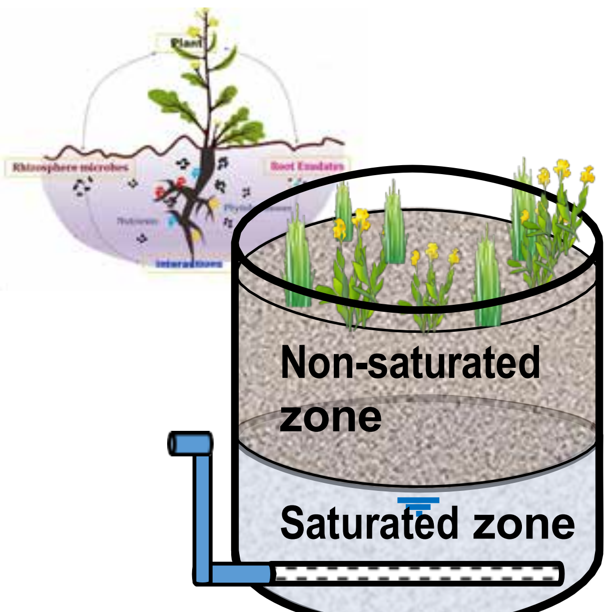


Fig.2 The configuration of the nature-based biofiltration system

PI: Peiying Hong

Email: Yanghui.Xiong@kaust.edu.sa

Water Desalination and Reuse Center

Water Security

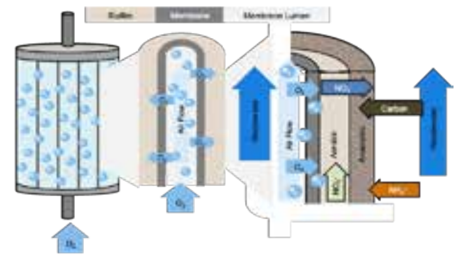
MABR as a feasible alternative to treat organic micropollutants in wastewater: mechanisms of removal, pathway and microbial community variation according to biofilm thickness

Claudia Sanchez-Huerta

Motivation

Wastewater reuse and reclamation has been proposed as an alternative to alleviate global water stress. However, one of the challenges in the reuse of reclaimed water is the presence of persistent and toxic organic micropollutants (OMPs) which are recalcitrant to conventional treatment process and pose high risk to the environment and public health (i.e., disruption to the endocrinal system, antibiotic resistance).

Membrane aerated biofilm reactor (MABR), a counter-diffusion biofilm process, promotes a unique stratified bacterial community and substrates gradient within its biofilm thickness, which could favor the selection of organisms with OMPs degrading abilities. Thus, this technology could be an efficient and economically feasible treatment to enhance OMPs removal.



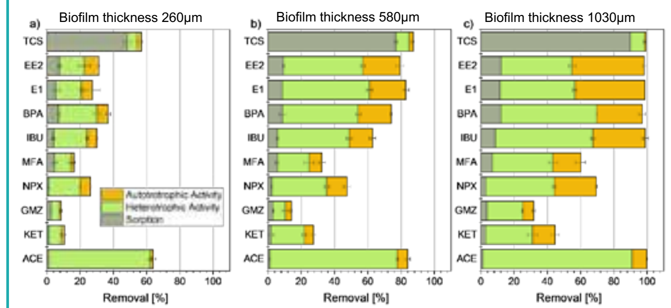
Challenge

MABR has been successfully applied for the simultaneous removal of conventional pollutants (i.e., ammonium, organic carbon) and OMPs like antibiotics. However, the mechanisms driving the removal, the fate of OMPs and, the microbial community involved in the degradation of OMPs remain unclear. Furthermore, the influence of biofilm thickness (a key feature of MABR) on MABR performance treating OMP-containing wastewater have not been well studied.

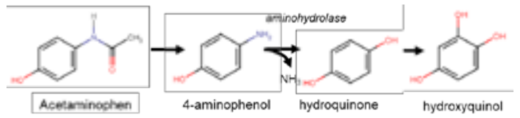
Research goals

Contribution of sorption and biodegradation mechanisms and MABR microbial community on the removal of OMPs including pharmaceuticals and endocrine disrupting compounds is explored at different biofilm thicknesses (260, 580 and 1030 μm).

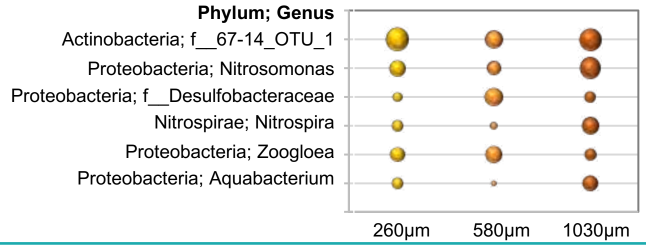
- Sorption is only significant for the removal of lipophilic neutral compounds like triclosan
- At all stages biodegradation drives the removal of targeted OMPs
- Heterotrophic activity is predominant at low biofilm thickness (< 260 μm)
- As thickness increases, nitrifying activity become more relevant enhancing OMPs degradation.



- OMPs degradation mainly depends on hydroxylation reactions, C-N, C-O and meta- cleavage reactions, driven by heterotrophic and nitrifying organisms.



- Increase of thickness from 580 and 1030 μm reduced microbial diversity and evenness, selecting for specific microbial populations capable of xenobiotic degradation (i.e., Proteobacteria *Aquabacterium* and *Nitrosomonas;* Nitrospirae *Nitrospira*, and Actinobacteria).



PI: Peiying Hong

Email: claudia.sanchezhuerta@kaust.edu.sa

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Water Security

Bioinspired Gas-entrapping Microtextured Surfaces

Sankara Arunachalam

Motivation: Numerous natural and engineering scenarios necessitate entrapment of air pockets on surfaces submerged in wetting liquids, e.g., airbreathing insects respiring under water, smartphones/devices, and separation and purification membranes. Current technologies rely on perfluorocarbons to achieve robust air entrapment, limiting their sustainability. Therefore, coating-free alternatives are desirable.

Our Approach: Towards a coating-free approach, we sought inspiration from the cuticles of springtails (*Collembola*) to create gas-entrapping microtextured surfaces (GEMS) from wetting materials.

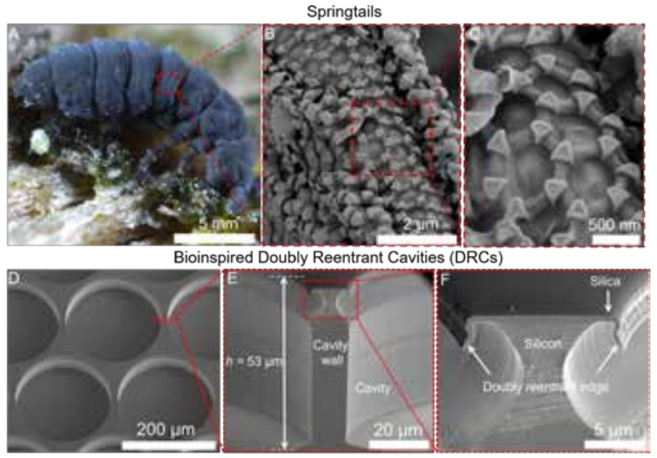

Fig 1. Images of Springtails (A-C) and Bio-inspired GEMS (D-F)

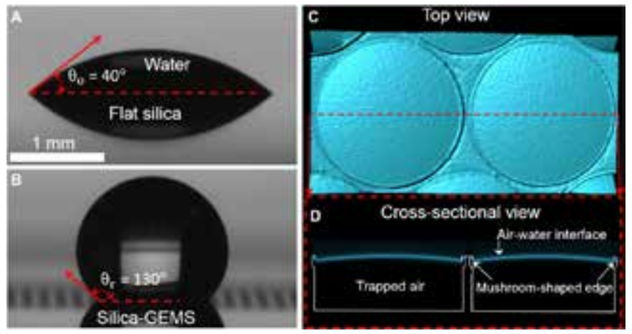

Fig 2. Wetting behaviors of smooth silica and silica-GEMS with water (A-B). Air-water interface at the inlets of silica-GEMS underwater visualized using confocal microscopy (C-D)

Goal #1: Underwater Breathing

What is the fate of the air pocket trapped inside a DRC under cyclic pressure, i.e., the effects of positive (>1 atm), negative (< 1atm), and positive-negative triangular waves.

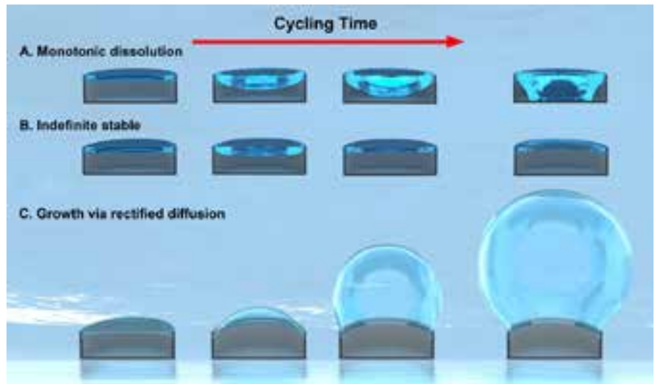

Fig 3. Under cyclic pressure, the air pocket trapped inside a DRC can attain one of the following three fates: the air pocket (i) monotonically depletes, (ii) is indefinitely stable, (iii) starts growing. (Illustration credit : Ella Maru)

Goal #2 : Directional Wetting Transitions

We have discovered that air pockets in arrays of submerged DRCs exhibit directionality in the wetting transitions. Underlying mechanisms are being explored.

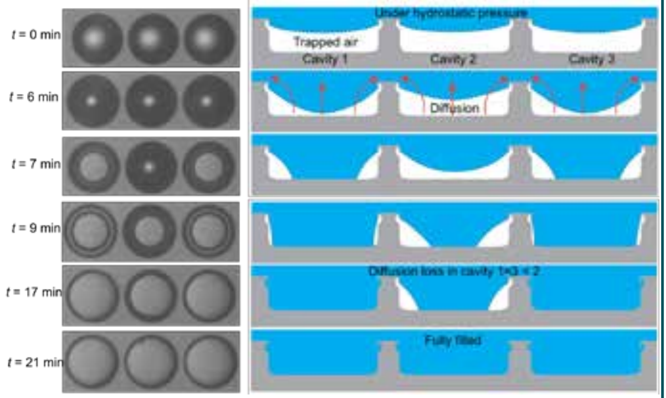

Fig 4. Directional filling of the line distribution of DRCs under 20 kPa hydrostatic pressure (left). Schematic of the shielding effect induced directional filling (right).

PI: Himanshu Mishra

Email: sankara.arunachalam@kaust.edu.sa

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Electrification at ±Charged Water–Hydrophobe Interfaces

Yinfeng Xu

Motivation

Hydrophobic surfaces are common in the water sector. Our previous researches show that these surfaces are negatively charged. Further questions:

i. Why are common water-hydrophobe interfaces negatively charged?
ii. Is it possible to realize positively charged water–hydrophobe interfaces?
iii. Could liquids besides water be electrified in contact with such surfaces?

Research goals

The goal of our work is to explore new water-hydrophobe interfaces which are positively charged. Based on that effects of multiple properties, such as ionic strength, pH and electrical permittivity of aqueous solutions will be investigated. The result will enhance our understanding of the relation between liquid repellency and surface charge in a fundamental liquid-solid system.

Strategies

Implement complementary experimental techniques
- Pendent droplets under uniform electric fields
- Direct measurement of electrical charges on droplets with electrometer

Vary materials of solid hydrophobes
- Polypropylene pipettes
- Glass capillaries with different perfluorocarbon coatings

Vary properties of aqueous solutions
- Ionic strength
- pH
- Electrical permittivity

References
Nauruzbayeva, J.; Sun, Z. H.; Gallo, A.; Ibrahim, M.; Santamarina, J. C.; Mishra, H., Electrification at water-hydrophobe interfaces. *Nature Communications* **2020**, *11* (1).

Current Progress

Experiment #1. Effects of uniform electric fields on aqueous droplets suspended from hydrophobic capillaries.

APTES:ODTS Ratio	APTES:ODTS 0:100	APTES:ODTS 0.05:99.95	APTES:ODTS 0.3:99.7
Receding Angle	80°±5°	87°±3°	82°±5°
Pendent drop under uniform electric field			
APTES:ODTS Ratio	APTES:ODTS 1:99	APTES:ODTS 10:90	APTES:ODTS 30:70
Receding Angle	99°±3°	85°±2°	88°±5°
Pendent drop under uniform electric field			

Figure 1. Water drops dispensed from capillaries with different ratios of APTES/ODTS coatings. The change in direction shows the change in the type of surface charge.

Experiment #2. Direct measurement of electrical charges on droplets.

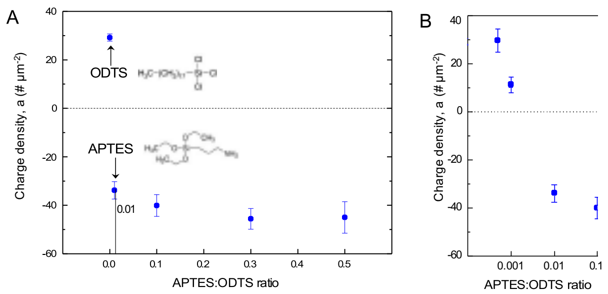

Figure 2. (A) Effects of the APTES:ODTS ratio on the charge density of pendant droplets. (B) Zooming into effects of the charge density on the mixing ratio of the silanes.

Conclusion

We obtained positively charged hydrophobic surfaces by mixing ODTS with APTES onto glass. This led to reverse electrification, i.e., pendant droplets were attracted towards positively charged electrode and the net droplet charge was negative (Figs. 1-2).

PI: Himanshu Mishra

Email: yinfeng.xu@kaust.edu.sa

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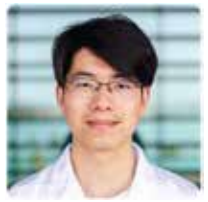
Water Security

Precision Desert Agriculture with SandX, Biochar, Sensors, and Machine Learning



Jiaqi Zhang Fabio Camargo

Motivation

Plant growth in arid and hot regions like the Middle East is hindered by a trio of stressors: water scarcity, heat stress, and low fertility soils. These stressors must be alleviated to realize giga-scale initiatives for desert rehabilitation and carbon sequestration, such as the Saudi Green Initiative. Thus, there is a need for technologies for enhancing irrigation efficiency, fertilizer-use efficiency, and field monitoring to predict and preempt the stressors. In response, we have pioneered the following technologies: (i) Superhydrophobic sand (SHS) mulch – common sand grains coated with a nanoscale layer of paraffin wax, and (ii) biochar – derived from the pyrolysis of organic waste such as date palm leaves. SHS prevents the evaporative water loss from the topsoil, while biochar enhances soil's ion-exchange capacity and water holding capacity. In this work, we evaluate a research field trial with 3600 tomato (Solanum lycopersicum) plants. Capturing Unmanned Aerial Vehicle (UAV) based multispectral images of our Thuwal field, complemented with regular ground-level measurements of plant yield.

Fig 1. Superhydrophobic sand(left) and biochar(right)

Scientific Challenge

- Unstable environmental conditions
- UAV temporal limitations
- Plant segmentation
- Number of parameters in the model
- Make accurate and timely decisions that account for spatial and temporal variability.

Research approach

1. Field preparation with SHS, biochar, and SHS + biochar treatments on tomato plants under controlled irrigation.
2. UAV-based multispectral images at regular intervals (Fig. 2).

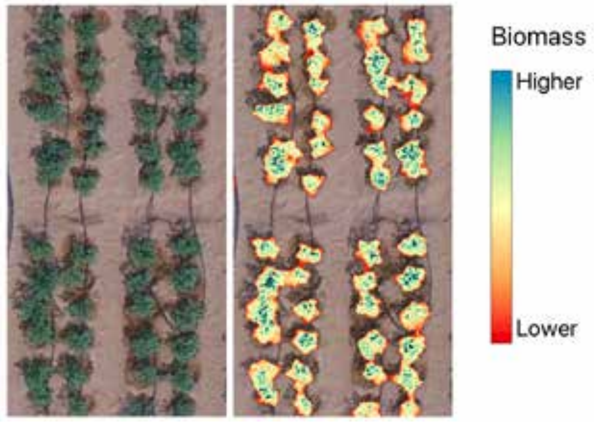


Fig 2: Flight 2 March 2023. Left: RGB composite, right: Biomass

3. Ensemble of machine leaning models architecture to predict total fruit yield after seven harvests using only Mar 2 multispectral image; preliminary result is shown below (Fig. 3).

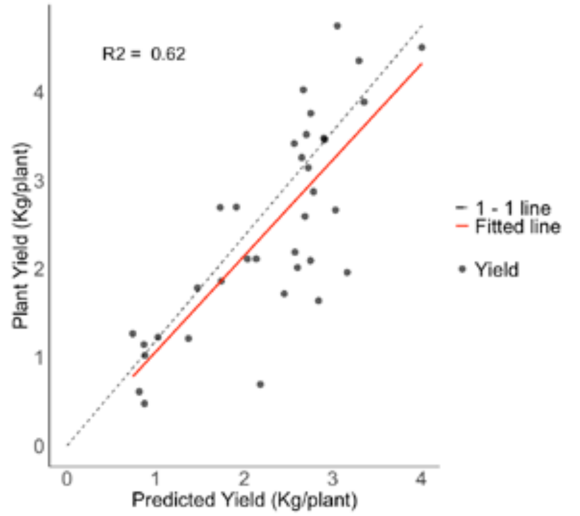


Fig 3. Validation of predict plant yield using a ensemble of machine learning models

PI: Himanshu Mishra (Collaborator: Prof. Matt McCabe)

Email: jiaqi.zheng@kaust.edu.sa, fabio.veigadecamargo@kaust.edu.sa

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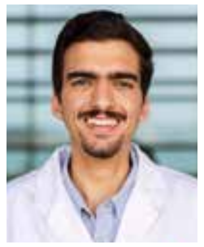
Water Security

Probing Effects of Superhydrophobic Sand Mulches on Water Evaporation from Sand-Columns: Effects of Surface Temperature and Water Table-Depth



Amr Al-Zu'bi

Introduction

In hot and arid regions such as the Middle East, irrigated agriculture claims the lion's share of freshwater resources. Large quantities of groundwater are regularly withdrawn, which rarely get replenished. Therefore, concerns over food–water security are rising. New approaches to curtailing evaporative water losses are needed. Our group has pioneered the Superhydrophobic Sand (SHS) mulching technology whose efficacy has been established for field crops and native tress in KSA.

Problem Statement

We probed the effects of SHS on the evaporative loss of water and the vertical temperature gradients across sand columns subjected to variable heat fluxes. Key variables included (i) Sand grain size; (ii) SHS thickness; and (iii) water table depth. Optical and infra-red cameras and soil moisture/temperature sensors were utilized.

Experimental Design:

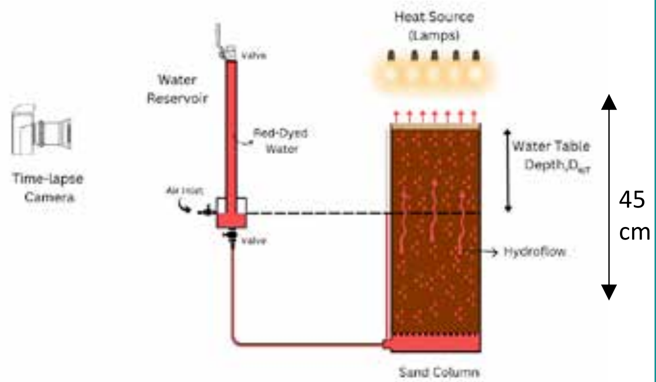


Figure 1. A schematic of the experimental rig used to quantify evaporative fluxes from the sand.

Materials used in the columns:

	Fine Sand	Silica Sand
• Sieve Size	75-600 µm	400-800 µm
• Capillary Rise	84 cm	8 cm

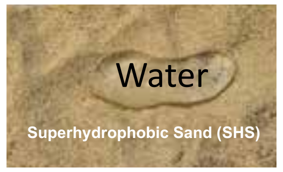


Figure 2. An image showing the Super Hydrophobic Sand that was used as a mulch

Results:

➤ **Evaporative fluxes:**

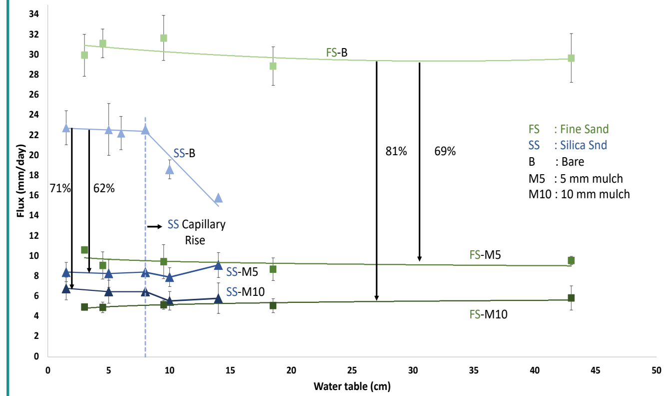


Figure 3. Experimental evaporative fluxes as a function of water table depth for 5 and 10 mm-thick SHS layers.

Within the capillary rise phase, evaporative flux was reduced:

a) 69% and 81% with 5 mm and 10 mm mulch respectively relative to the bare fine sand;
b) 62% and 71% with 5 mm and 10 mm mulch respectively relative to the bare silica sand.

➤ **Vertical temperature distributions:**

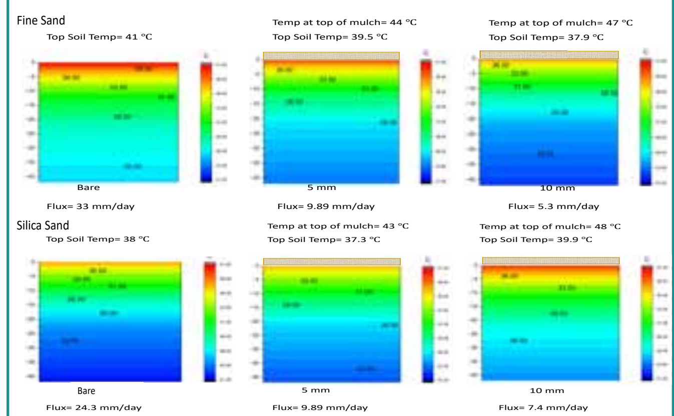


Figure 4: Shows the temperature profile of the sand columns using different types of sandy soil and SHS mulch thicknesses

In Fine Sand, SHS mulch caused a cooling effect, while in Silica Sand, SHS Mulch caused a heating effect.

PI: Himanshu Mishra

Email: amr.alzubi@kaust.edu.sa

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Water Security

Three-dimensional open architecture enabling salt-rejection solar evaporators with boosted water production efficiency

Kaijie Yang

Motivation and challenge

Direct solar desalination exhibits considerable potential for alleviating the global freshwater crisis. However, the prevention of salt accumulation while maintaining high water production remains an important challenge that limits its practical applications because the methods currently employed for achieving rapid salt backflow usually result in considerable heat loss.

Research goals

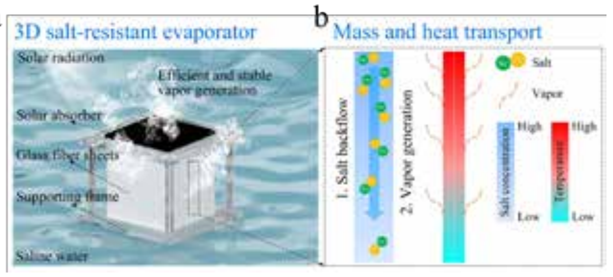

Figure 1. a. Schematic of the 3D salt-rejection evaporator, **b.** Working principle includes salt rejection and evaporation enhancement.

In this study we developed a rationally designed architecture to address the challenge of heat dissipation during rapid salt backflow. The key component is a number of vertically aligned mass transport bridges which not only allows rapid salt backflow but also can recovery the conductive heat to generate vapor.

Performance

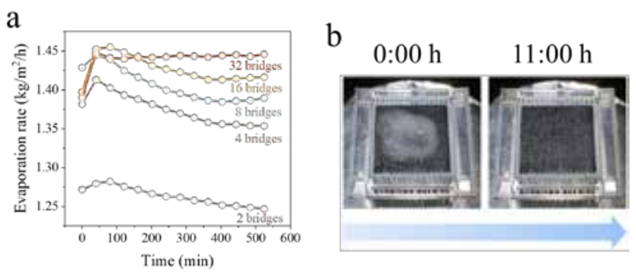

Figure 2. Salt rejection performance. a. Evaporation rate variations of evaporators with different MTBs number, **b.** Photos of salt re-dissolving from the surface of a 32-bridge evaporator.

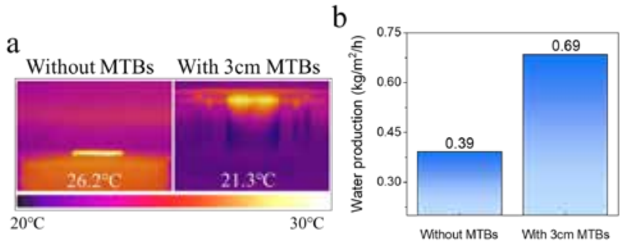

Figure 3. Boosted water production. a. Demonstration of the bulk water temperature after 3 h operation with different evaporators, **b.** Water production of evaporators with and without MTBs structure.

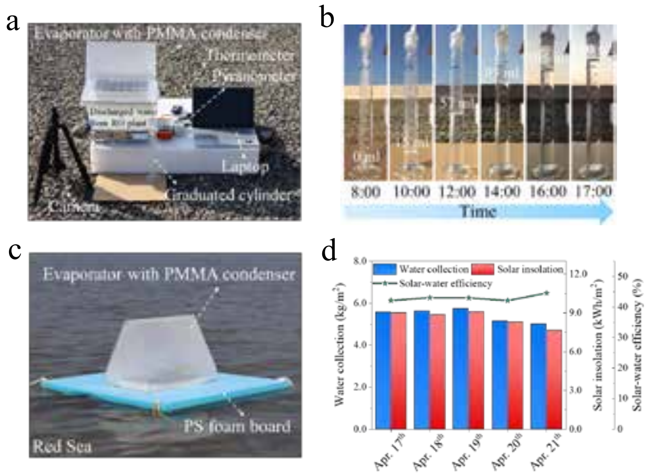

Figure 4. Field tests. a. Photography of rooftop experiment setup, **b.** Time-lapse photos of the collected water from 8:00 to 17:00. **a.** Photograph of the floating system for the ocean test, **b.** Daily water collection, solar insolation, and solar–water efficiency during the ocean test from Apr. 17 to 21, 2022.

Reference

Yang, K.[1]; Pan, T.[1]; Dang, S.; Gan, Q.*; Han, Y.* *Nature Communications*, **2022**, *13*, 6653

PI: Yu Han and Qiaoqiang Gan

Email: Kaijie.yang@kaust.edu.sa

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Water Security

Engineering biomaterials for accelerated interfacial solar evaporation

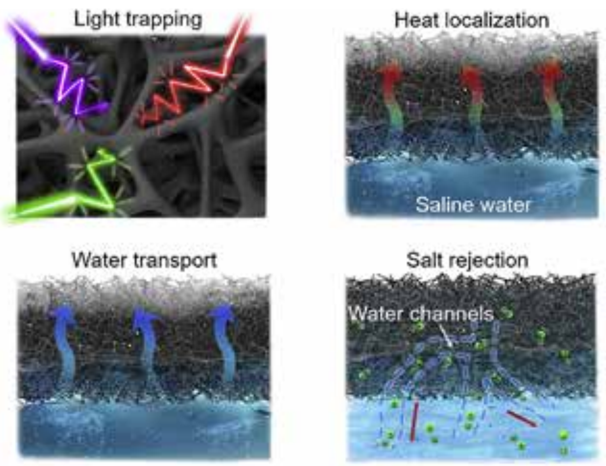
Yanpei Tian

Motivation

Freshwater scarcity is one of the most prevalent issues affecting people. Biomaterials that are abundant and recycled after their lifespan provides a perfect alternative for sustainable and scalable solar desalination systems. We are exploiting new biomaterials and engineering them into the efficient solar evaporators.

Challenge

- Enhanced solar absorptance through cost-effective materials
- Efficient water transportation for quick evaporation and salt rejection
- Low thermal conductivity for improved heat localization [1]
- Cost-effective materials for scalable deployment



1) Microporous acts as a blackcavity for solar trapping; 2) Low thermal conductivity enables heat localization for a quick interfacial steam generation; 3) Randomly arranged fibers enabled a fast pump of water to the top evaporative surface; 4) Salt dissipation is enabled by the porous structure.

Reference

Tian et al, Desalination 523 (2022): 115449.
Tian et al, Cell Reports Physical Science 2, no. 9 (2021): 100549.
Chen et al, Joule 3, no. 3 (2019): 683-718.

Research goals

1. Developing carbonized cattle manure (agriculture biomass) to achieve a hierarchical architecture structure for solar evaporation.

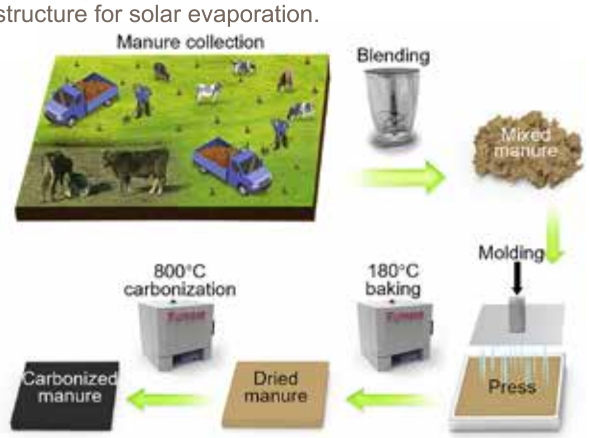


Figure 1: The fabrication process of carbonized manure.

2. Engineering the agar (ocean biomass) hydrogel evaporator with vertically aligned pores for light trapping, water transport, and salt rejection.

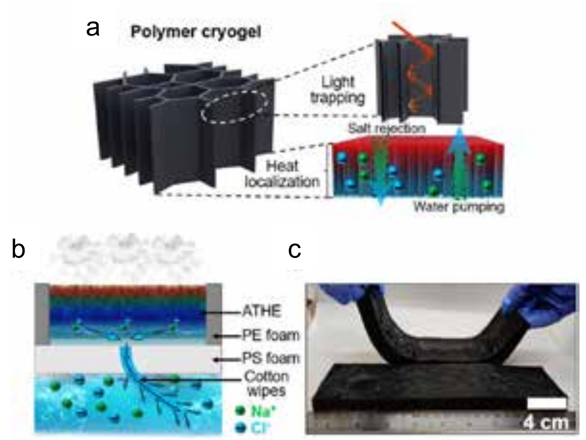


Figure 2: (a) The agar cryogel with vertically aligned light trapping channels efficiently absorbs solar flux. These channels simultaneously serve as water-pumping and salt-dissipation pathways. (b) Polystyrene foam serves as a thermal barrier to reduce heat dissipation towards the bulk seawater. (c) Large-area agar hydrogel evaporator.

PI: Qiaoqiang Gan

Email: yanpei.tian@kaust.edu.sa

At the World Water Day 2023 event, Professor Himanshu Mishra's students showcased SandX and CarboSoil technologies, they aim to transform desert landscapes, aligning with Saudi Vision 2030 and the pivotal goals of the Saudi Green Initiative.

Professor Peiying Hong has developed a zero-energy anaerobic membrane bioreactor (AnMBR) technology that produces minimal sludge and recycles wastewater sustainably. MODON is piloting Professor Hong's technology in Jeddah's 1st Industrial City, aiming to treat wastewater with low energy costs.

*The **WDRC** celebrated **World Water Day** on March 21st 2023 with activities to promote awareness of the **importance of water**, its **source**, **consumption**, and **management** and guided the community in making sustainable drinking water choices.*

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King Abdullah University of Science and Technology

Water Desalination and Reuse Center

wdrc.admin@kaust.edu.sa
4700 King Abdullah University of Science and Technology
Thuwal, 23955 SAUDI ARABIA

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