WORSKSHOP 04
Novel Feed Spacer Design for Fouling control in Membrane Filtration

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Saudi Arabia

arwadex 2019

TUESDAY 23 APRIL 2019
11:00 - 12:00
InterContinental City Stars, Cairo

INTRODUCTION

The major constraints of spiral wound membarne elements application are represented mainly by the fouling phenomenon leading to high concentration polarization and loss of pressure. Their performance can be improved by reducing these constraints which are primary linked to feed spacers design, membrane properties and operating conditions.

The role of the feed spacer is not only to keep membrane sheets separated but also to generate feed flow unsteadiness/turbulence that aid in reducing the concentration polarization and thus resulting in higher permeate production. Conversely, it is also known that although the feed spacers can enhance the permeate production, it also elevates the pressure drop along the module due mainly to obstructing the flow in the feed channel, thereby increasing the water production cost. Several studies have also reported that the feed spacers promote biofilm growth close to spacer strands before spreading over the rest of the membrane area.

This short workshop focuses on development of novel spacer designs aiming to enhance the water flux and reduce the pressure drop in these kinds of modules by different means. Experimental and simulations results of a specific case study will be presented.

WORKSHOP OBJECTIVES

- Lean about fundamentals of feed spacers and their role in enhancing the membrane filtration performance (hydrodynamics, concentration polarization)
- Learn about novel techniques and advanced equipment of spacer manufacturing, and membrane fouling monitoring and control

WORKSHOP CONTENT

- Types of membrane fouling
- Feed spacers
- Case study: Proposed novel spacer design
- Experimental data and numerical validation
- The use of advanced equipment (3-D printing, OCT)
- Performance evaluation

WORKSHOP LANGUAGE

English

WHO SHOULD ATTEND

This workshop is suitable for technicians, operators, engineers, and researchers from academia and industry.

ABOUT WORKSHOP INSTRUCTOR

Noreddine Ghaffour is a professor at the Water Desalination & Reuse Center (WDRC) at King Abdullah University of Science and Technology (KAUST).

مؤتمر تحلية المياه الثاني عشر في الدول العربية
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Novel feed spacer design for fouling control in membrane filtration

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Sarah Kerdi, Adnan Qamar, Johannes Vrouwenvelder

http://wdrc.kaust.edu.sa/Pages/Noreddine-Ghaffour.aspx

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Contents

- Water desalination
- Membrane fouling
- Membrane feed spacers
- Experimental results & discussion
- Simulation results & discussion
- Conclusion

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Water Desalination & Reuse Center (WDRC)

Three flagship themes:

Greener Desalination

less energy, chemicals, discharge

Water Security

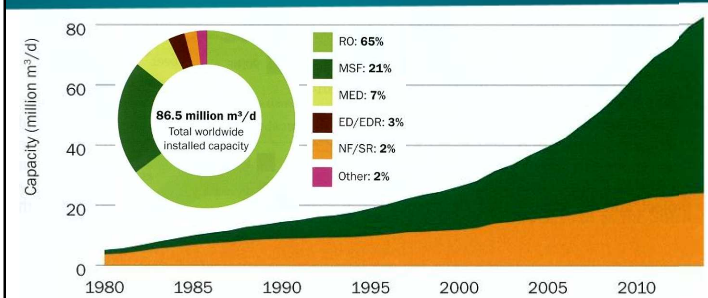
sufficient & safe for all

Waste to Resource

recovery of water, nutrients, minerals and energy

3 WDRC Water Desalination and Reuse Center

Global market evolution



Thermal > SWRO **>> Innovative processes**

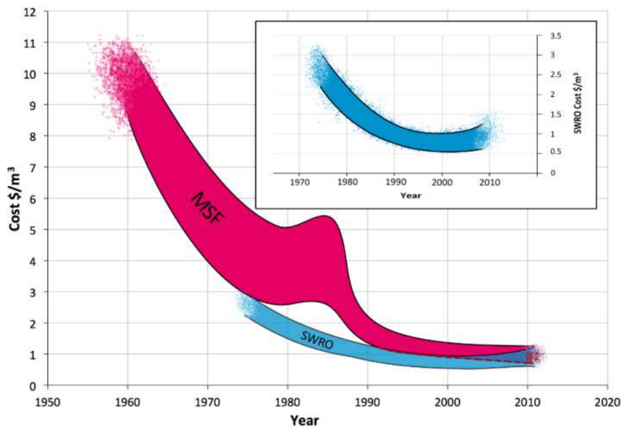
Extensive pretreatment and chemicals use.

- ✓ New membranes
- ✓ New Technologies

Ref. GWI/WDR, 2017

Desalination euse Center

Trends in desalination cost



Ghaffour et al., Desal. 309 (2013) 197-207.

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WDRC Water Desalination and Reuse Center

Basic components of spiral wound modules

- Centre tube
- Brine seal
- Anti - telescoping device
- Membrane
- Permeate-spacer (Tricot)
- Feed/brine-spacer
- Special glue

First Osmosis Membrane - 1964

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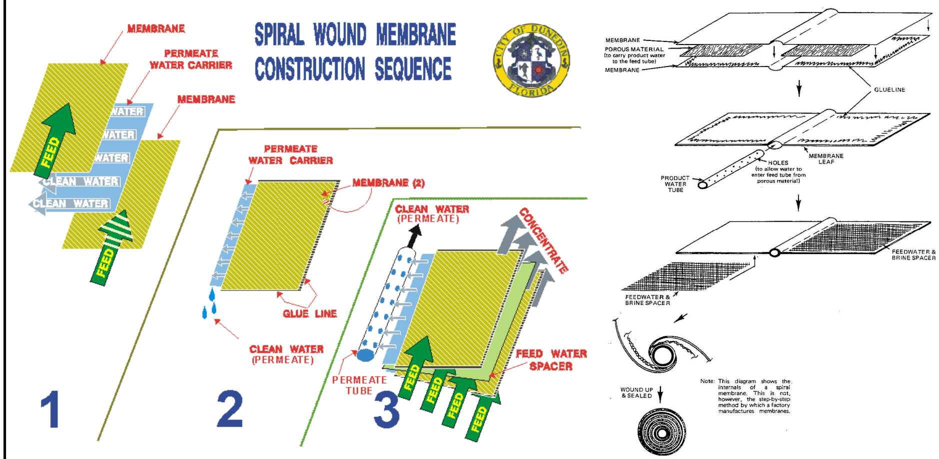
Spiral wound modules

KAUST



Details with Animation 7

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Spiral wound modules

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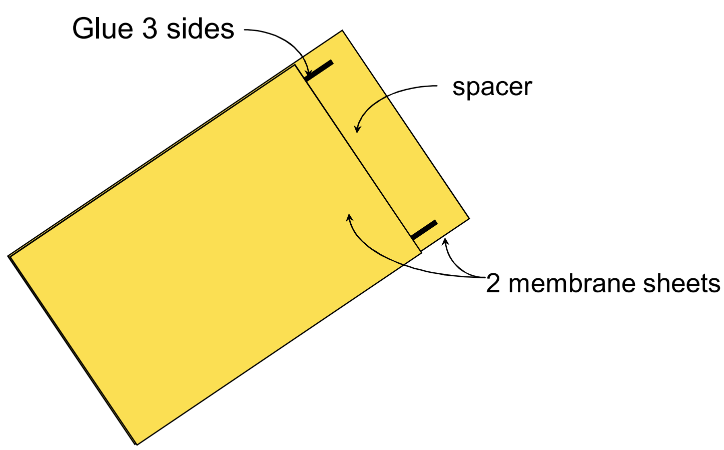

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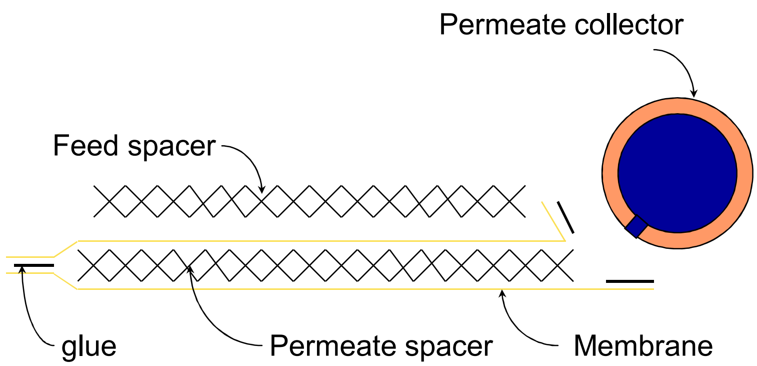
Spiral wound modules



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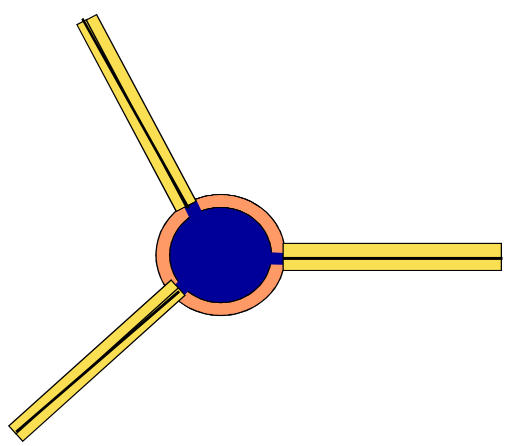
Spiral wound modules



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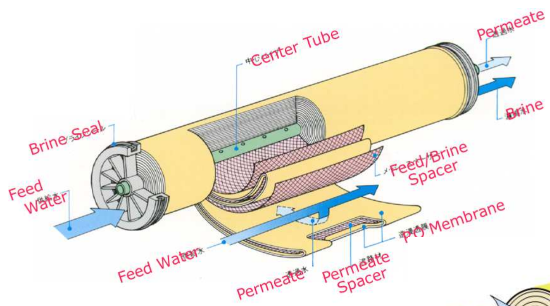
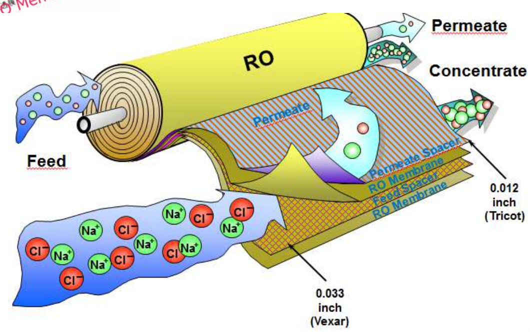
Unrolled spiral wound modules and water circulation

كاوست KAUST





TFC membrane structure

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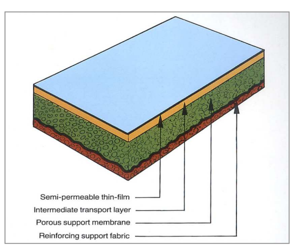

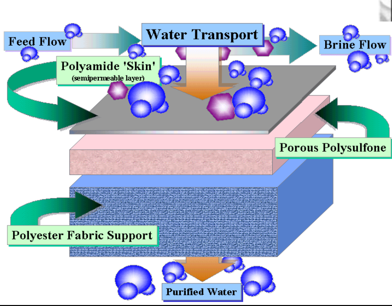

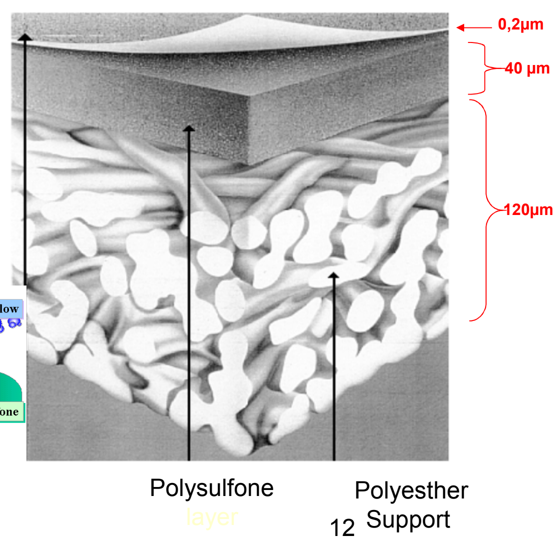

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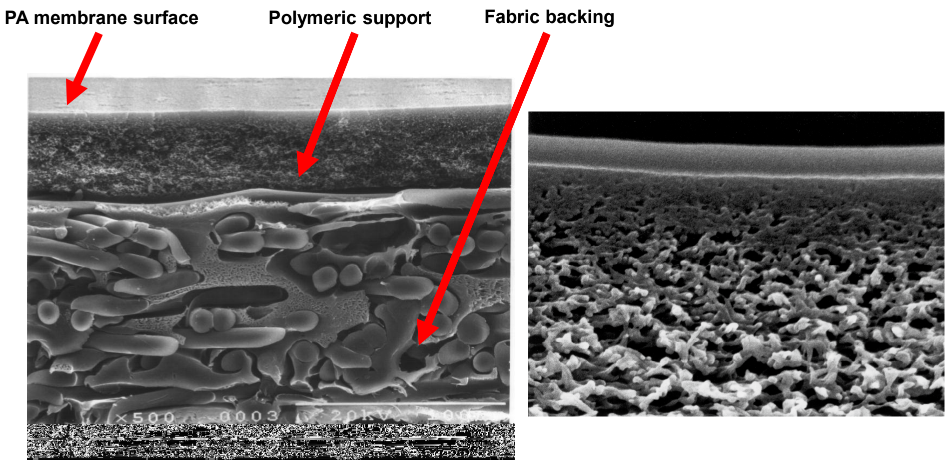
TFC membrane structure (SEM)



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Fundamentals of deposition

Scale and Fouling are an accumulation of deposits on the surface of the membrane

SCALING - hard mineral deposits including calcium carbonate, calcium sulfate, barium sulfate, and silica

FOULING - organic in nature includes silt, clay, colloidal and suspended matter, metal oxides, biological growth, manganese, and aluminum

WDRC Water Desalination and Reuse Center

Types of fouling

- Fouling - Surface deposition of material present in feed water (inorganic and organic)
  - ✓ TSS - silt, clay, and other suspended solids
  - ✓ Bacteria, algae
  - ✓ Organics
  - ✓ Colloids
  - ✓ Metal oxides of iron, manganese, and aluminum
  - ✓ Sulphides, sulphur
- Common in surface water supplies
- Bacteria stick to the membrane surface and form a biofilm

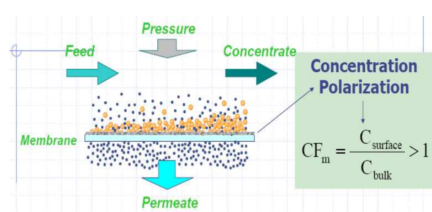
Concentration polarization

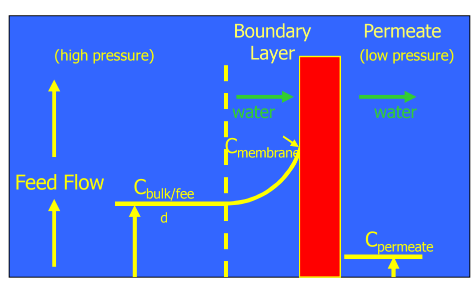
Concentration polarization is:

Accumulation of salts (ions) at the membrane surface.

This phenomenon results from:

- water flow through a membrane
- salts (ions) are rejected
- retained salts (ions) accumulate at the membrane surface





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Concentration polarization

- The higher the permeate flow (Q_p) in an element, the higher the transport of salts (ions) to the membrane surface.
  - As a result accumulation will be higher and Concentration Polarization will be higher
- The higher the cross flow along the membrane surface the higher the back diffusion
  - As a result accumulation will be reduced and concentration polarization will be lower

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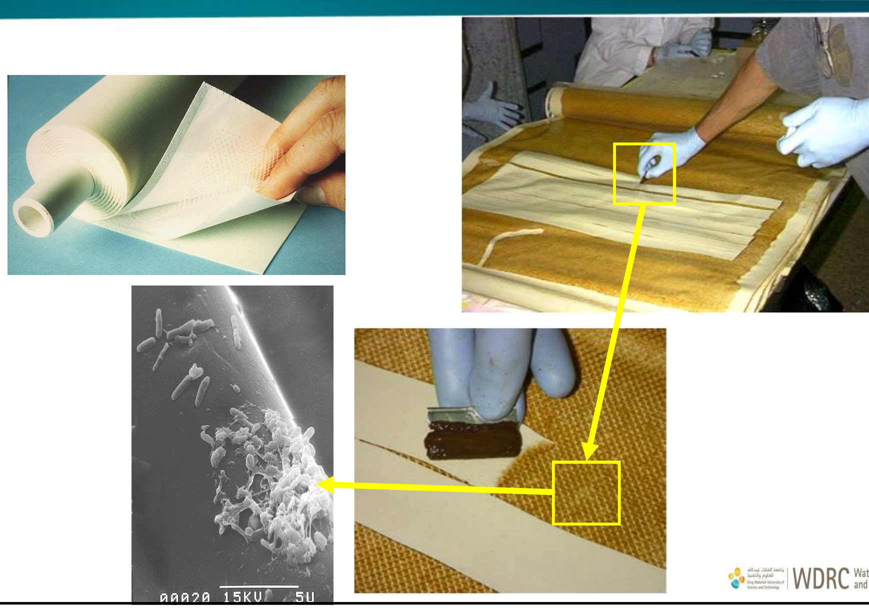
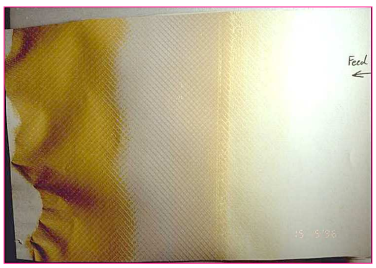
Membrane autopsies



Membrane autopsies



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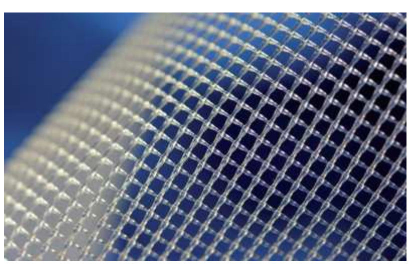
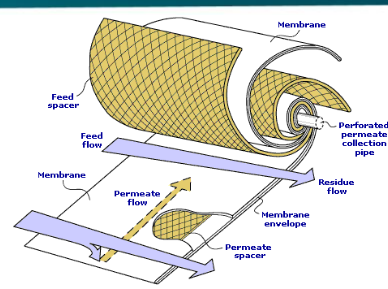
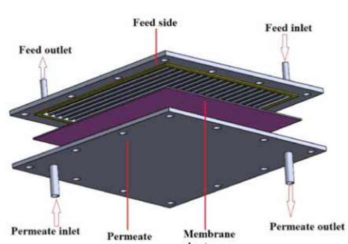
Feed spacers





- Generate feed flow unsteadiness-turbulence that aid in reducing CP
- Enhance flux but elevates ΔP
- Can promote biofilm growth



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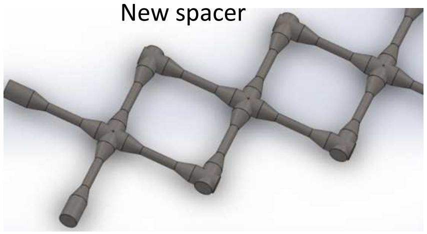
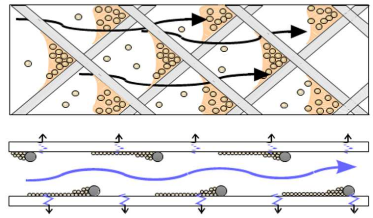
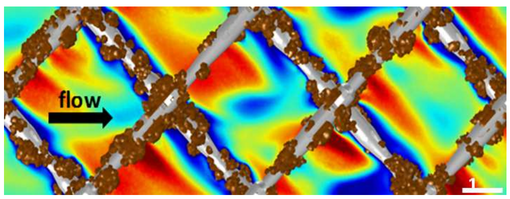
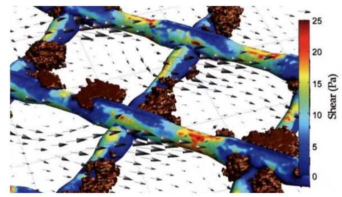
Feed spacers & fouling

New spacer









Foulants deposited on the spacer showing dead zones and first accumulation of foulants

Ref. Vrouwenvelder et al., (2014)

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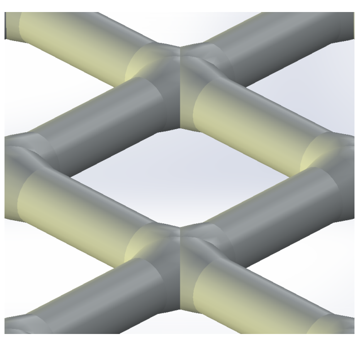
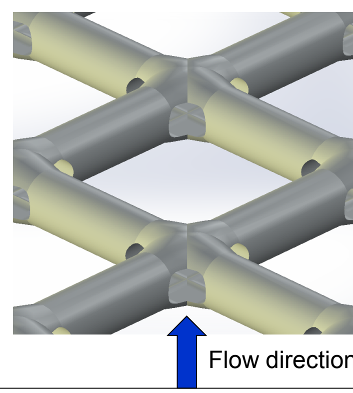
Proposed spacer design for fouling control

Standard spacer



Perforated spacer



Flow direction

Spacer orientation, internal stand angle, etc to improve the hydrodynamics to decrease fouling and CP

- Perforations can provide micro-jets inside the filament cell producing high shear stress
- It can sweep away and avoid foulants to deposit
- Increase the feed channel porosity which helps reducing ΔP

Patent WO 2017/175137 A1 (2017)

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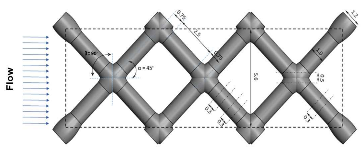
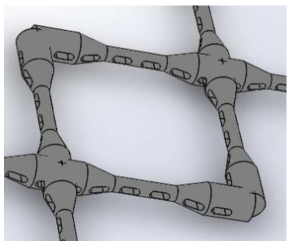
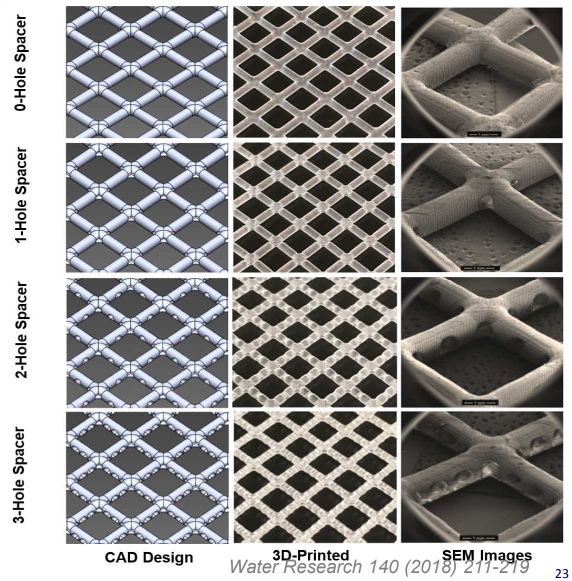
Different perforated spacers (3D printed)







Patent WO 2017/175137 A1 (2017)

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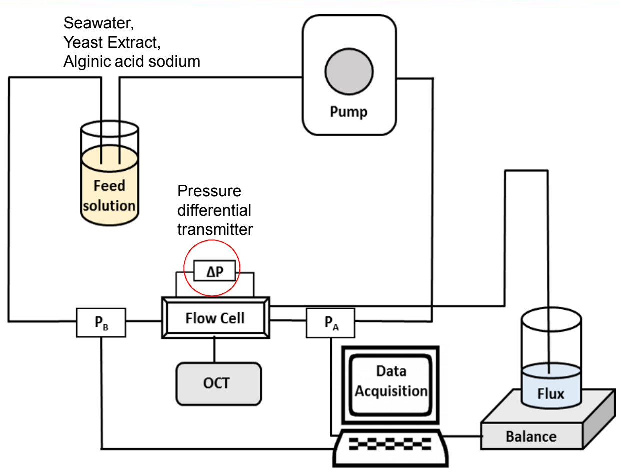
Experimental setup



- Optical Coherence Tomography (OCT)
- Direct Numerical Simulation (DNS)
- KAUST Supercomputer facilty

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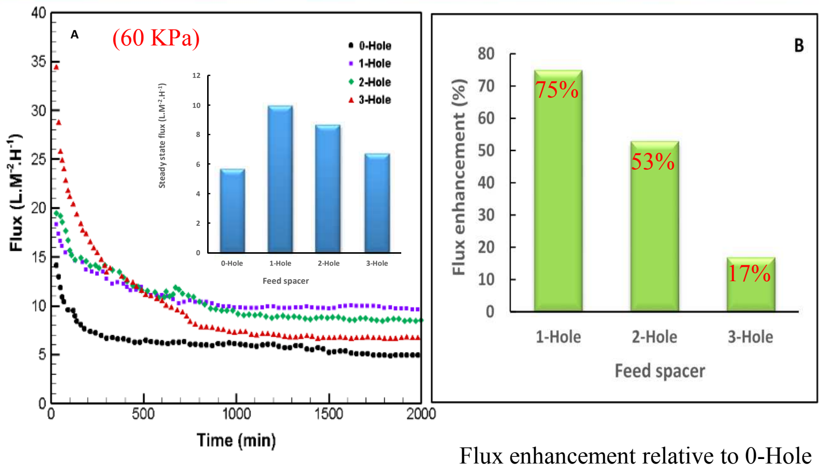
Performance under constant pressure



Flux enhancement relative to 0-Hole spacer for all perforated spacers when steady state is achieved.

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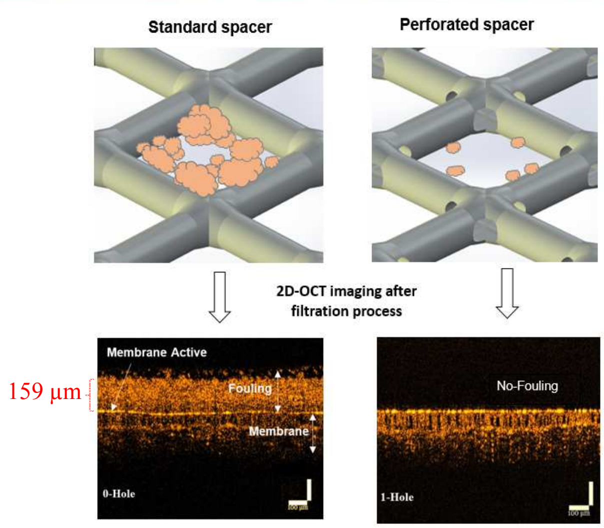
OCT scans for fouling taken after 40h filtration



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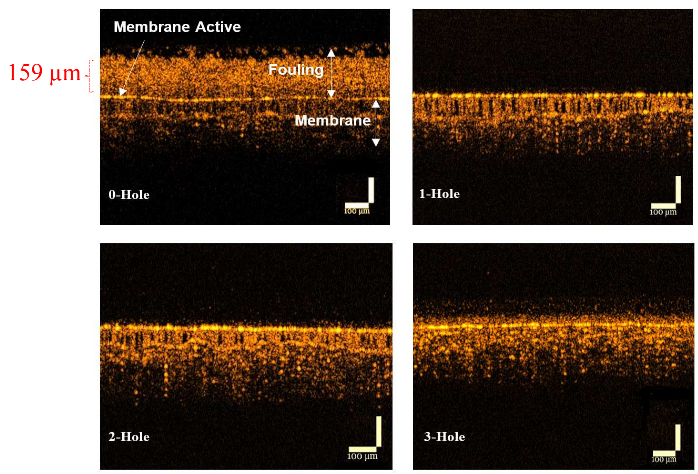
OCT scans for fouling taken after 40h filtration



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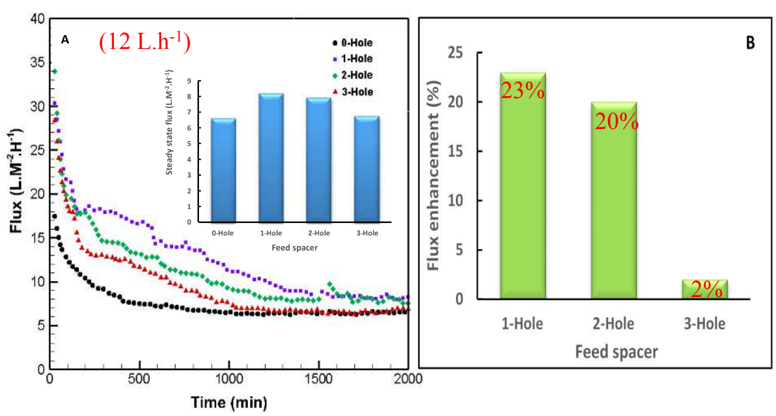
Performance under constant feed flow



% of flux enhancement is lower than under constant pressure due mainly to higher ΔP across the module.

Flux enhancement relative to 0-Hole spacer for all perforated spacers when steady state is achieved.

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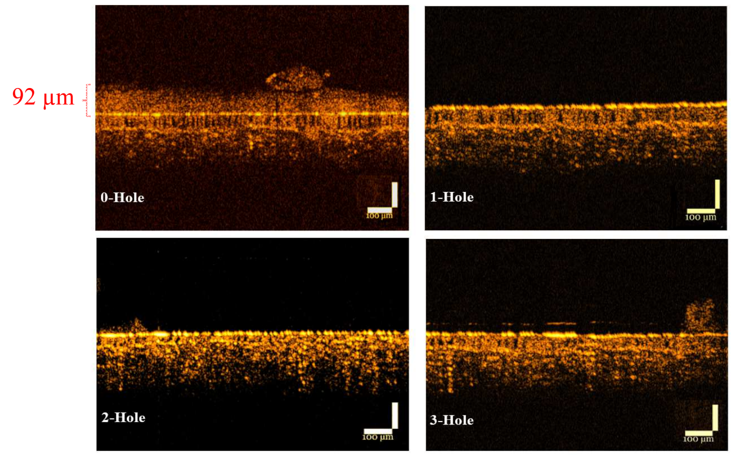
OCT scans for fouling taken after 40h filtration



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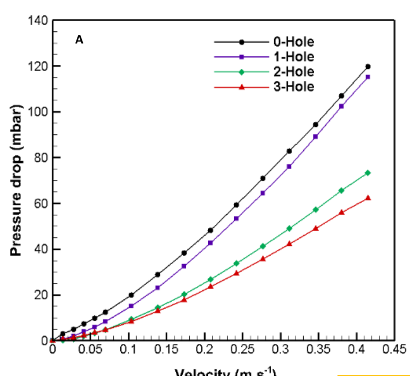
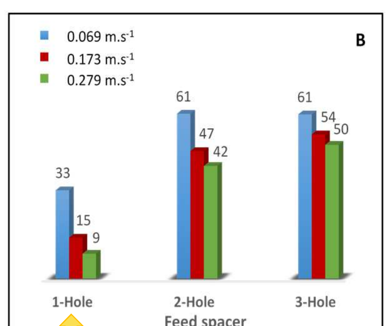
Hydraulic resistance





High flux and cleaner surface

The decrease in ΔP appears more significant when the number of holes is the spacer filaments is increased. Due to the increase in channel porosity.

Percentage reduction of feed pressure drop relative to 0-Hole at various velocity rates.

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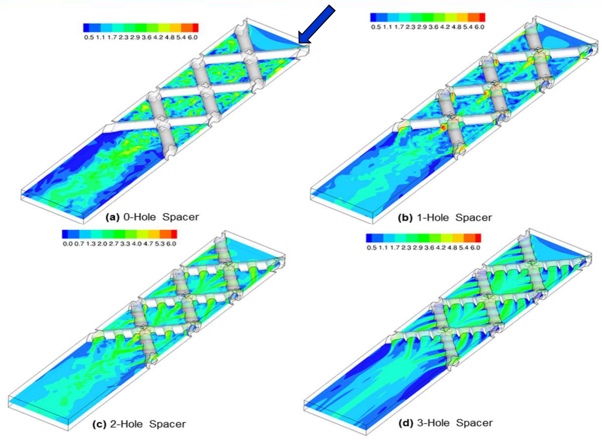
Direct numerical simulation (DNS) results

KAUST



Non-Dimensional velocity magnitude for different spacers at central plane of the feed channel from DNS calculation using more than 1 spacer cell.

When the hole was introduced more turbulent intensity was observed, but it decreases by increasing the number of holes.

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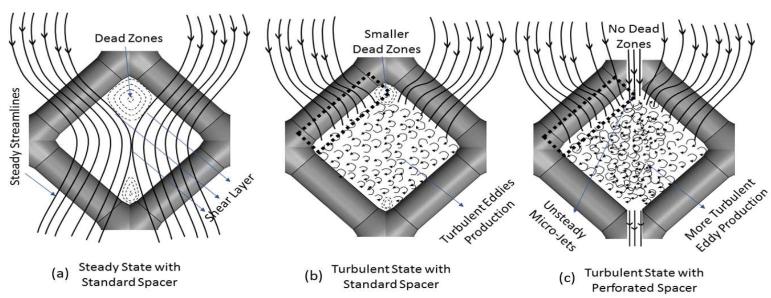
Fluid flow behavior under different states

KAUST



Steady flow conditions | Turbulent condition | Turbulent state in presence of perforated spacer

- The intersection of filaments obstructs the flow, hence exposed to low velocities.
- Dead-zones or recirculation vortex have been created enabling foulants deposition.
- Higher velocities lead to perturbation of the dead zones, hence pass to unsteady regime.
- By default, perforated spacer overcomes this hurdle by eliminating the dead zones.

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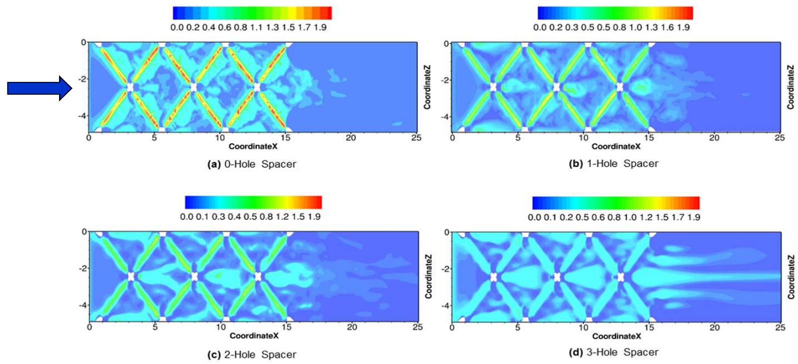
Non-dimensional shear stress contours



- Perforations in the interconnection of spacer filaments create micro-jets offering higher turbulence
- Better mixing at lower energy

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Perforated spacers illustration

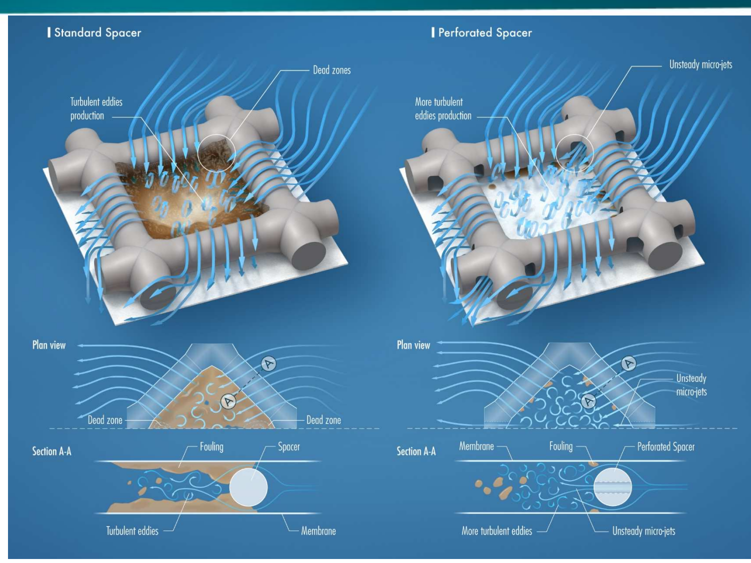

Illustration prepared by Mr. Xavier Pita, KAUST illustration team. *Water Research 140 (2018) 211-219*

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Conclusion

- Perforated spacers could increase the flux by 75% (1-H) and reduce ΔP by 15%. ΔP could be further improved to 54% with more perforations (3-H) but at the expense of flux reduction (17%).
- Perforations created micro-jets inside the filament cell, which not only eliminated the dead zones but also aided in redistributing/diffusing the shear stress to minimize foulants attachment.
- Simulations indicated that increasing the number of perforations also reduces the fluid unsteadiness which result in fouling formation on the membrane (layer is much thinner compared to the standard spacer).

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Please find more details in:
S. Kerdi, A. Qamar, J.S. Vrouwenvelder, N. Ghaffour, Fouling resilient perforated feed spacers for membrane filtration, ***Water Research 140 (2018) 211-219.***

Thank You

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