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In-situ monitoring of RO membranes using electrical impedance spectroscopy: Threshold fluxes and fouling

Hans G. L. Coster
School of Chemical and Biomolecular Engineering, University of Sydney, Sydney, Australia, hans.coster@sydney.edu.au

Jia Shin Ho
Division of Chemistry and Biological Chemistry, School of Physical and Mathematical Sciences ; Singapore Membrane Technology Centre, Nanyang Technological University, Singapore

Lee Nuang Sim
Singapore Membrane Technology Centre, Nanyang Technological University, Singapore

Anthony G. Fane
Singapore Membrane Technology Centre ; School of Civil and Environmental Engineering, Nanyang Technological University, Singapore

In-situ Monitoring of RO Membranes using Electrical Impedance Spectroscopy: Threshold fluxes and Fouling

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The University of Sydney

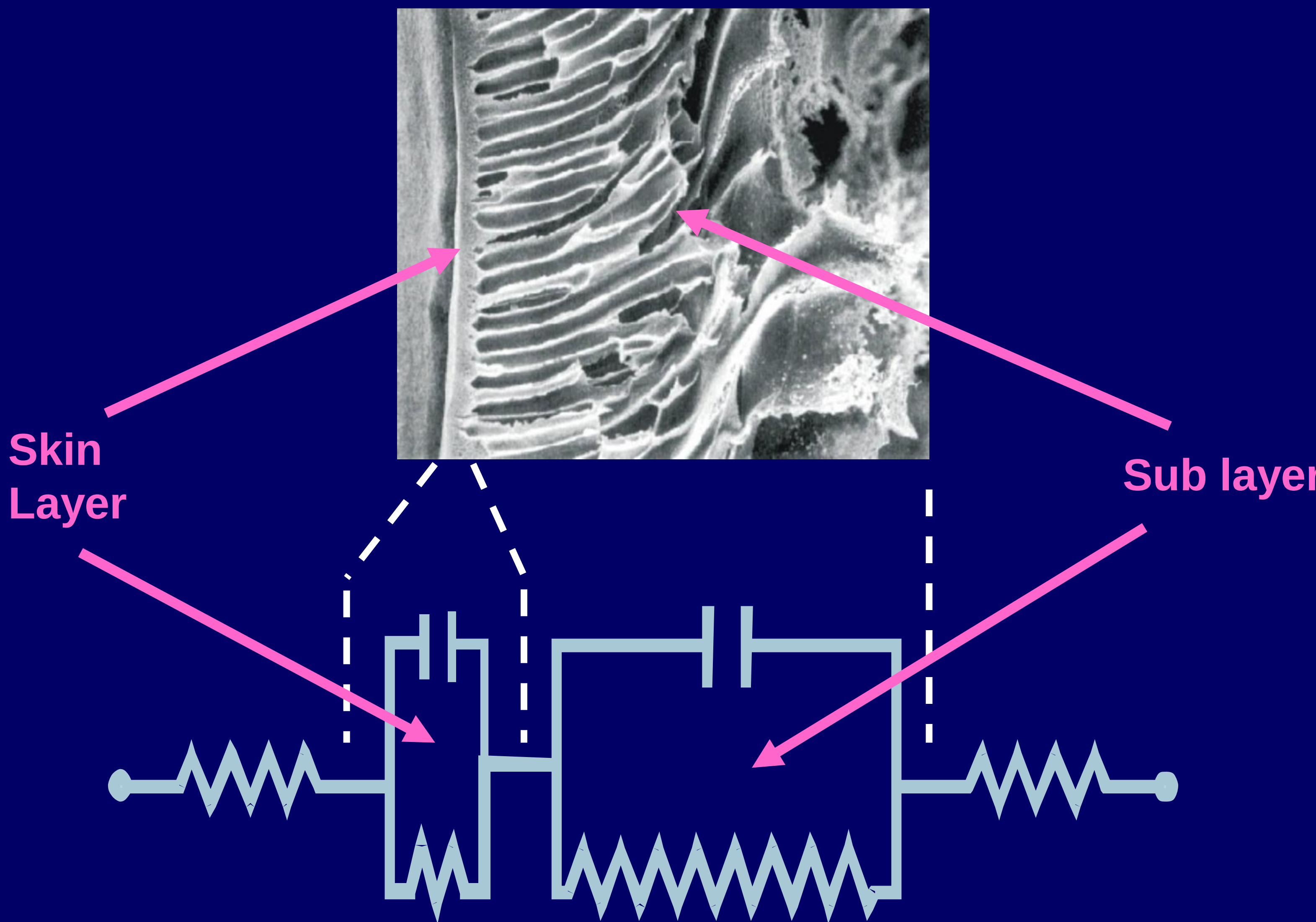
School of Chemical and Biomolecular Engineering

In collaboration with

NANYANG TECHNOLOGICAL UNIVERSITY

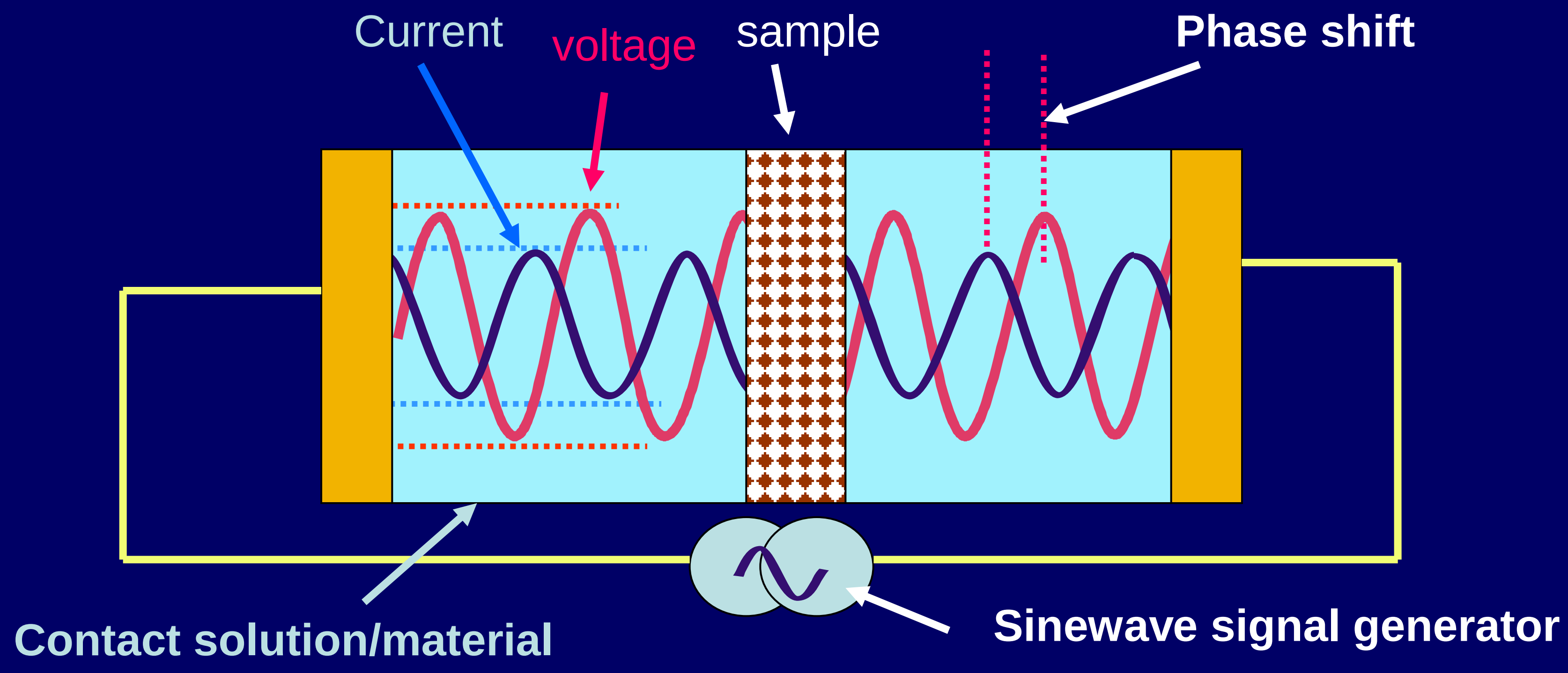
Singapore Membrane Technology Centre

Membrane Dielectric Structure

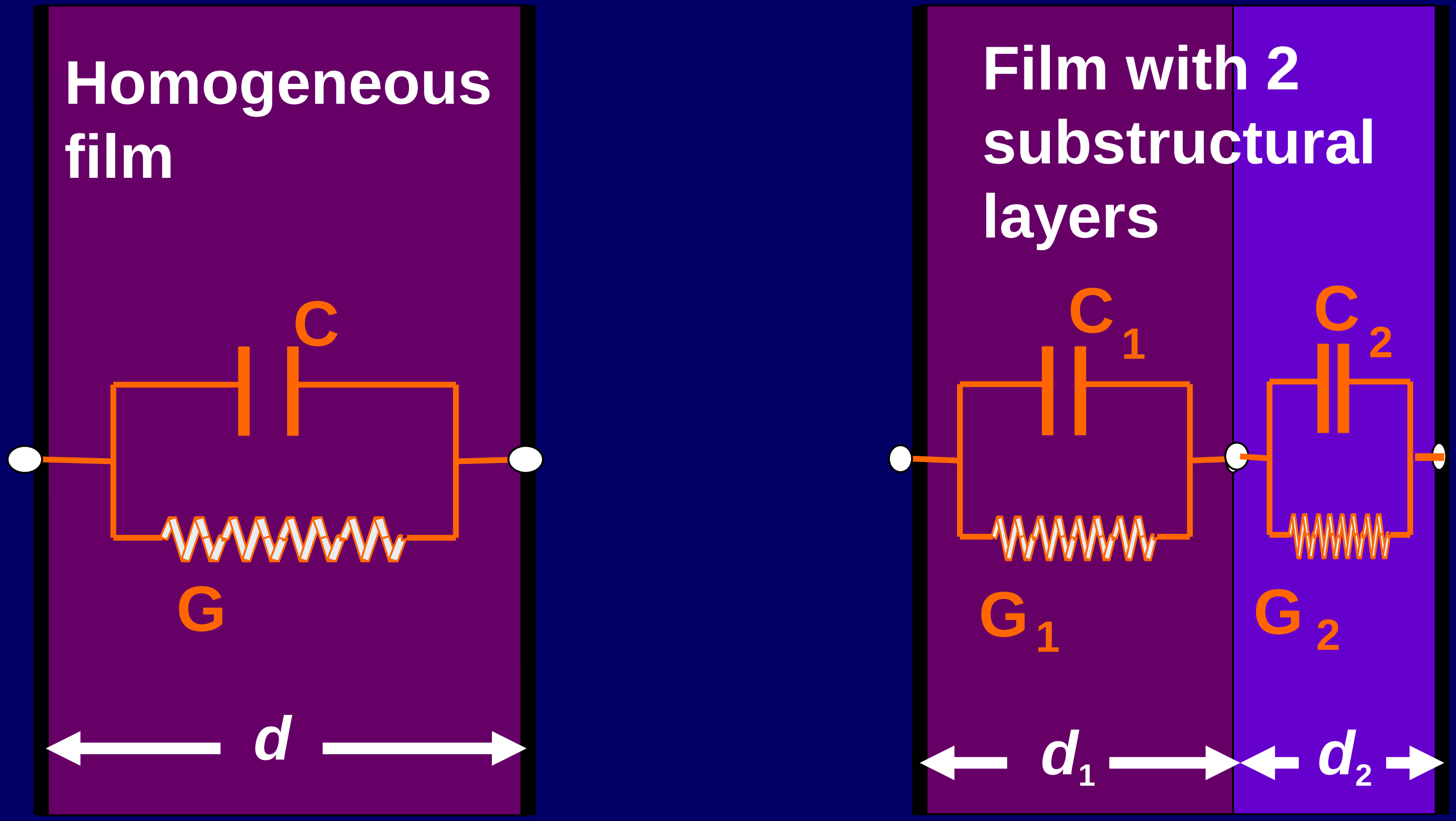


What is involved in Impoedance Spectroscopy ?

- Injection of sinusoidal AC currents through the membrane
- Measurement of the current and voltage across the membrane
- Measurement of the phase shift between the voltage & current



Electrical representation of films

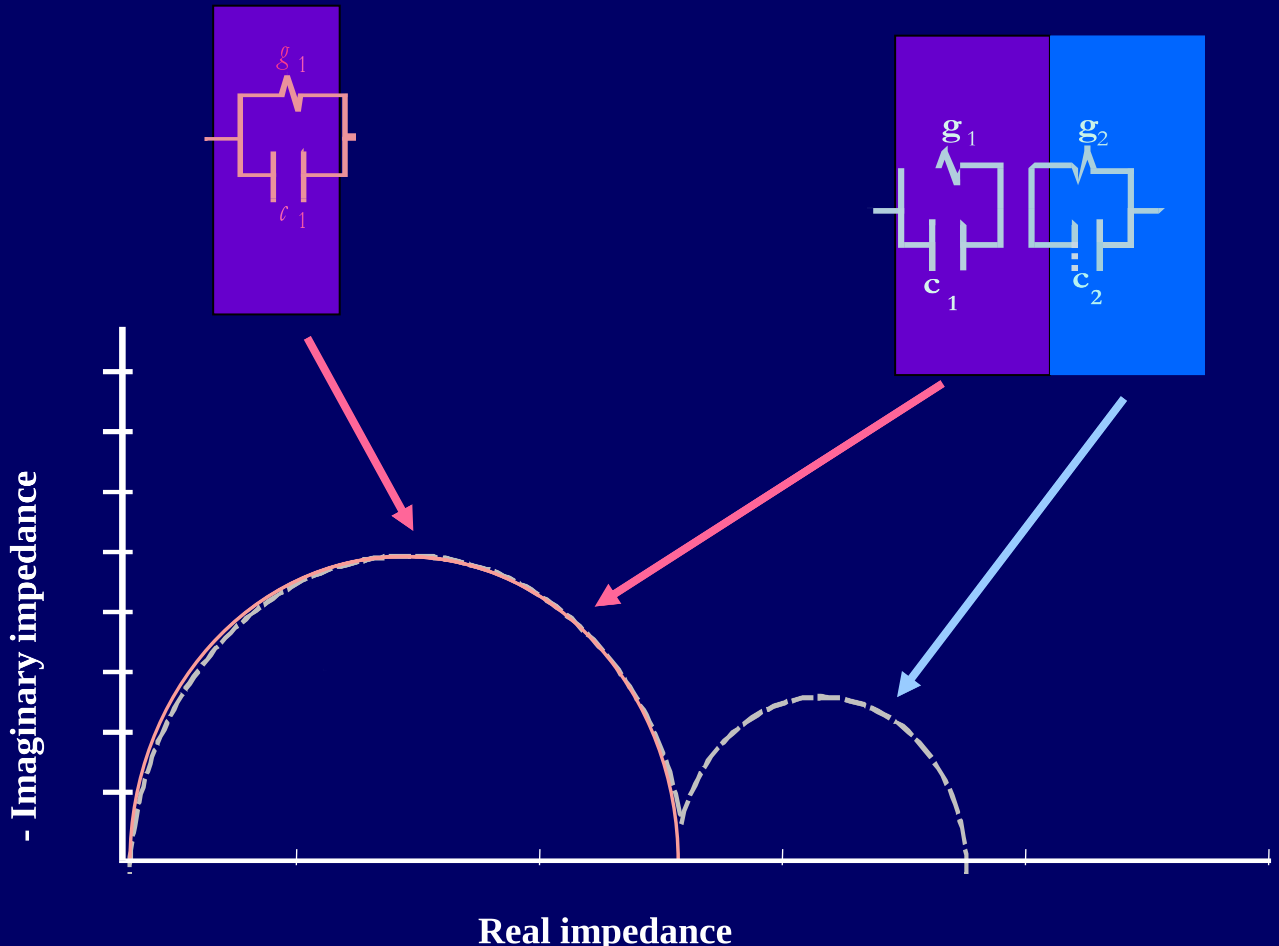


$C_1 = 0.006\ F/m^2$ $C_2 = 0.059\ F/m^2$

$G_1 = 0.003\ S/m^2$ $G_2 = 4.35\ S/m^2$

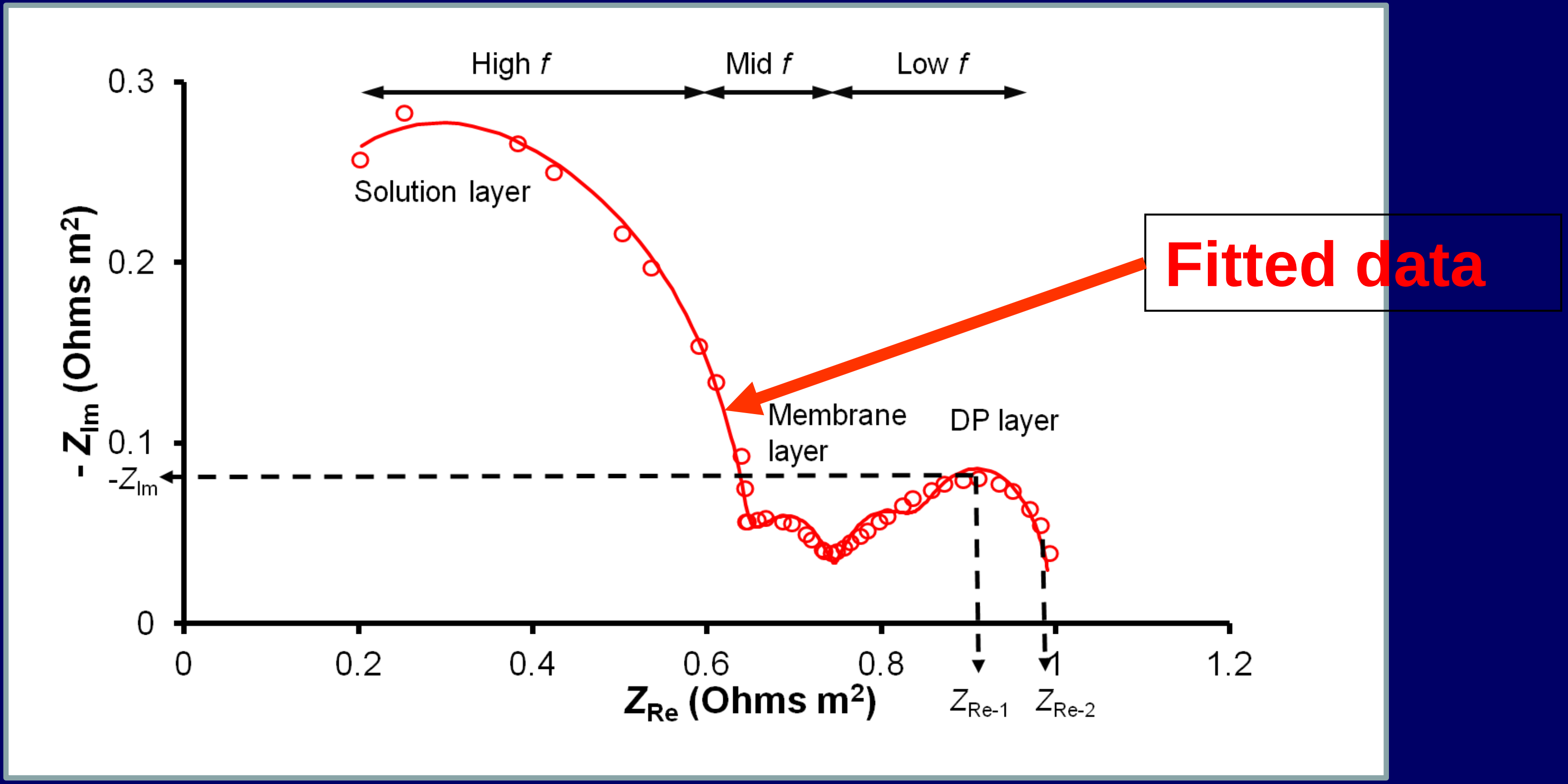
Nyquist Plots

Help to discern various processes and layers with different time constants



additional arcs appear for each element with a different time constant

EIS Membrane characteristics



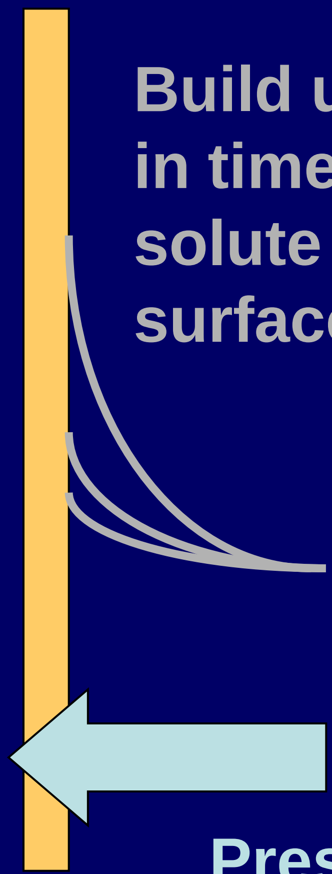
Each dielectric element or transport process will have a characteristic electrical time-constant.

These various elements/processes can be readily distinguished in a Nyguist plot of the imaginary vs the real impedance.

Data for RO with NaCl 2000ppm and silica 200 ppm, crossflow 0.15 m/s: from Ho, Sim, Gu, Webster, Fane & Coster (2015) .

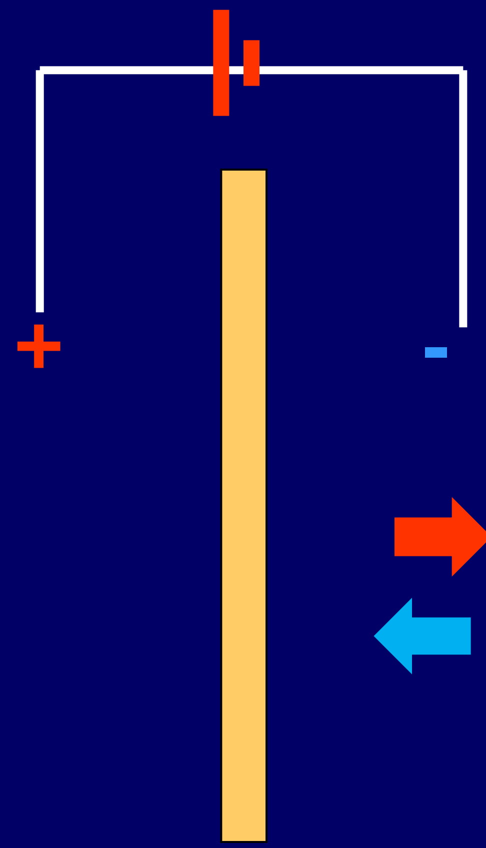
Non-linear Effects: Concentration polarization

membrane



Build up in time of solute at surface

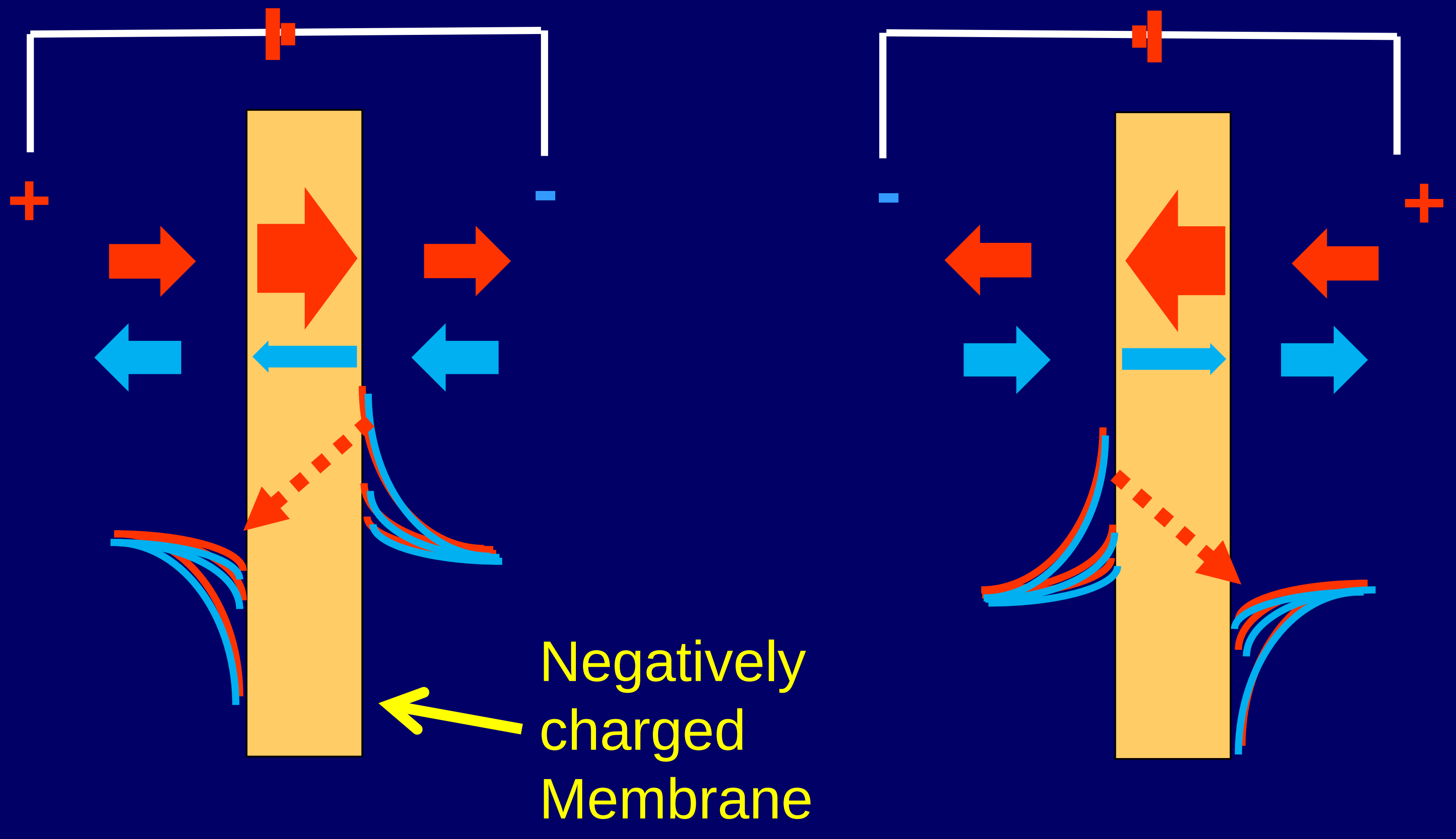
Pressure driven flux



Electrically driven transport of ionic solutes

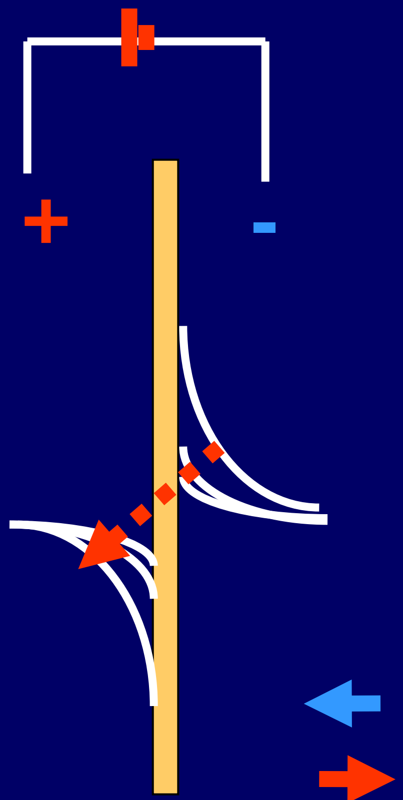
Ion concentration profiles will depend on the transport numbers

Electrical Diffusion Polarization

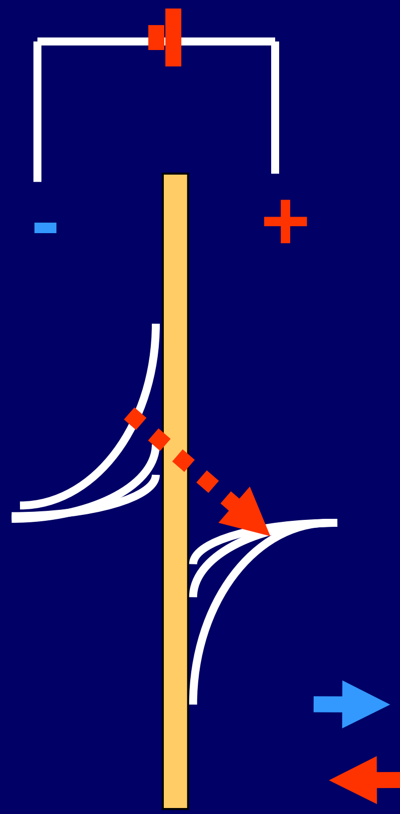


The electric potential due to the back diffusion is in the same direction as the driving potential

AC Diffusion Polarization Effects



With AC currents, the profiles undergo an inversion during each cycle

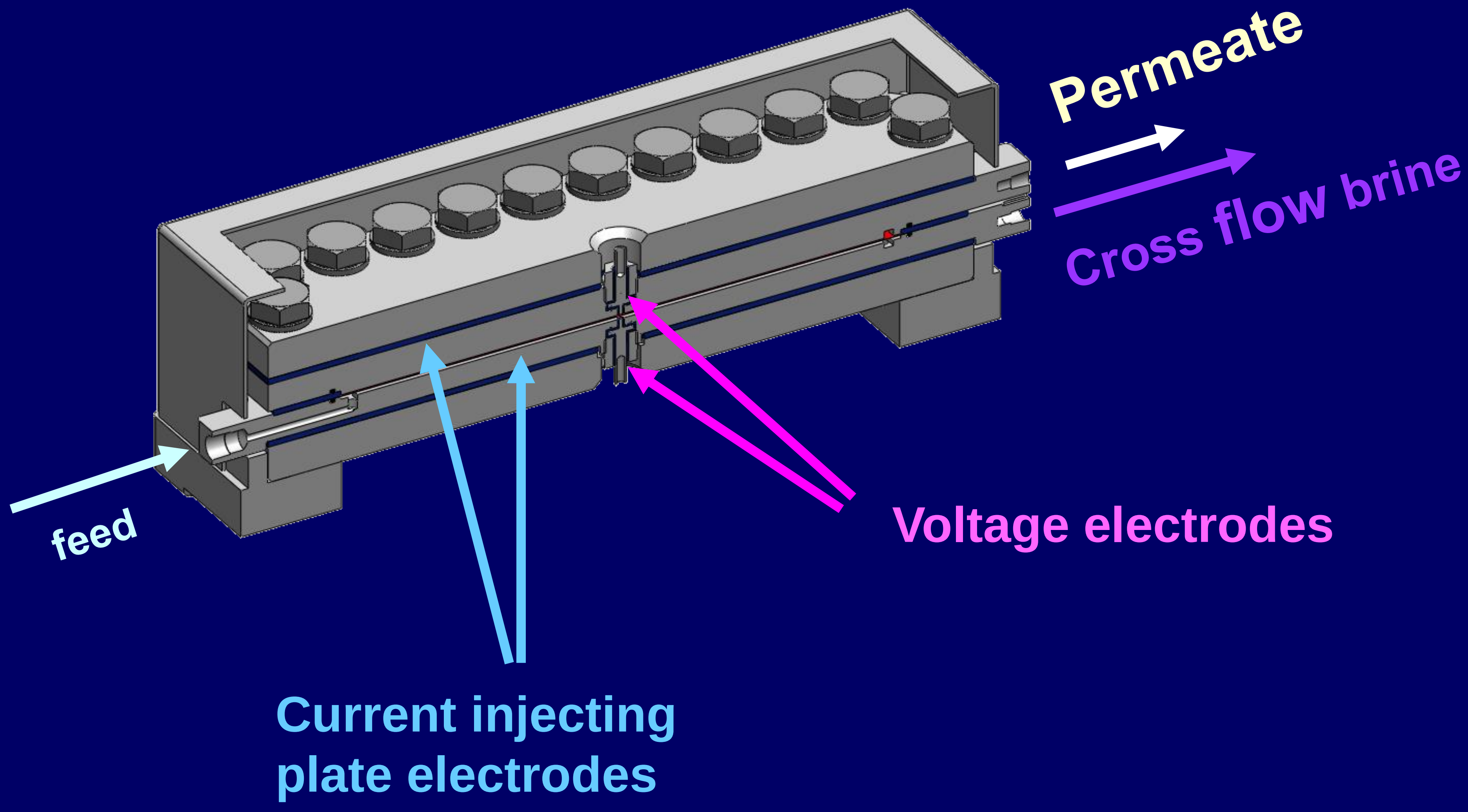


At very high frequencies there is insufficient time for concentration polarization to manifest

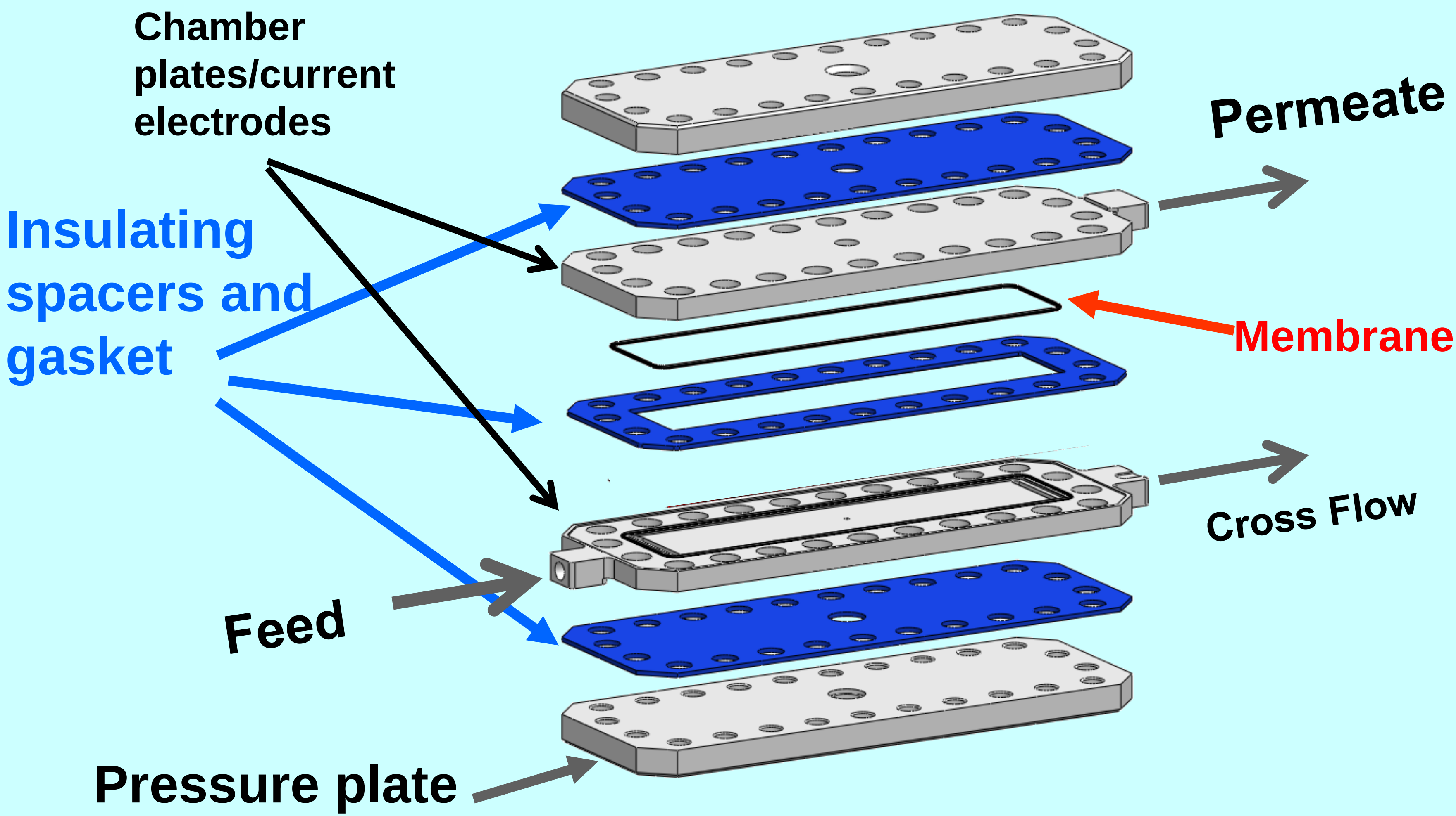
At low frequencies the concentration polarization will be much larger than at high frequencies of the AC.

Impedance Monitoring Cross-flow Module

Cross section of module

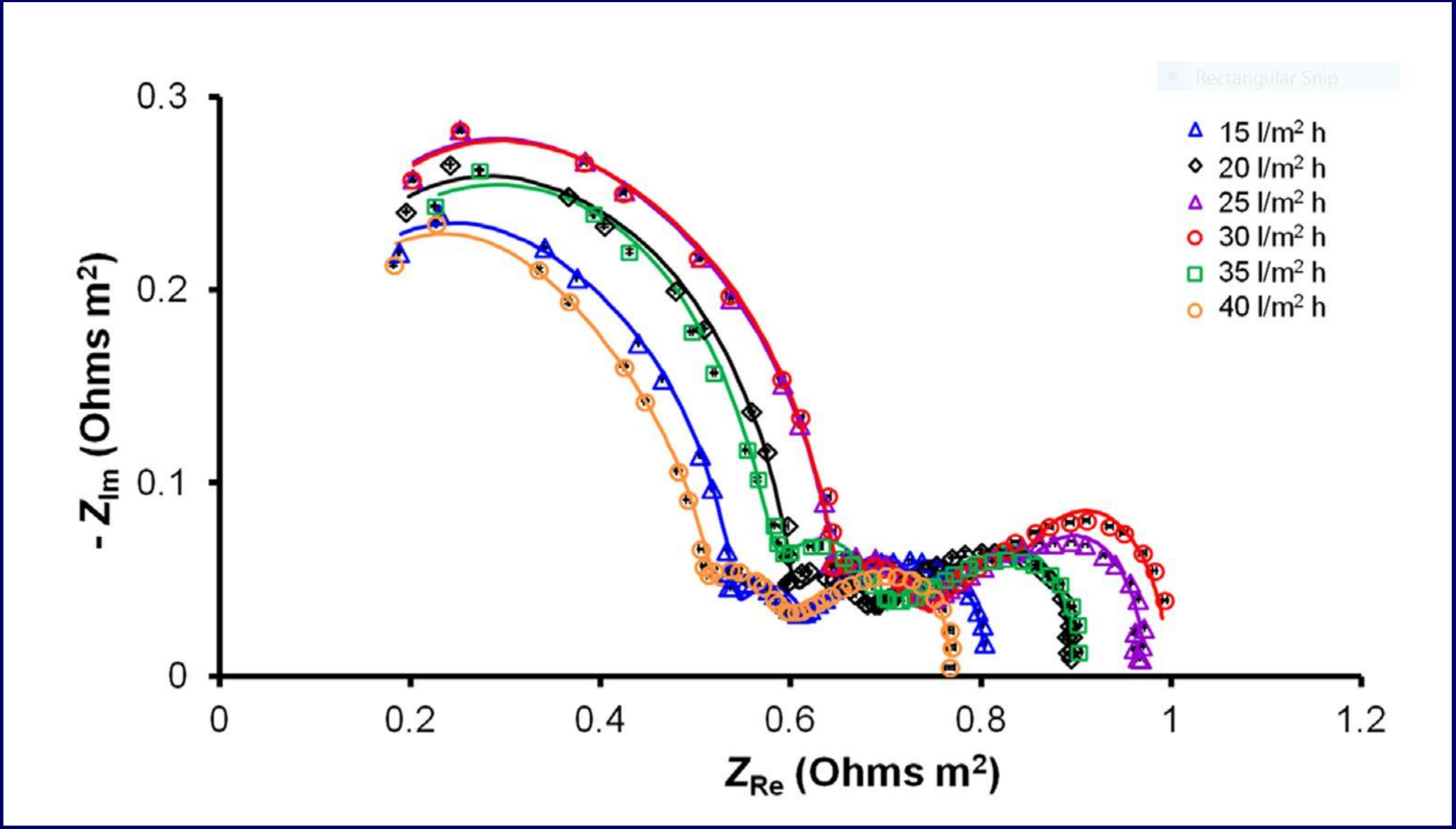


An Impedance Cross-flow Module for monitoring membrane fouling *in situ*



Exploded view of internal plates and gaskets.

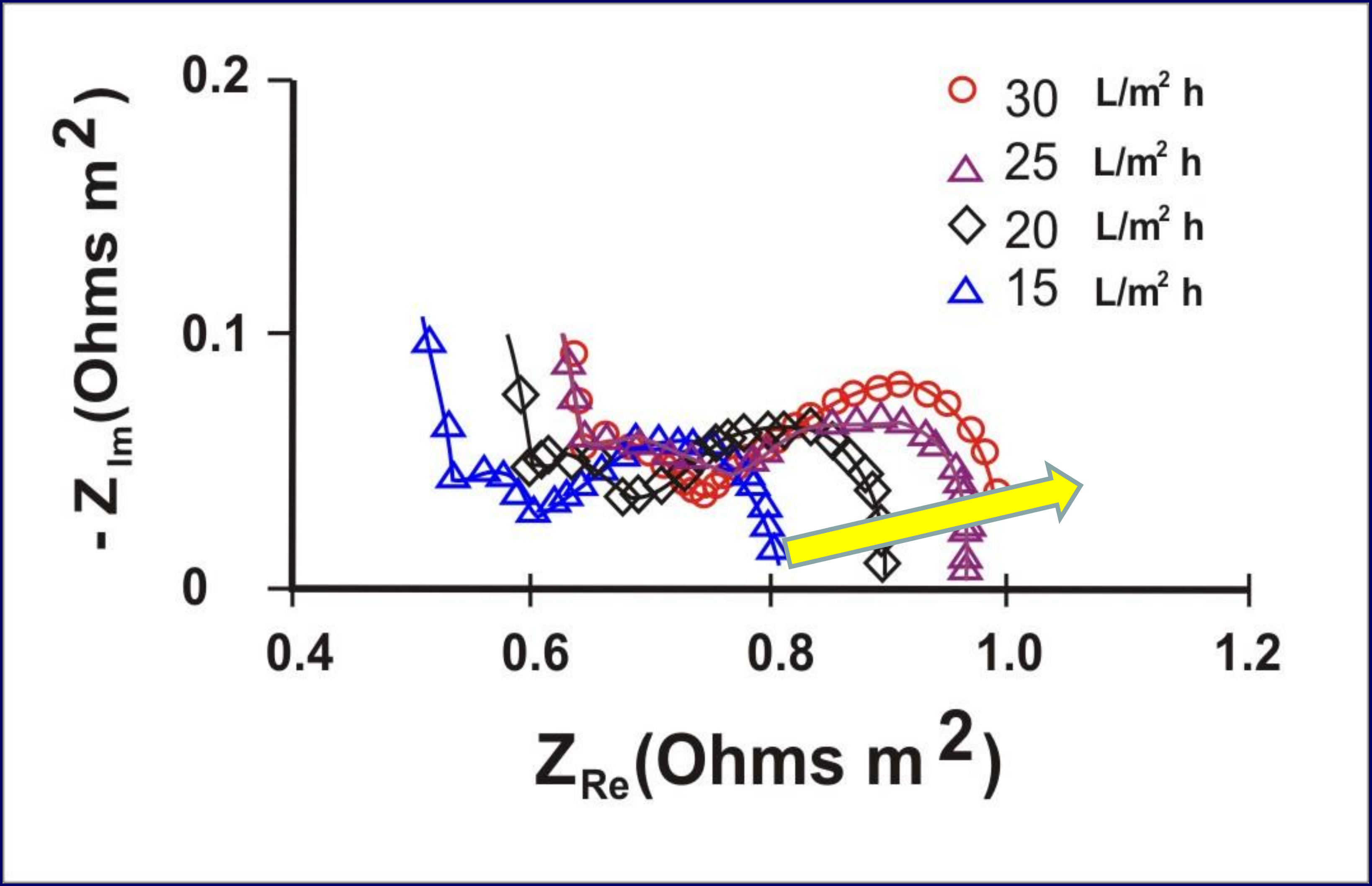
EIS: Effect of Flux



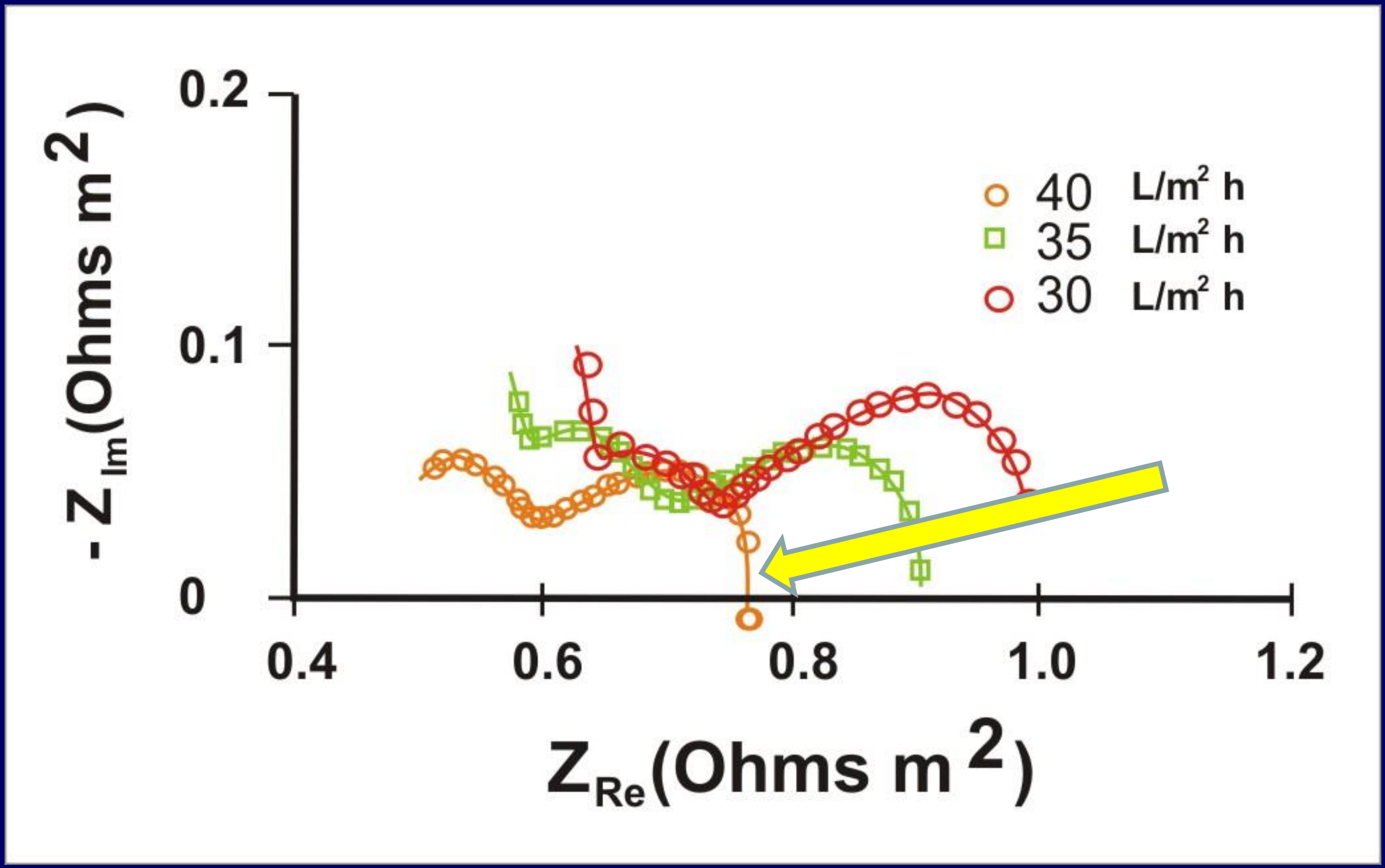
RO feed: 200 ppm silica with 2000 ppm NaCl; crossflow velocity; 0.15 m/s.

Ho, Sim, Gu, Webster, Fane & Coster / Journal of Membrane Science 500 (2016) 55–65

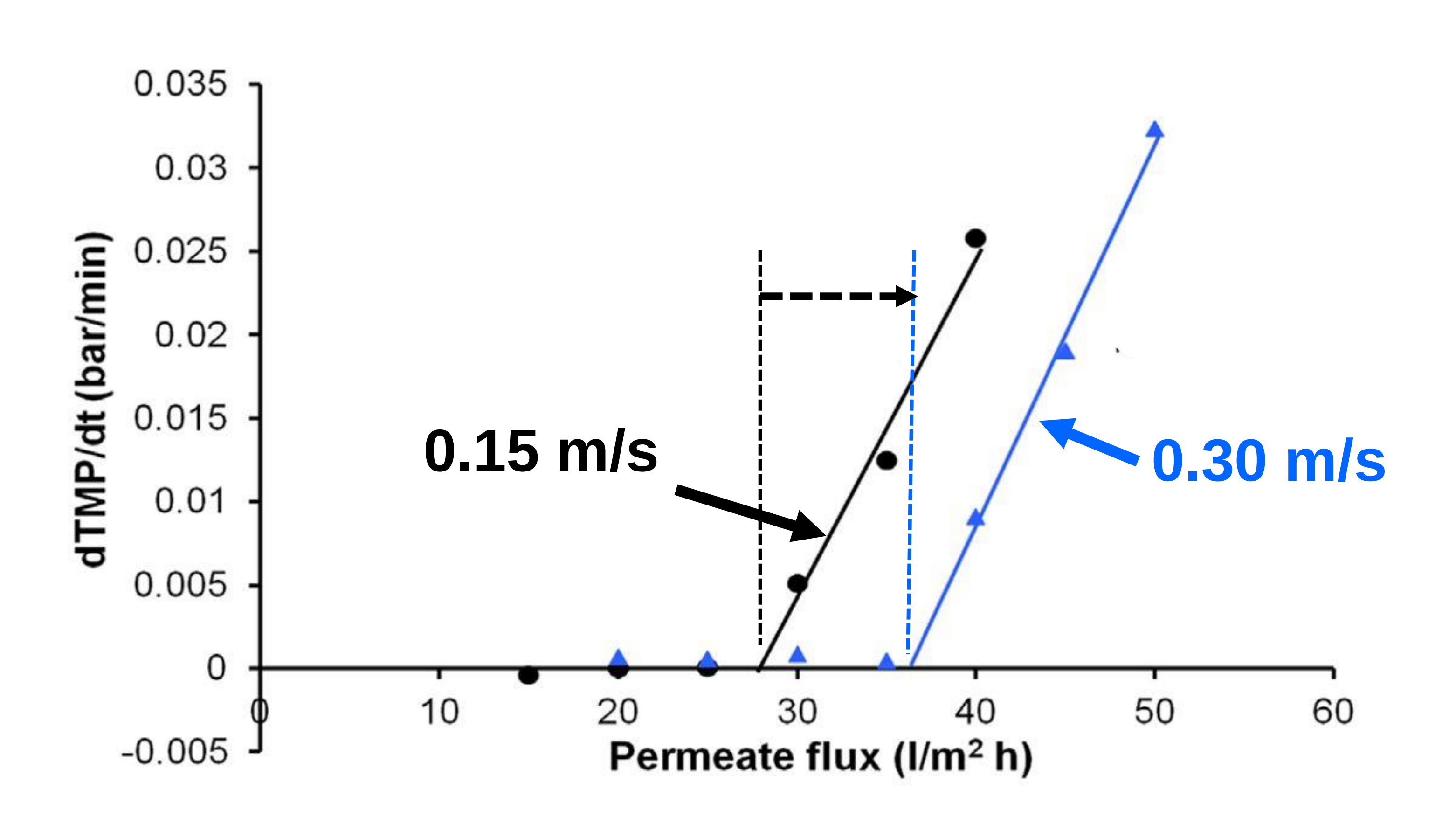
EIS Nyguist plots vs Flux at low fluxes



EIS Nyquist plots at higher fluxes



Fouling: A Threshold Phenomena



RO feed: 200 ppm silica with 2000 ppm NaCl.

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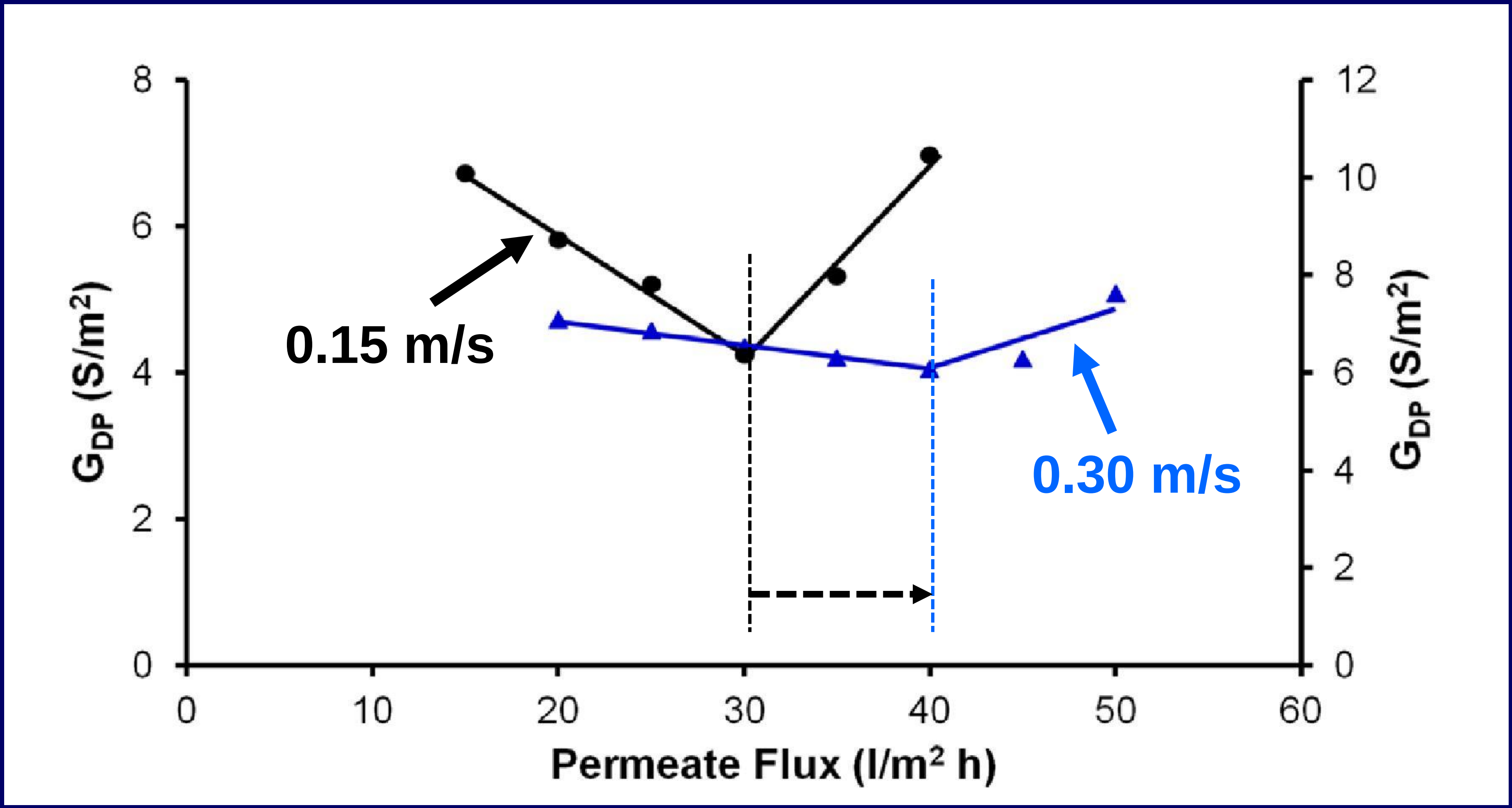
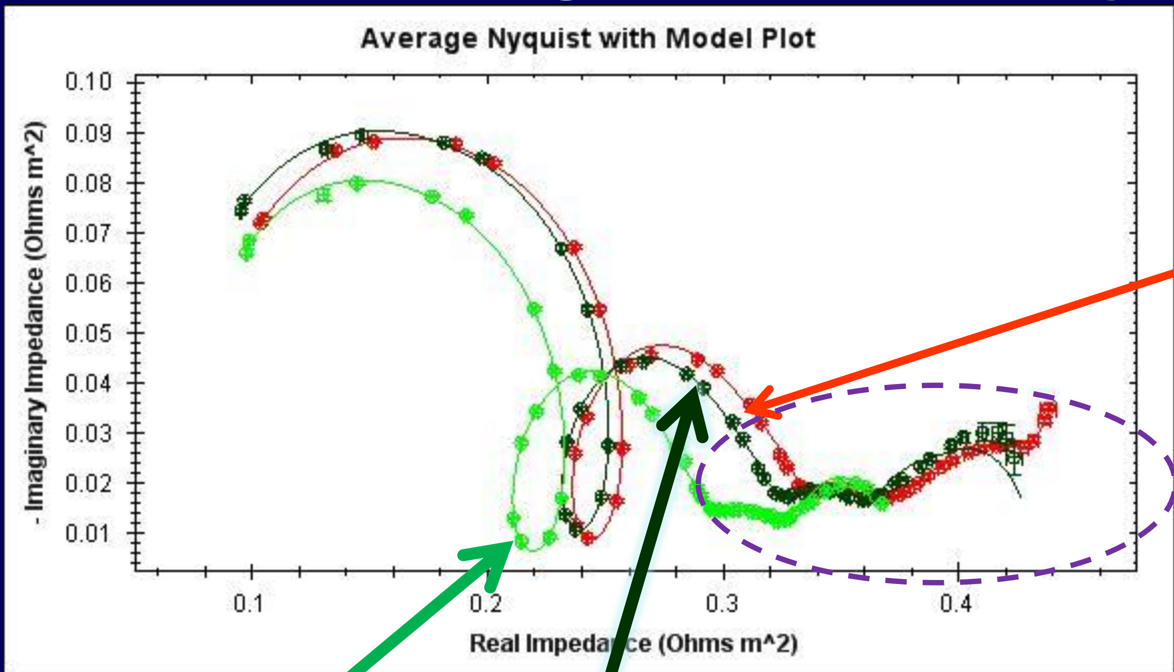
EIS detection of the Threshold



RO feed: 200 ppm silica with 2000 ppm NaCl.

Ho, Sim, Gu, Webster, Fane & Coster / Journal of Membrane Science 500 (2016)

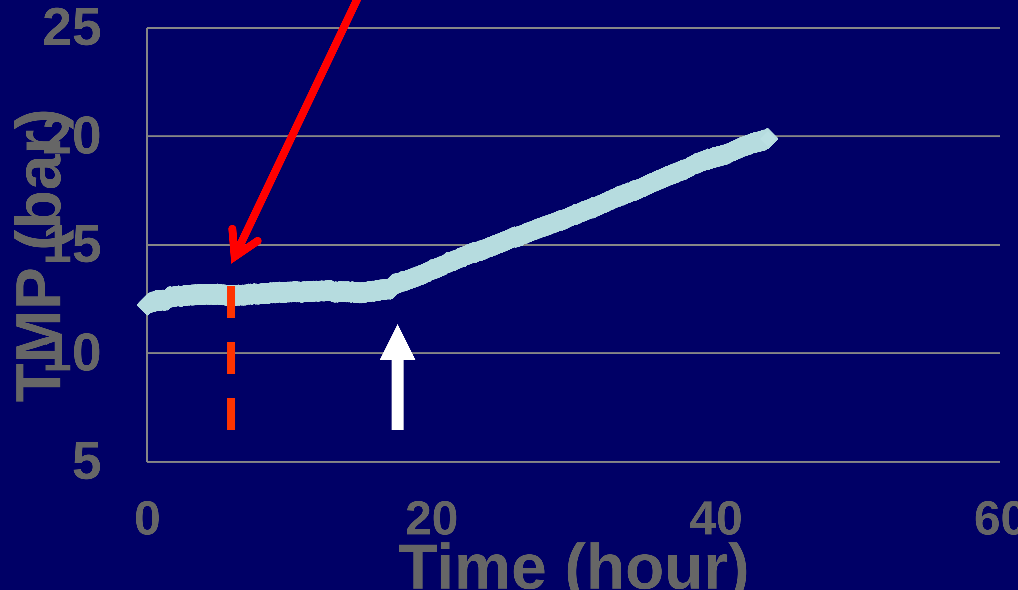
Membrane Signatures in early stages of Filtration



5 hrs silica

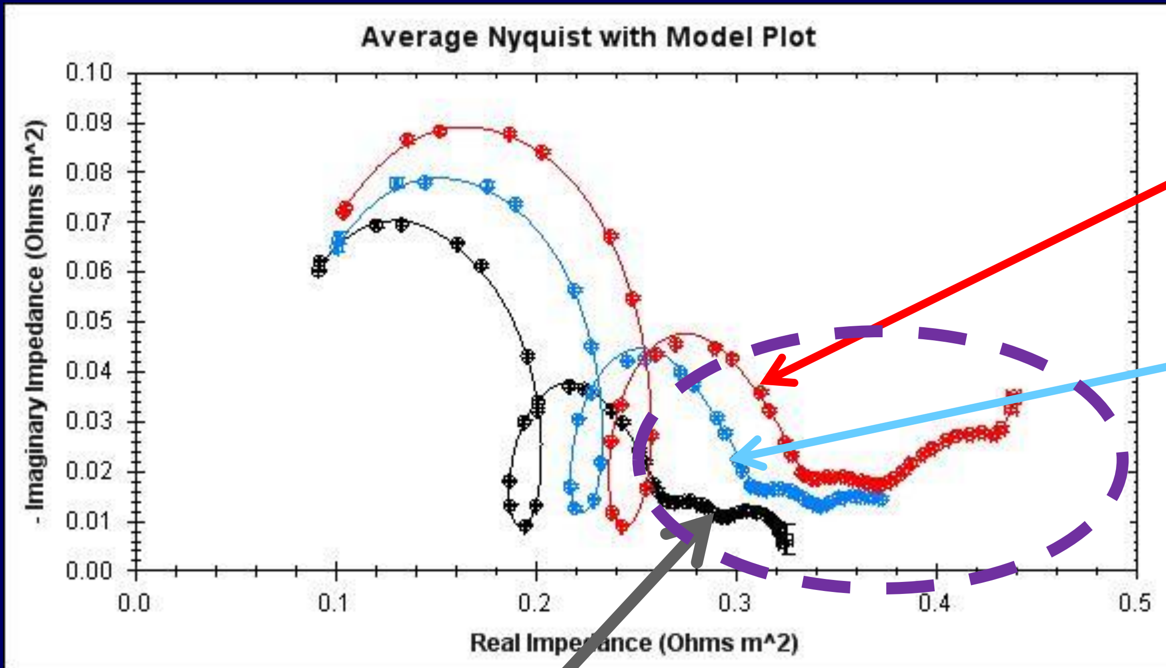
Saline – no silica

2 hrs Silica



Wang, Sim, Gu, Coster & Fane J Mem Sci

Signatures of Membrane Fouling



5 hrs silica

15 hrs silica

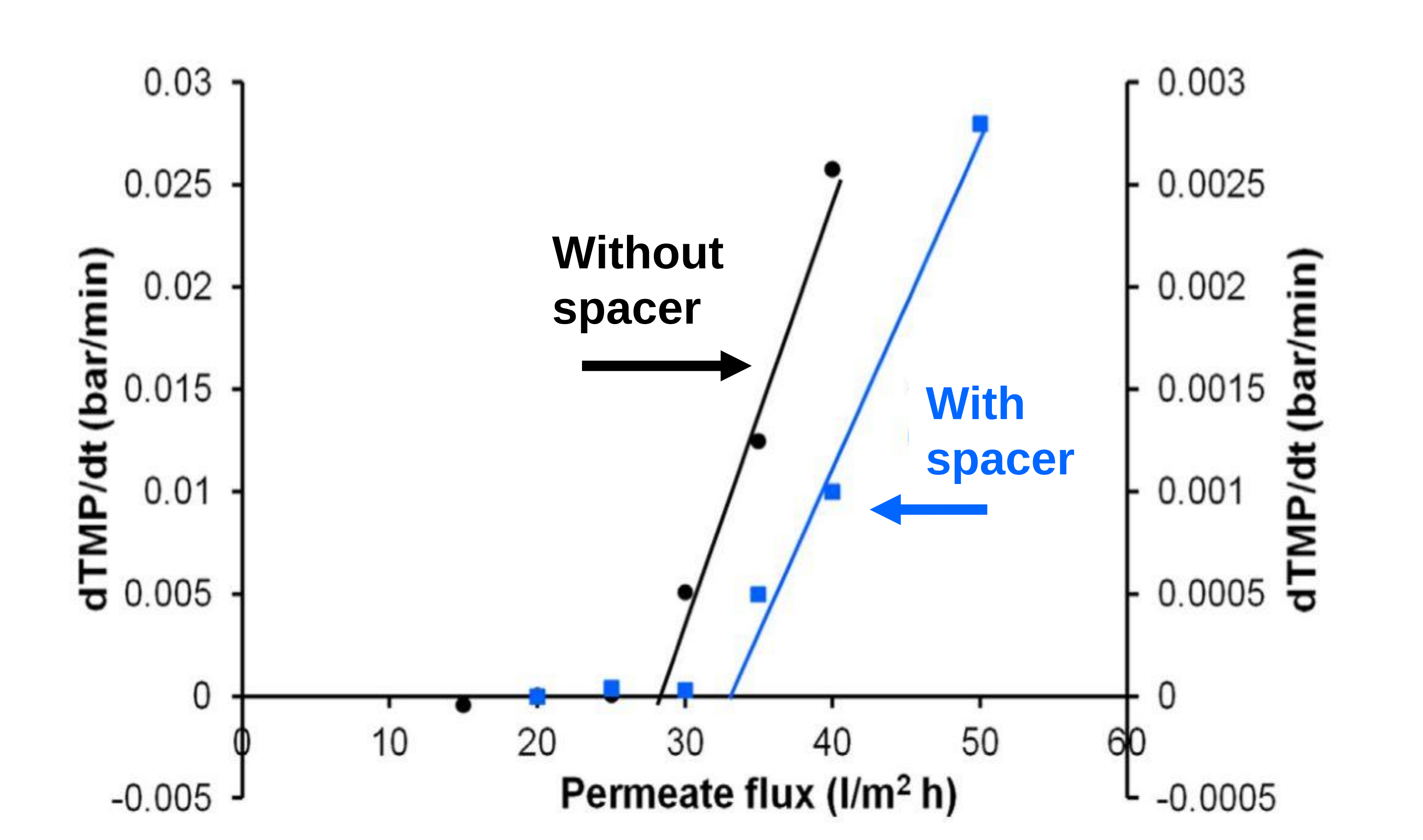
48 hrs silica

Cake enhanced concentration polarization

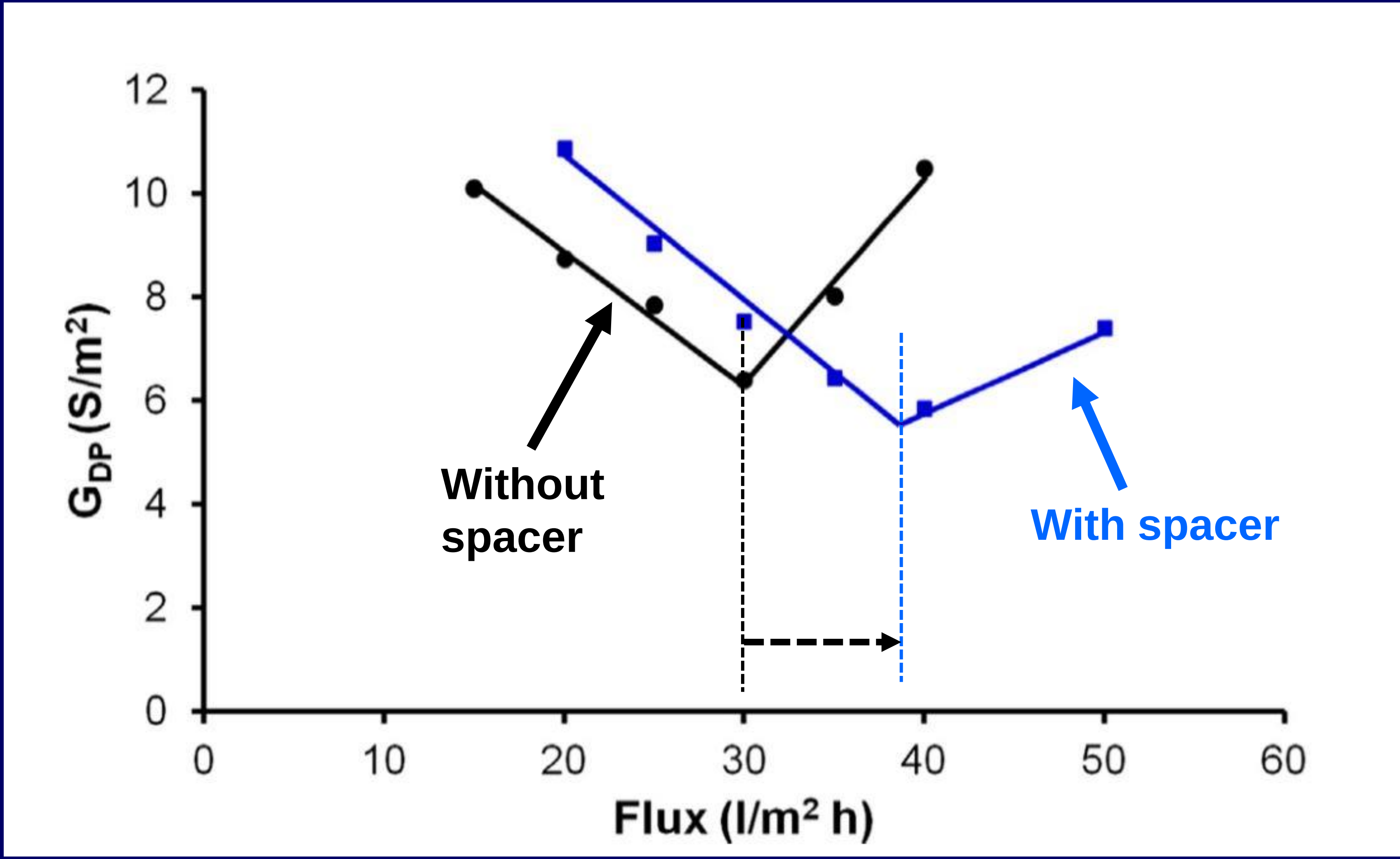
The EIS signatures changed well ahead of fouling revealed by TMP

Data from Wang, Sim, Gu, Coster & Fane J. Mem Sci 2015

Effect of Spacers



Effect of Spacers on Gdp



RO feed: 200 ppm silica with 2000 ppm NaCl; crossflow velocity; 0.15 m/s

Ho, Sim, Gu, Webster, Fane & Coster / Journal of Membrane Science 500 (2016)

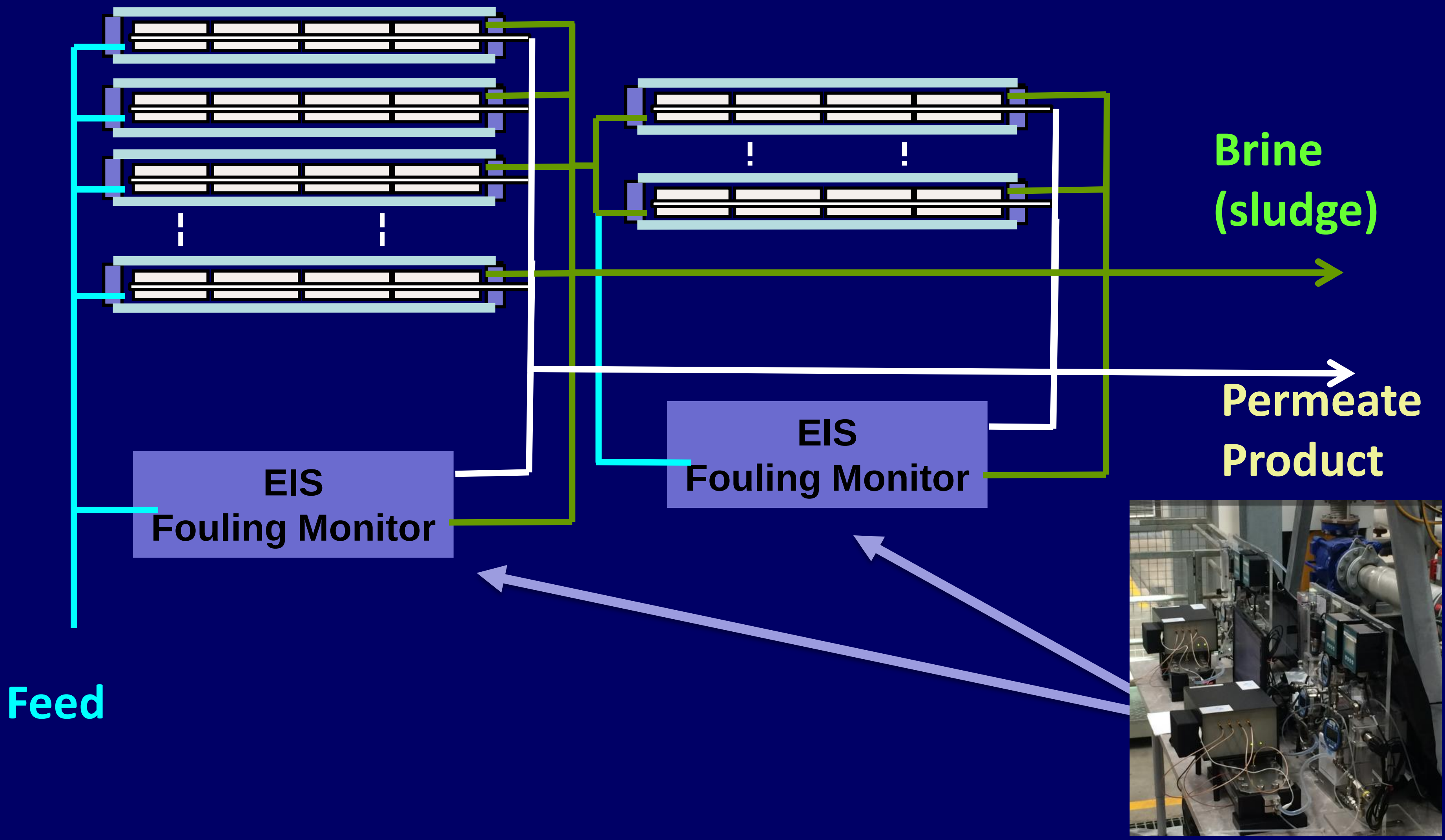
Silica fouling: Suggested mechanism

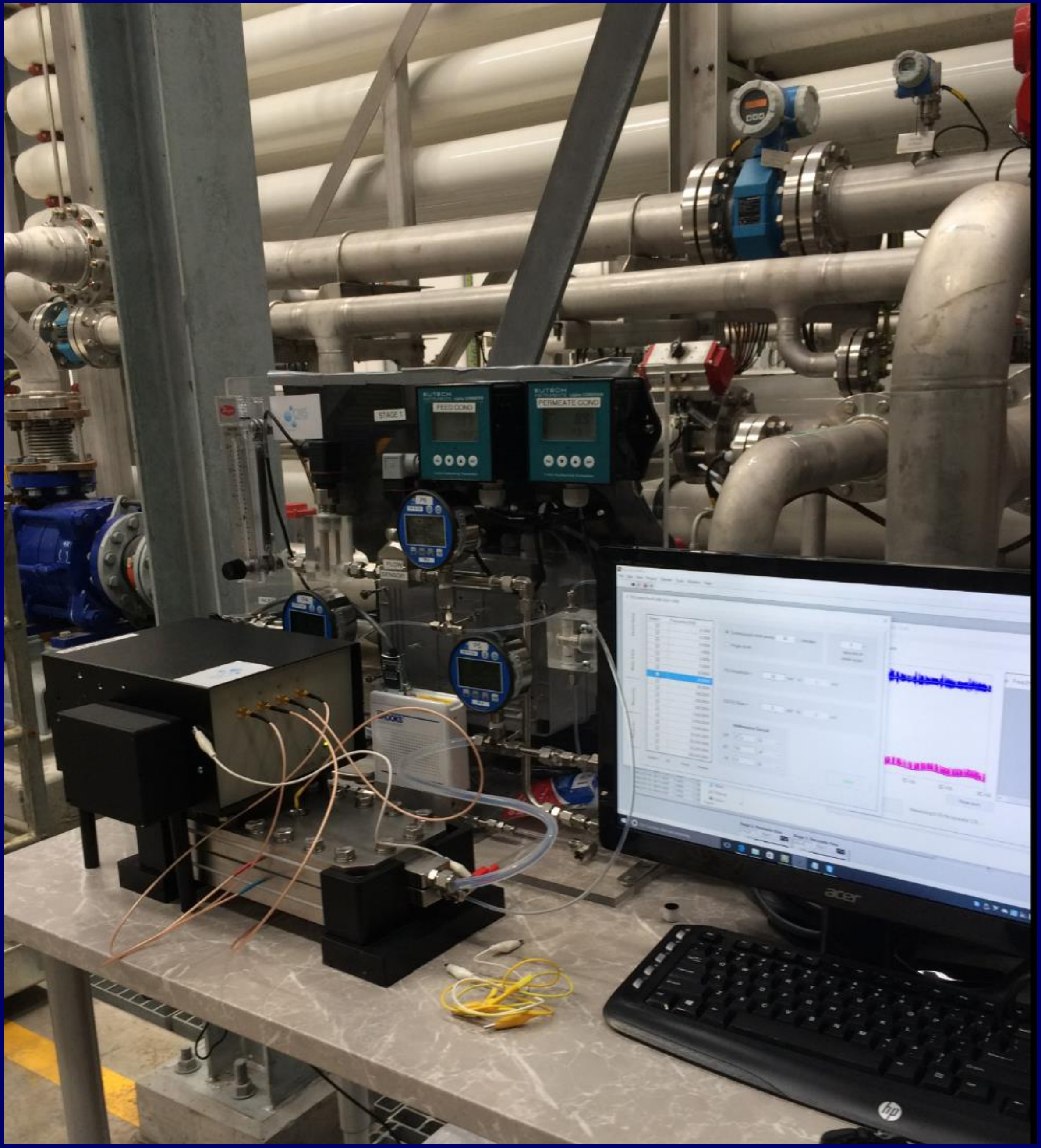
- **Slow built up of the silica layer on the membrane surface; Electrical conductance in the concentration polarization layer drops- G_{dp} decreases.**

- **Impact of the cake enhanced concentration polarization (CECP) effect; The increased concentration polarization of NaCl at the membrane surface increases the conductance of the concentration polarization layer and G_{dp}.**

- **More NaCl permeates through the membrane which shows up in a decrease in rejection.**

Locating a “Canary” Membrane Fouling Monitor in Water Treatment Plants




STAGE 1
FEED COND
PERMEATE COND
acer

Collaborators

Singapore

SMTC, NTU
A.G. Fane
L. N. Sim
Z.J. Wang
C. Tang
J. S. Ho
J. Gu

Australia

Chemical Eng., USYD
T. Chilcott
J. Kavanagh
G. Barton
J. Cien
S. Hussain
T. Handelsman

CMS innovations Pty Ltd
Andrew Sinclair
Peter Martin