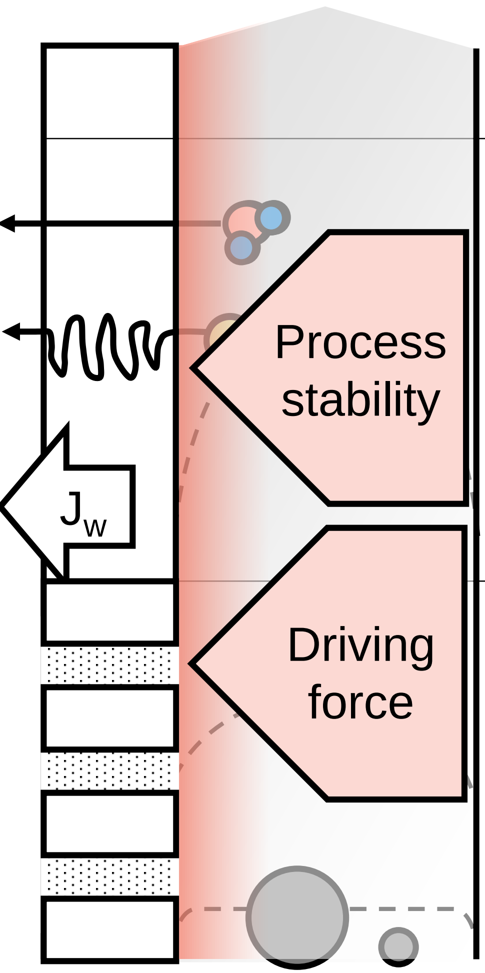
Manipulation and characterization of interfacial phenomena in membrane processes

Alexander V. Dudchenko
Department of Civil and Environmental Engineering
Stanford University
adudchen@stanford.edu

Interfacial phenomena govern membrane process performance



Reverse Osmosis
"pore size" <5 nm
NaCl rejection >95%

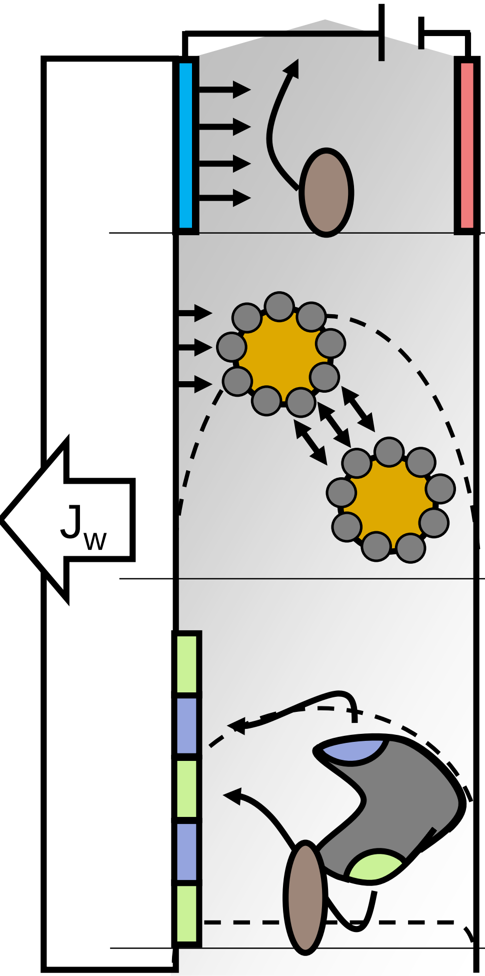
Nanofiltration
"pore size" 5-10 nm
NaCl rejection 20-90%

Ultrafiltration
pore size ~ 10-100 nm

Microfiltration
pore size >100 nm

Interfacial phenomena govern membrane process performance

Foulant adsorption

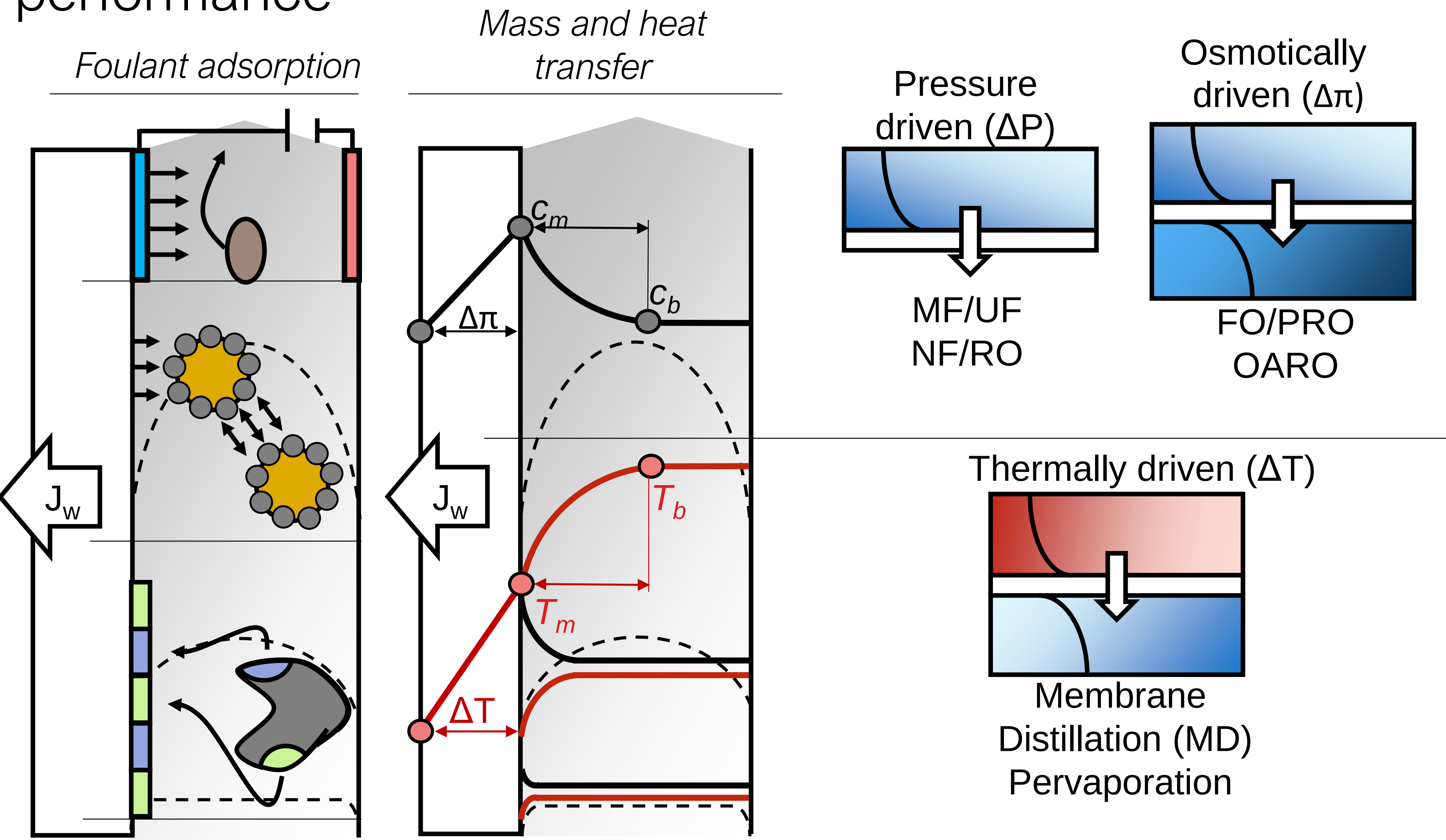


Generation of electrostatic forces
A. V. Dudchenko et al. J.Memb. Sci (2014)

Nanoparticle/Oil interface
A. V. Dudchenko et al. ACS Nano (2015)

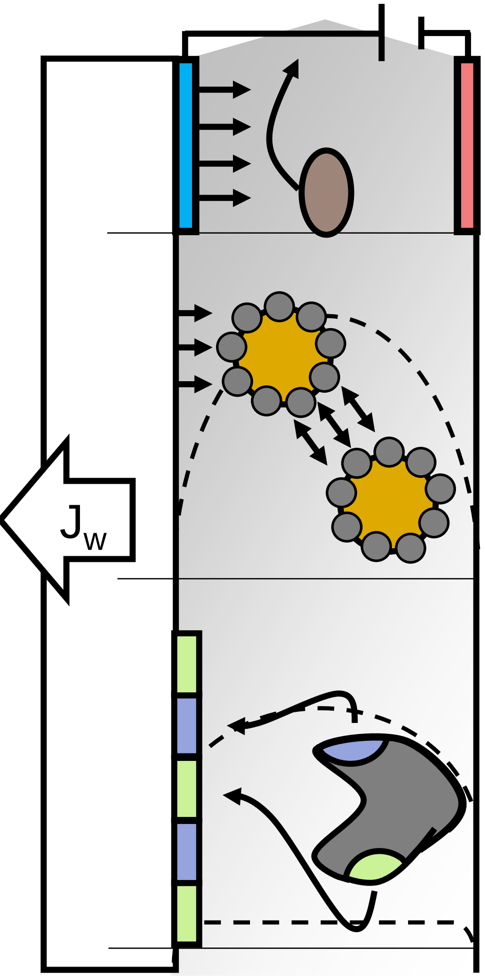
Adsorption resistance of heterogeneous surfaces
A. V. Dudchenko et. al. J. Mater. Chem. A (Under review)

Mass and heat transfer limits membrane process performance

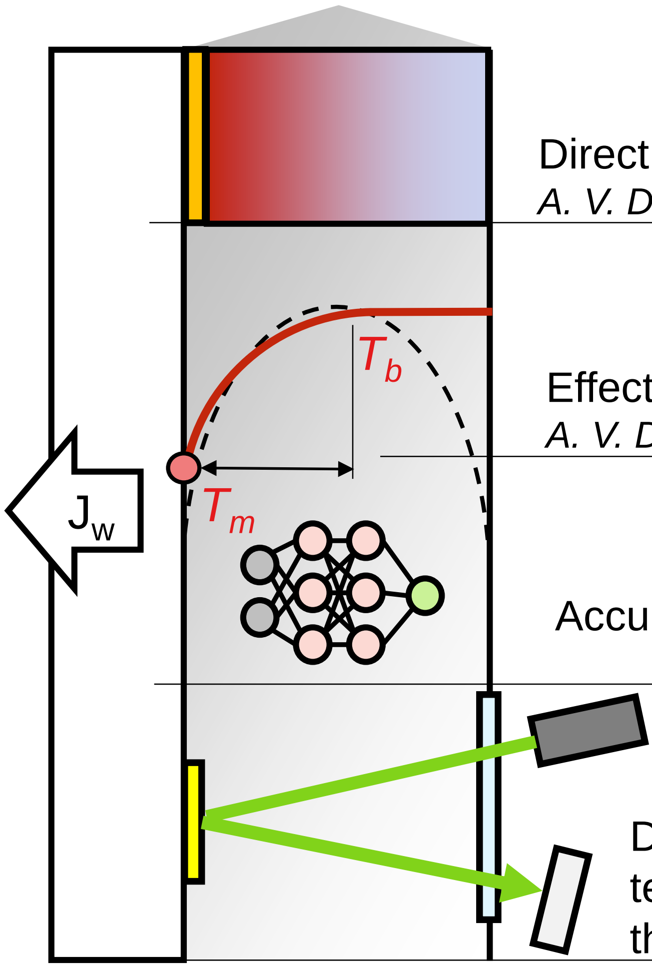


Mass and heat transfer limits membrane process performance

Foulant adsorption



Mass and heat transfer



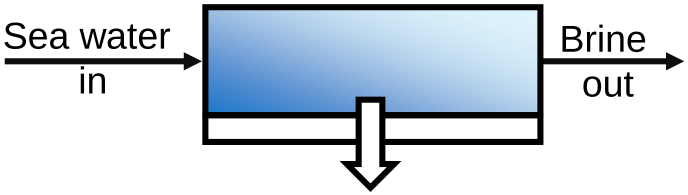
Direct surface heating
A. V. Dudchenko et al. Nature Nano. (2017)

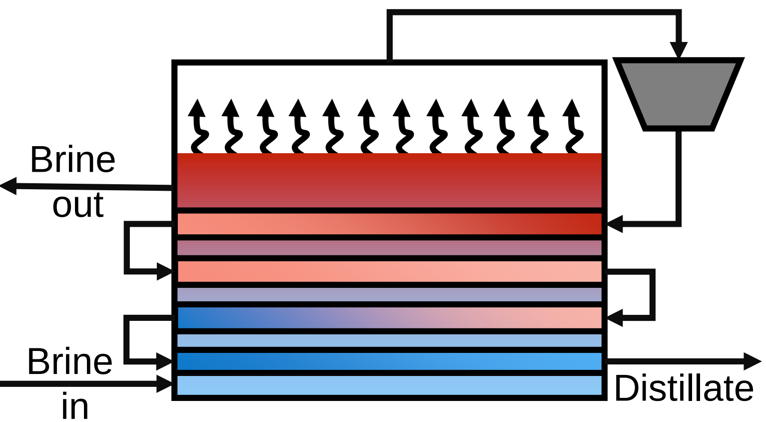
Effect of module size on heat transfer rate
A. V. Dudchenko et al. J.Memb. Sci (Under review)

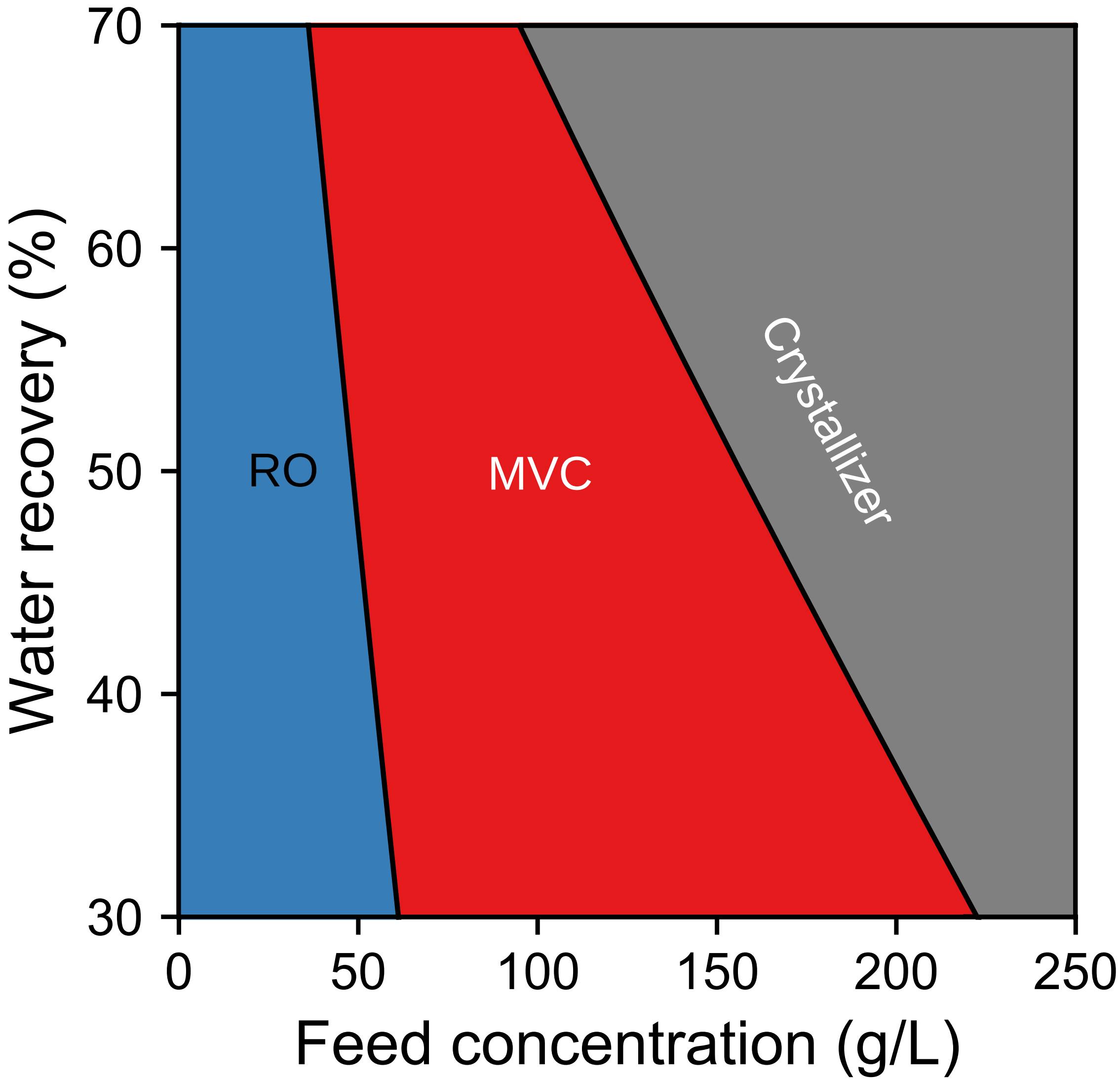
Accuracy of indirect characterization method

Direct surface temperature measurement using thermoreflectance

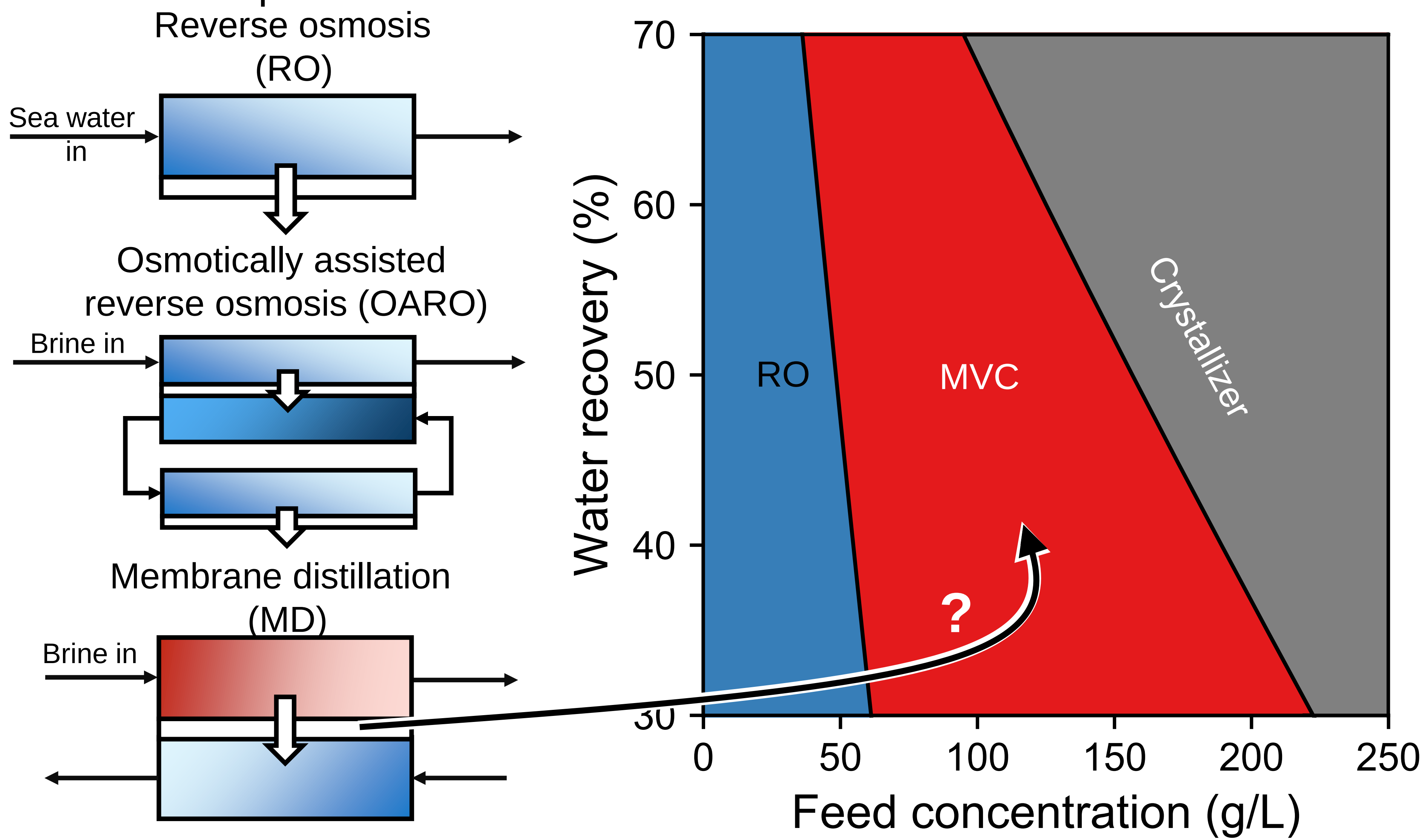
Thermal processes are current state of the art for high salinity treatment







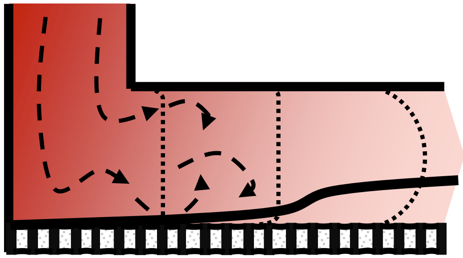
Membrane processes can potentially displace traditional treatment processes



Bartholomew, T. V., Mey, L., Arena, J. T., Siefert, N. S. & Mauter, M. S. *Desalination* (2017)

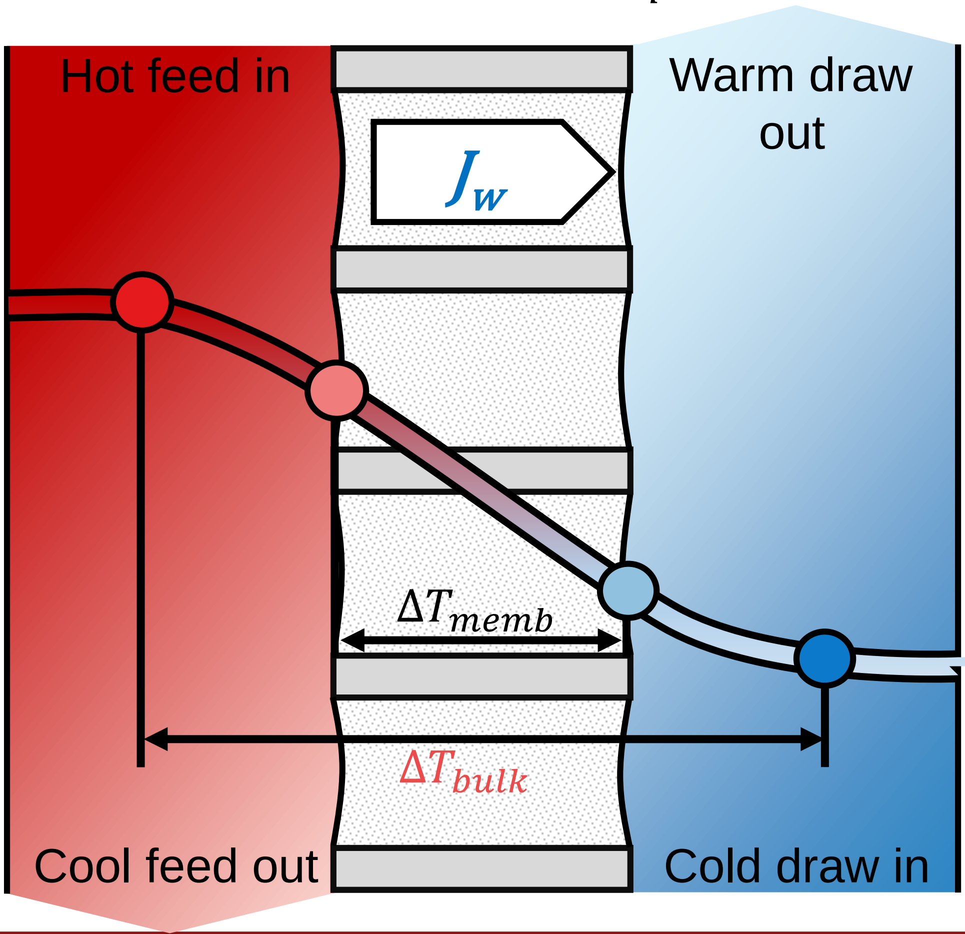
Quantifying interfacial phenomena in MD

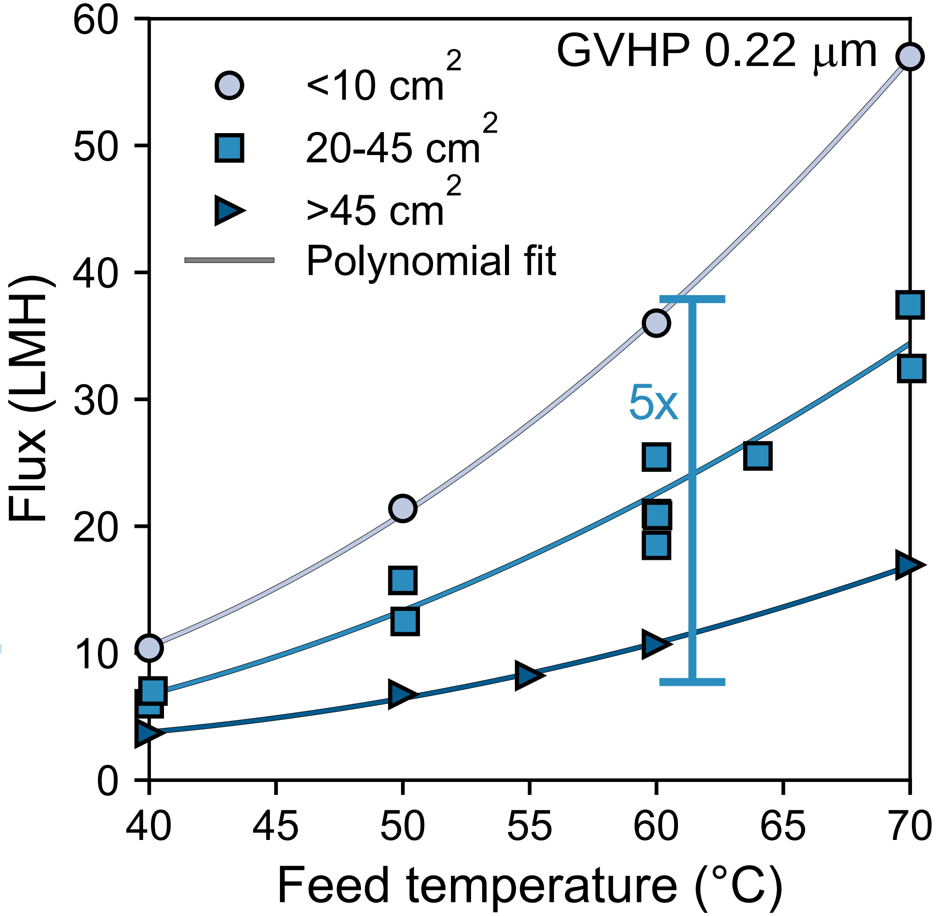
Effect of module design on heat transfer rate in MD



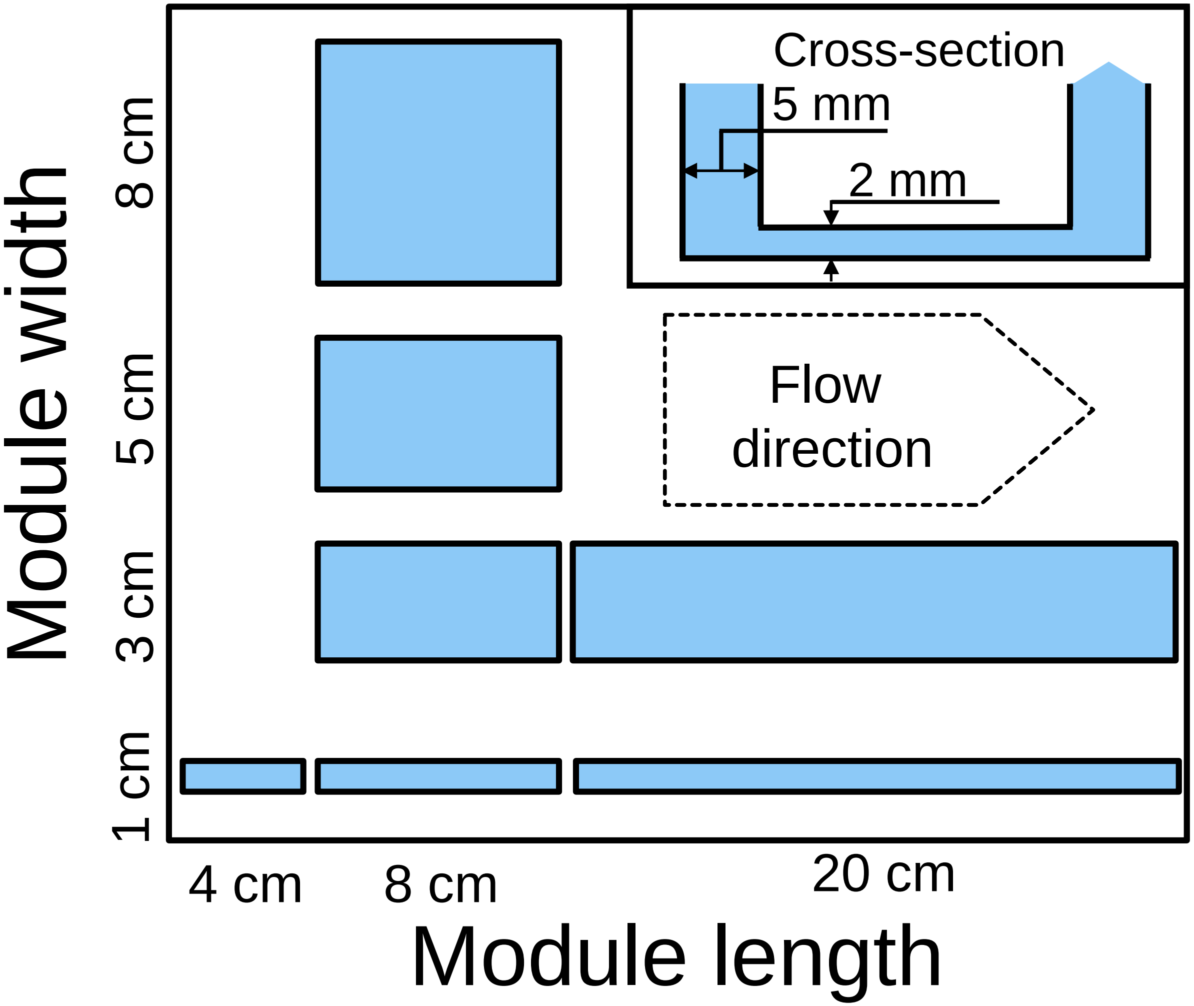
Literature data on MD reports x5 spread in permeate flux for the same membrane

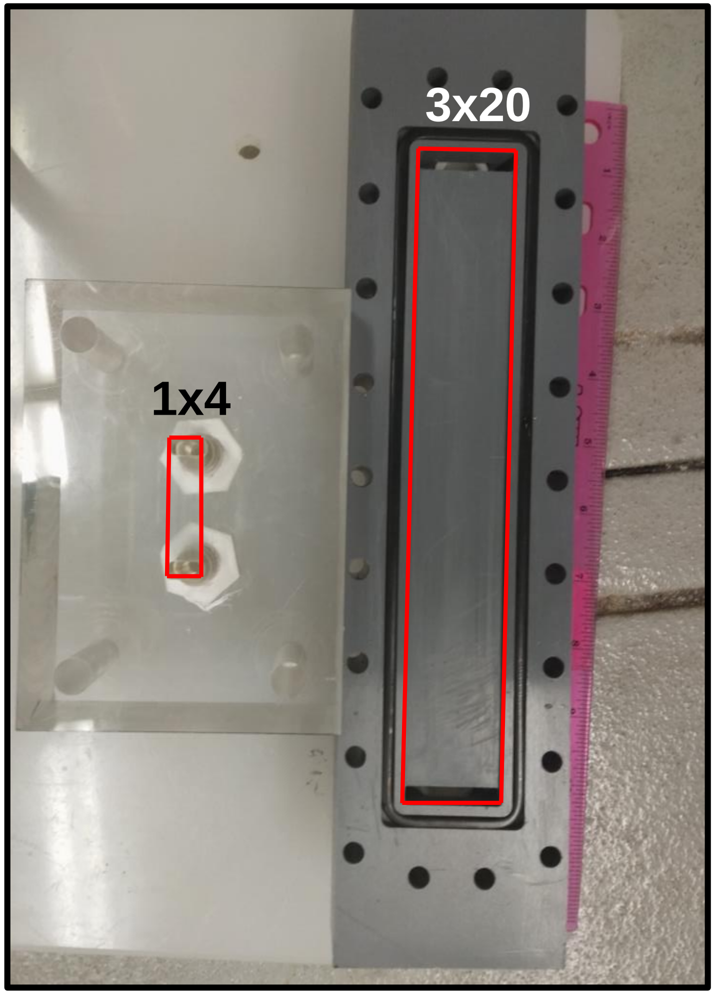
$$Permeability\ (\beta_{w,i}) = \frac{J_w \delta_m}{\Delta p_{vap}} \qquad \Delta p_{vap} = f(\Delta T_{memb}) \qquad Nu = aRe^b Pr^c \left(\frac{d_h}{L}\right)^d$$



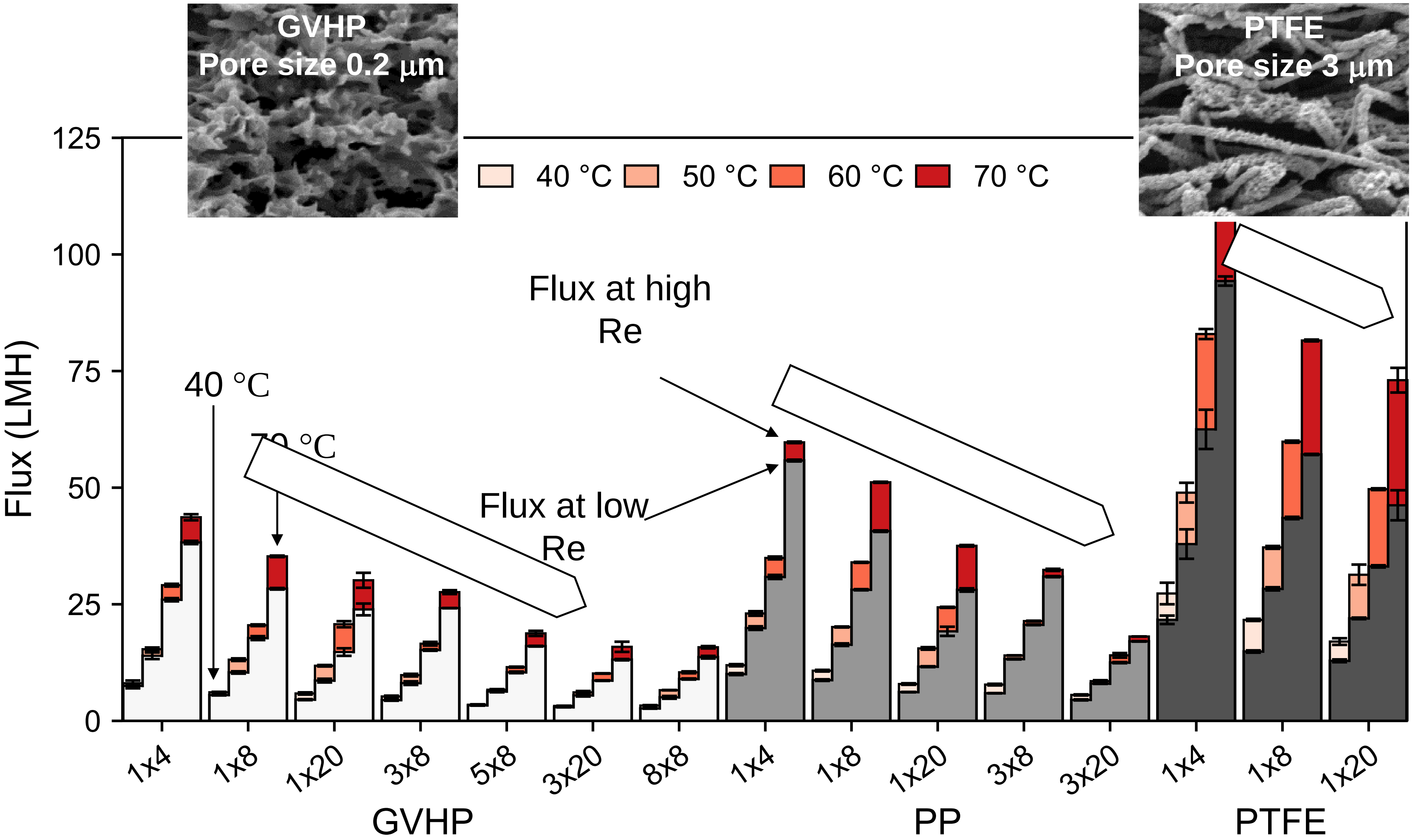


Effect of module dimensions tested by systematically varying module width and length



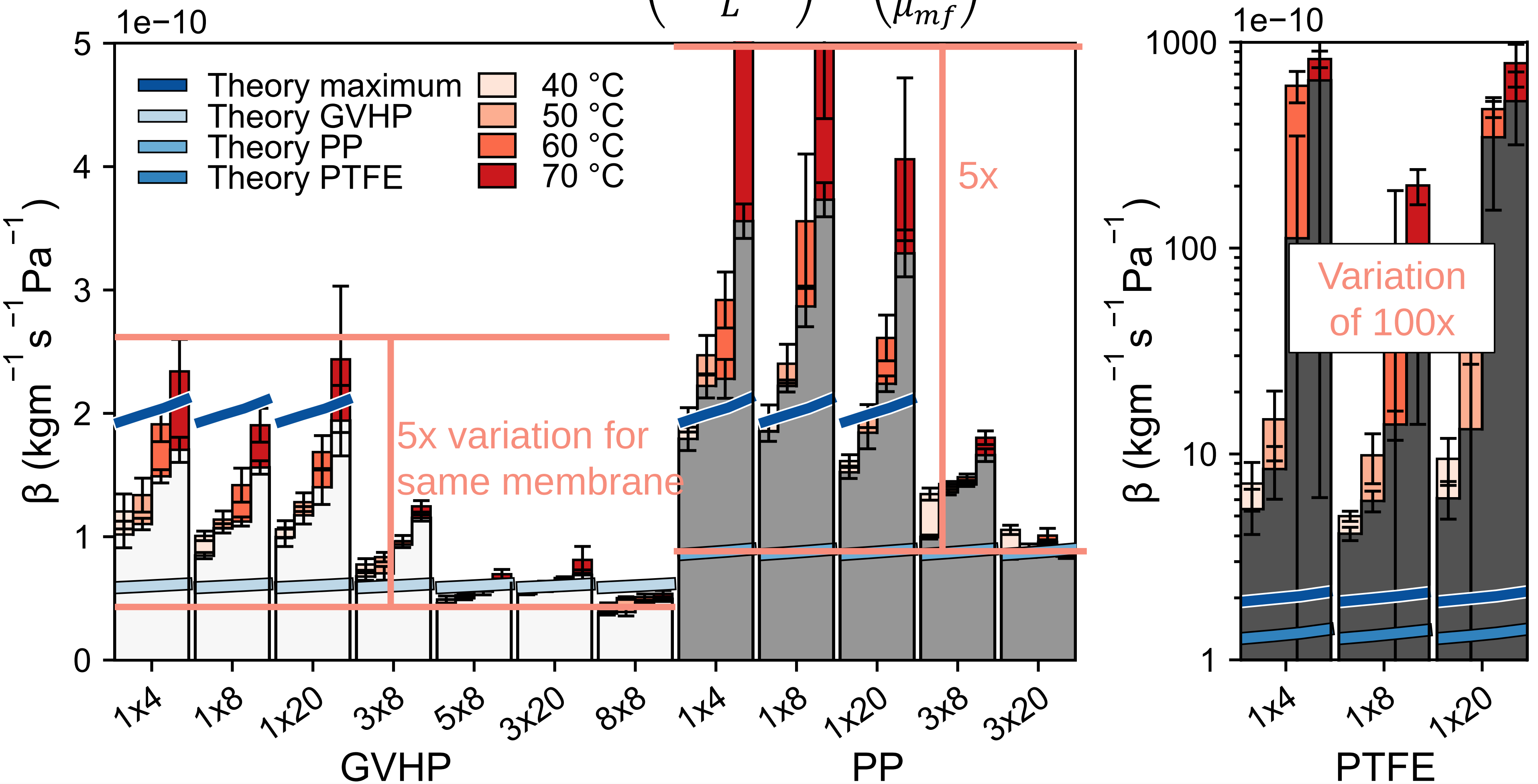


Module area strongly impacts measured permeate flux



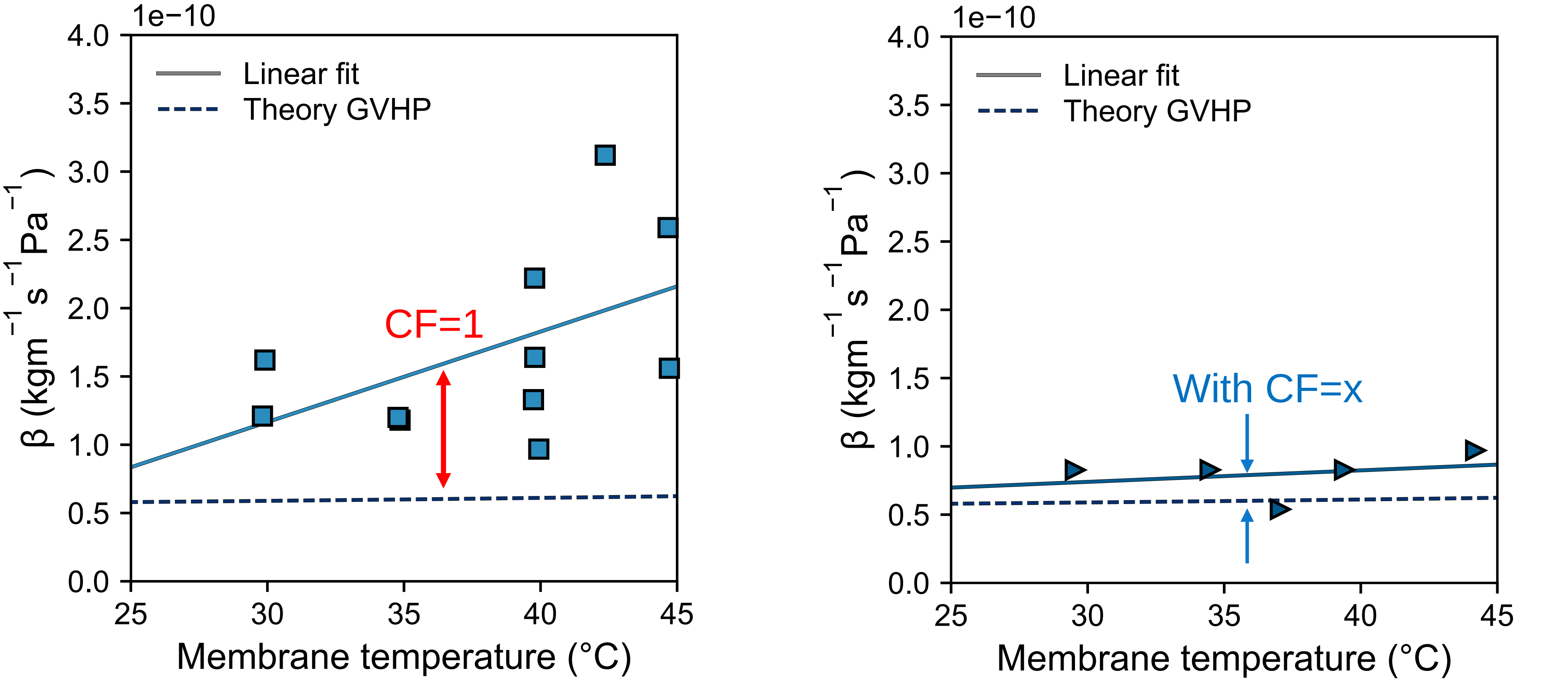
Nusselt correlations can fail to capture heat transfer in smaller modules, overestimating permeability

$$\overline{Nu} = 1.86\left(\frac{RePrd_h}{L}\right)^{1/3}\left(\frac{\mu_{bf}}{\mu_{mf}}\right)^{0.14}$$



Heat transfer rate can be validated by comparing the experimental slope to theoretical slope

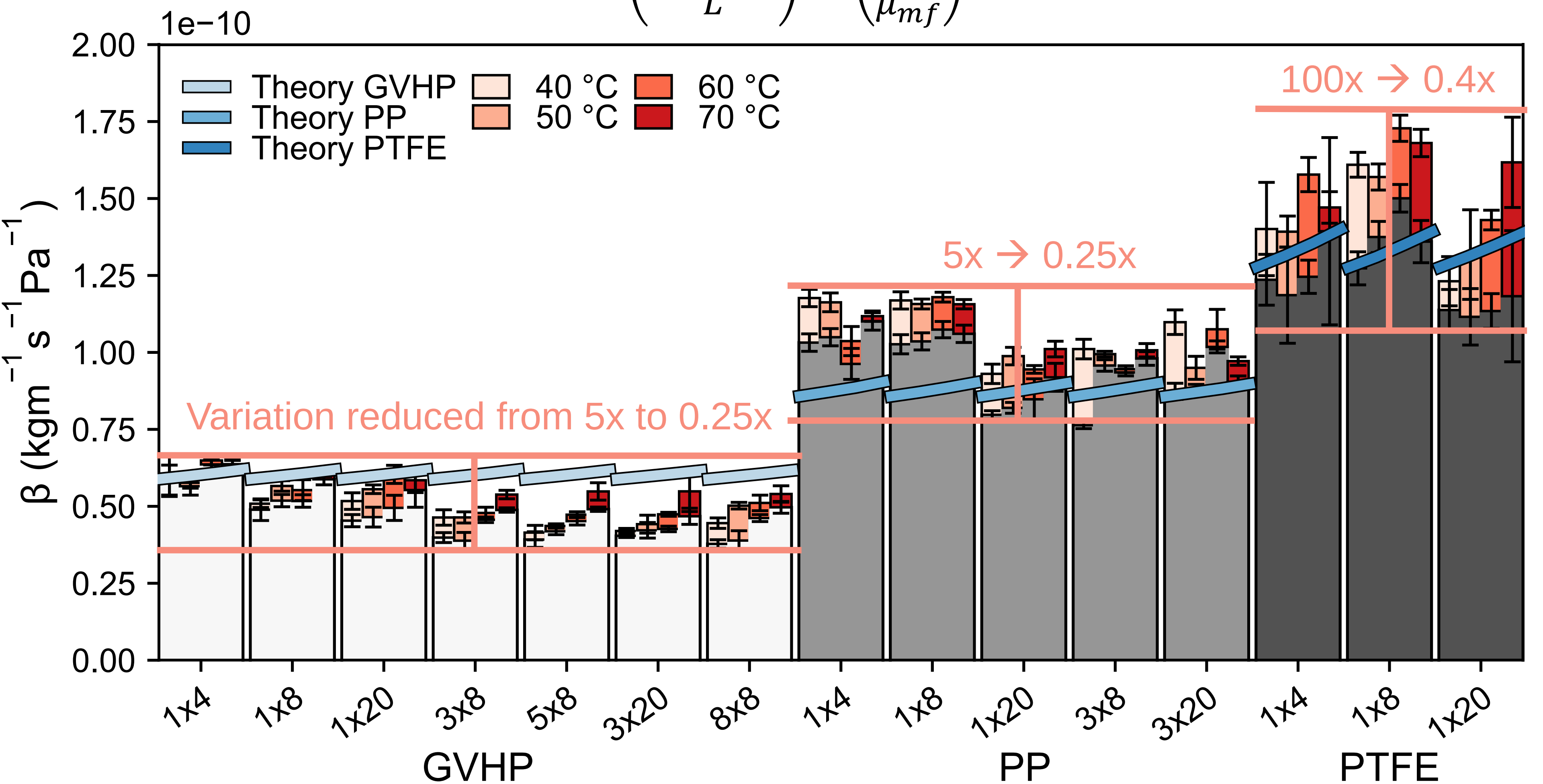
$$\overline{Nu} = 1.86\left(\frac{RePrd_h}{L}\right)^{1/3}\left(\frac{\mu_{bf}}{\mu_{mf}}\right)^{0.14} * CF$$



Leitch, M. E. et al. *Journal of Membrane Science* (2017)
Dudchenko, A. V. et al. *Journal of Membrane Science (Under Review)*

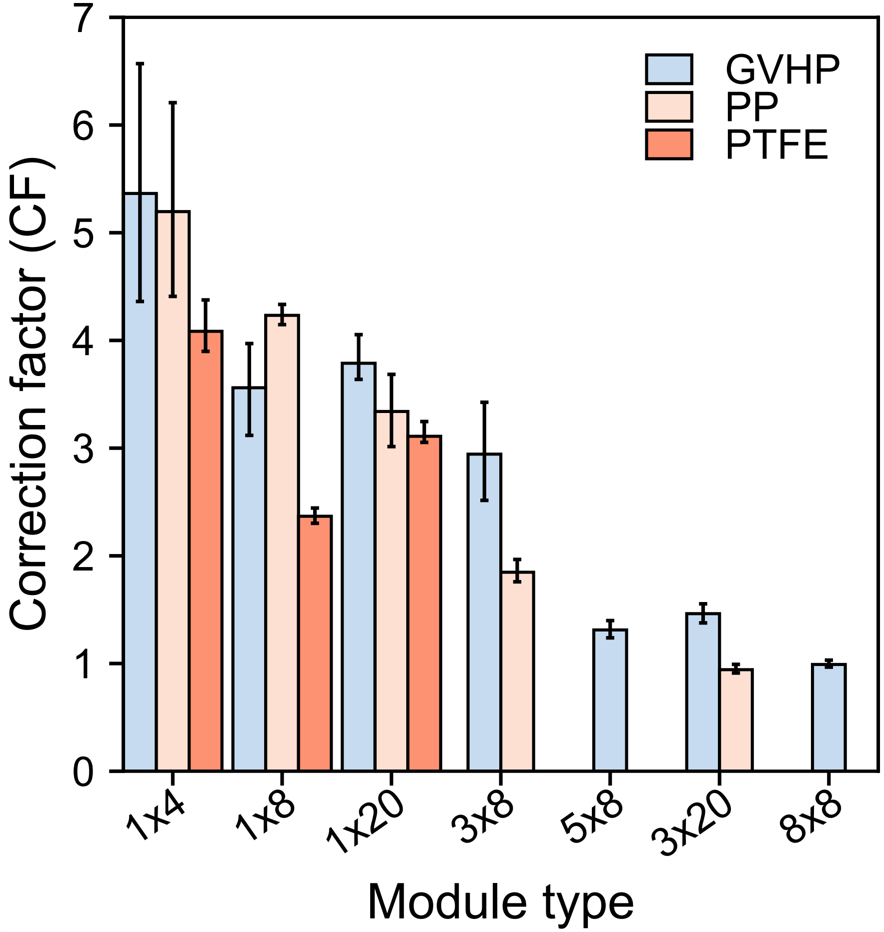
Correction of Nusselt correlation reduces spread in permeability estimates

$$\overline{Nu} = 1.86\left(\frac{RePrd_h}{L}\right)^{1/3}\left(\frac{\mu_{bf}}{\mu_{mf}}\right)^{0.14} * \mathrm{CF}$$

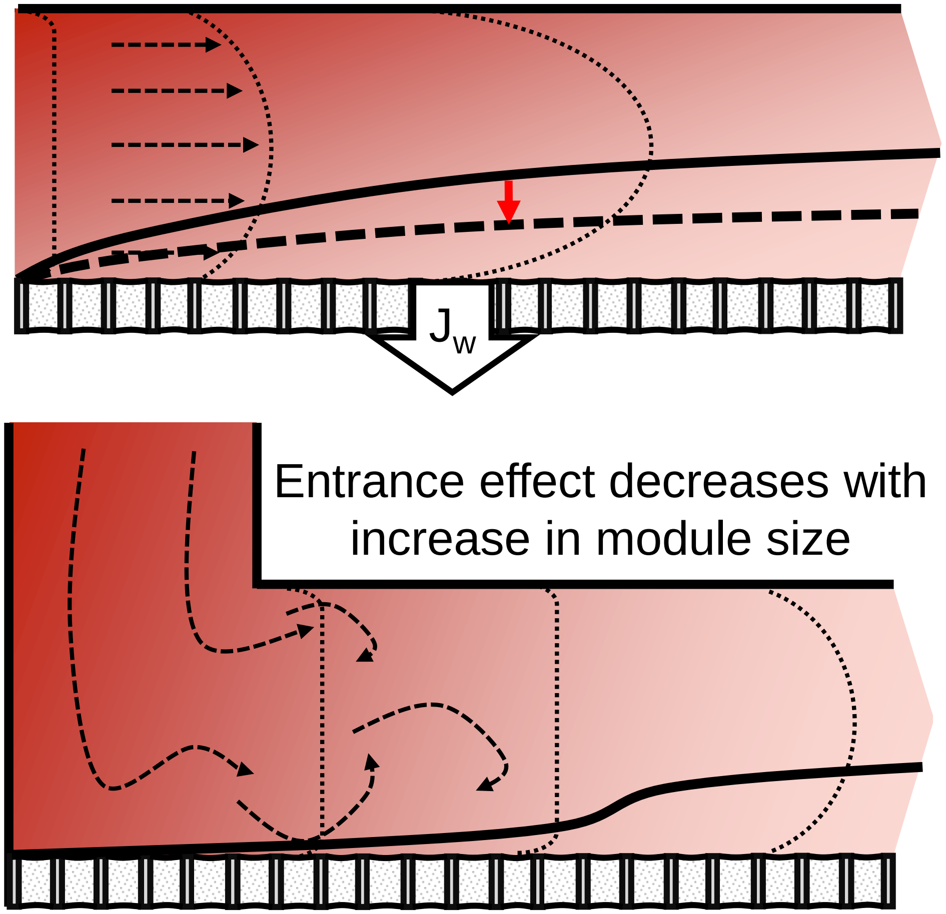


Heat transfer in short modules is dominated by entrance effect

$$\overline{Nu} = 1.86\left(\frac{RePrd_h}{L}\right)^{1/3}\left(\frac{\mu_{bf}}{\mu_{mf}}\right)^{0.14} * \mathrm{CF}$$



Mass transfer effect is not observed (No correlation between CF and membrane type)



Comparison of experimental to theoretical trendlines provides insight into MD heat transfer rates

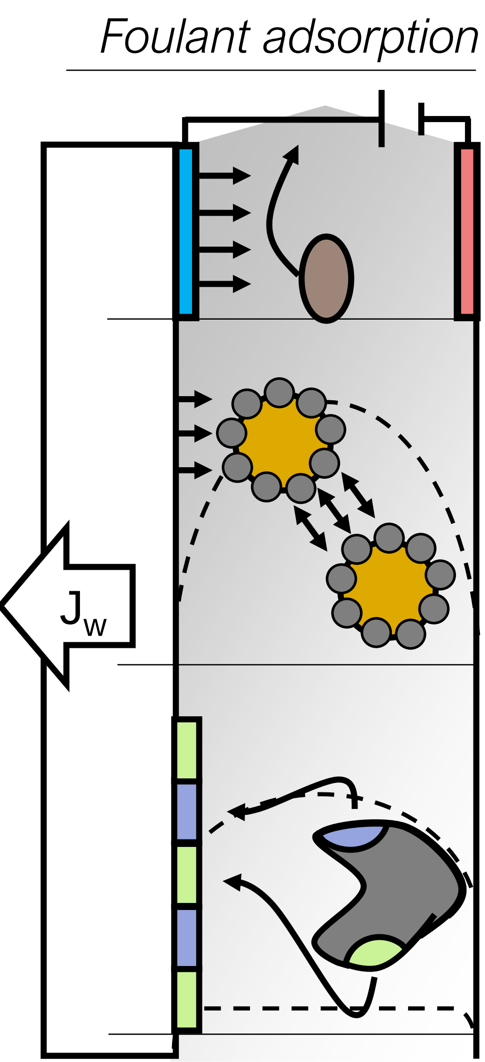
The slope of permeability can be used to correct existing heat transfer correlation

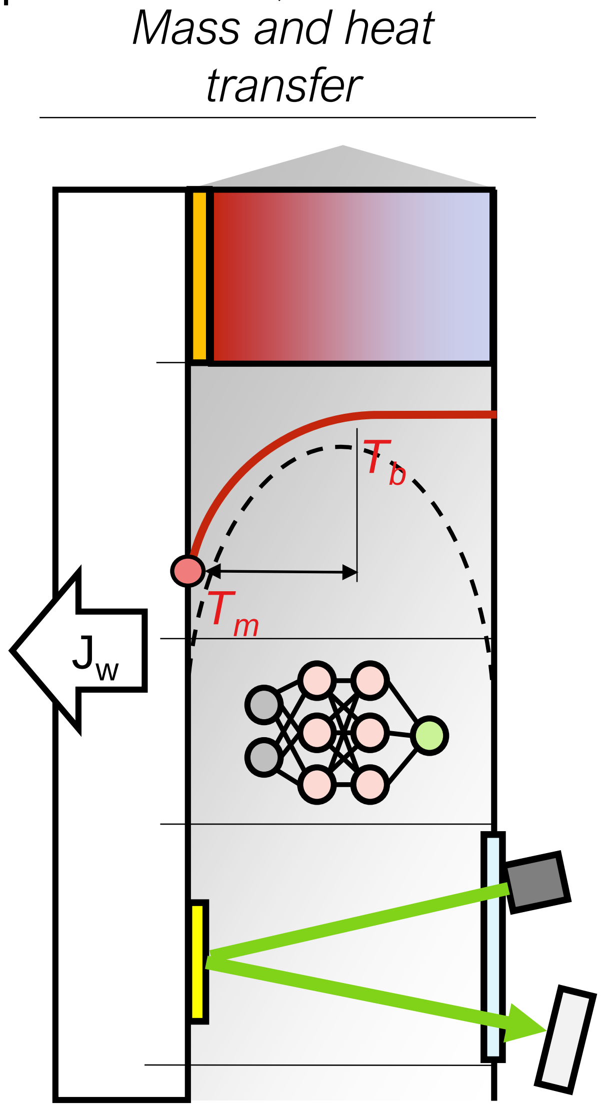
The entrance changes the fluid flow in the module

Enhances heat/mass transfer rates by as much as 5x

Nusselt correlations can be used for large scale module analysis

Development of next-gen water treatment process requires combination of experiments, direct characterization, and models





Skillsets

Material synthesis
Material characterization
Experimental hardware/software design
Fundamental modeling
Process modeling

LBNL

Advanced light source
Molecular foundry
Super computing at NERSC

ESDR Division

Synthesis of advanced materials
Processes for distributed water treatment
On-line characterization of water

Acknowledgements

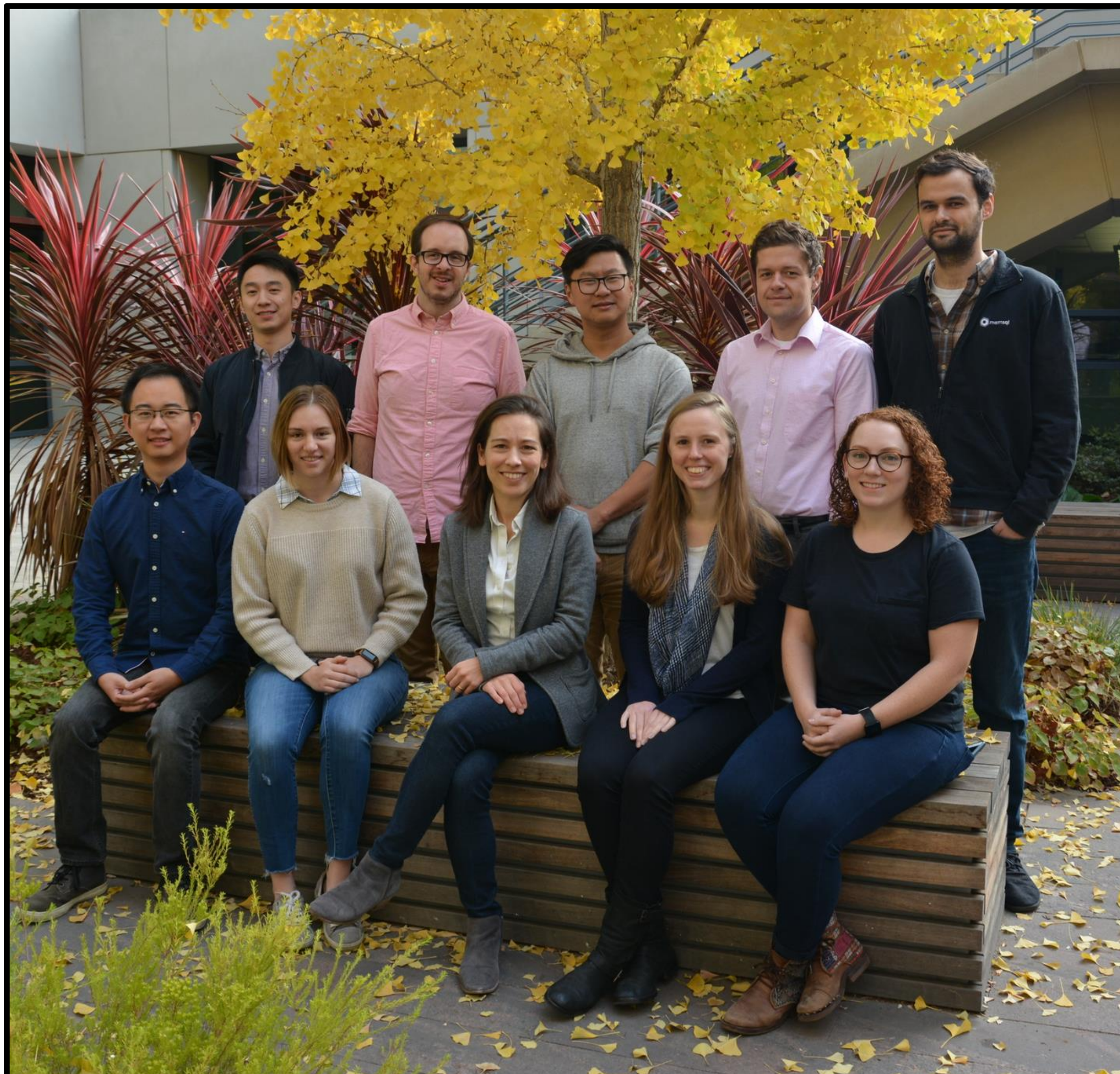
Mentor:
Dr. Meagan Mauter

Students:
Mukta Hardika
Alaina Anand
Shounak Joshi
Ruikun Xin
Nikita Sharma
Ruoyu Wang

NSF: SusChEM - 1507850
NSF: CBET - 1554117

DOE: SunSHOT

python
ARDUINO
PyTorch



Questions?