تحت رعاية معالي رئيس مجلس الوزراء المصري المهندس شريف إسماعيل
مؤتمر تحلية المياه الحادي عشر في البلدان العربية
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A new approach for assessment of the performance efficiency of DCMD when desalting feeds of high salinity

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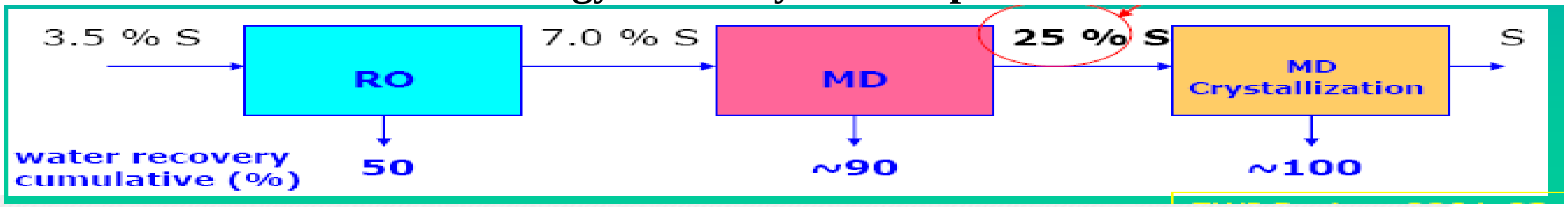
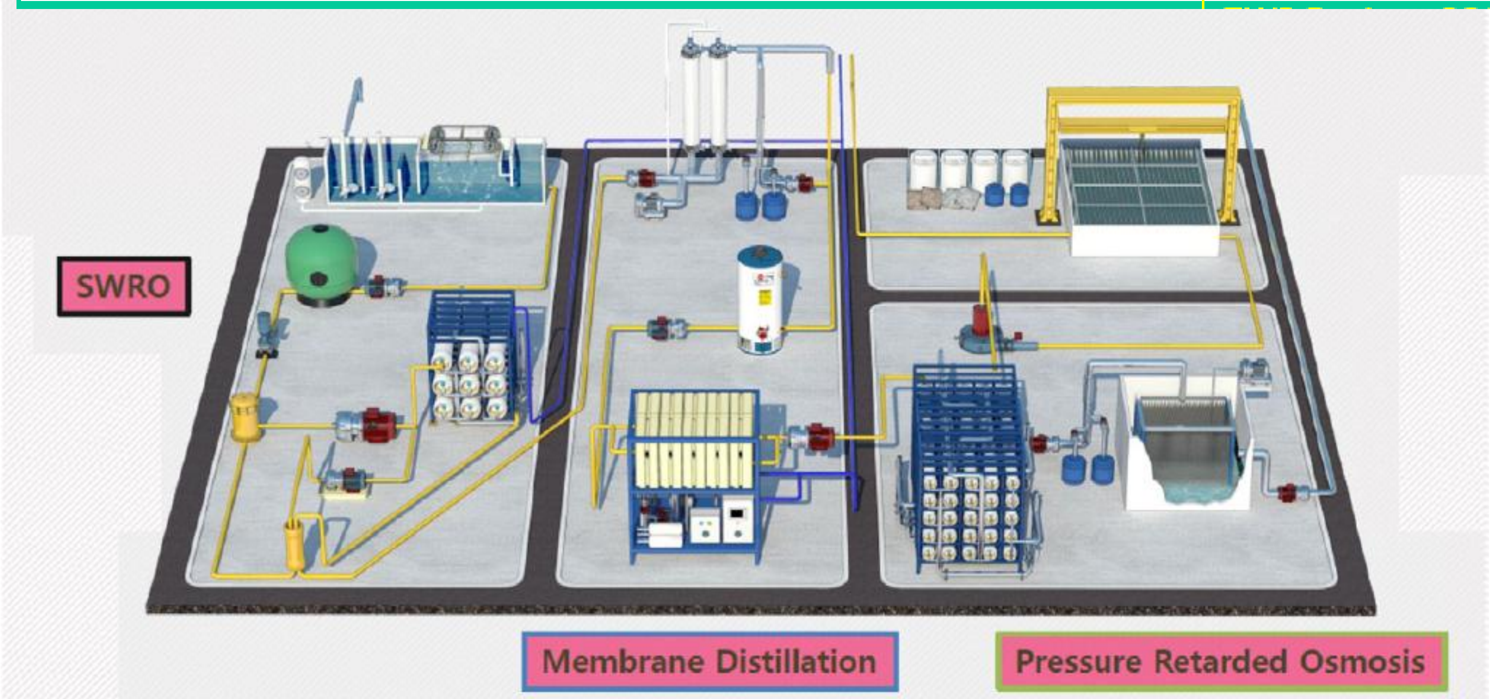
The need for non conventional desalination

Drivers for the third generation desalination technology

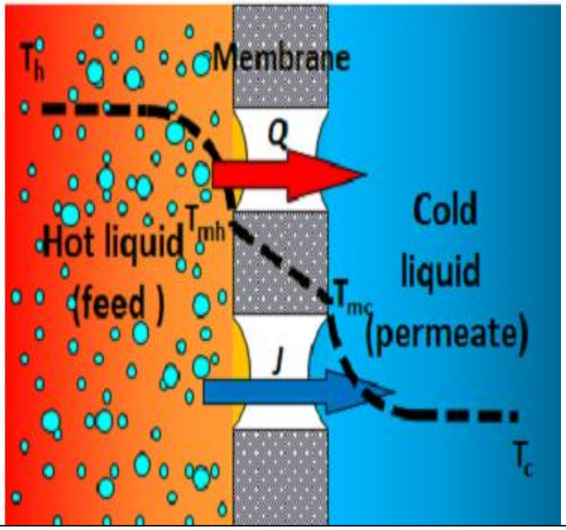
- ❖ Utilize different forms of energy (i.e. waste heat, solar thermal energy)
- ❖ Increase the overall recovery ratio of RO and MSF plants especially for inland brackish groundwater RO plants
- ❖ Increase the overall energy efficiency of MSF plants

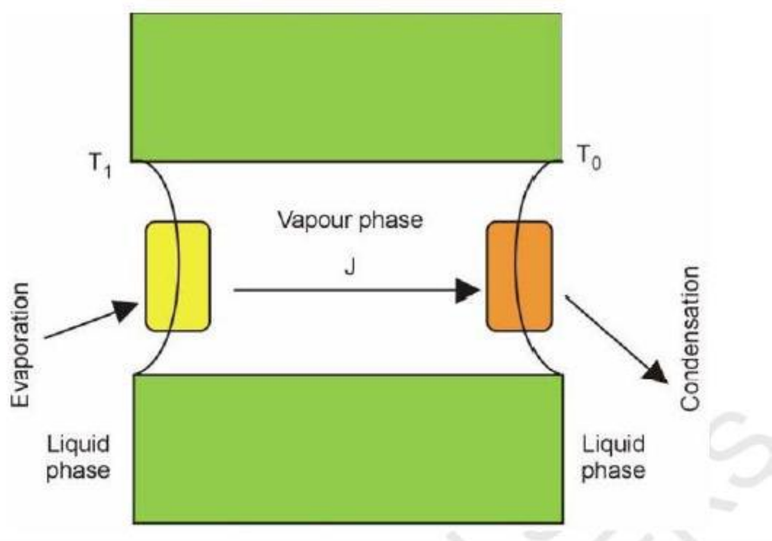




Korean R&D Program: Global MVP (2013-2018): www.globalmvp.org

Membrane distillation (MD)

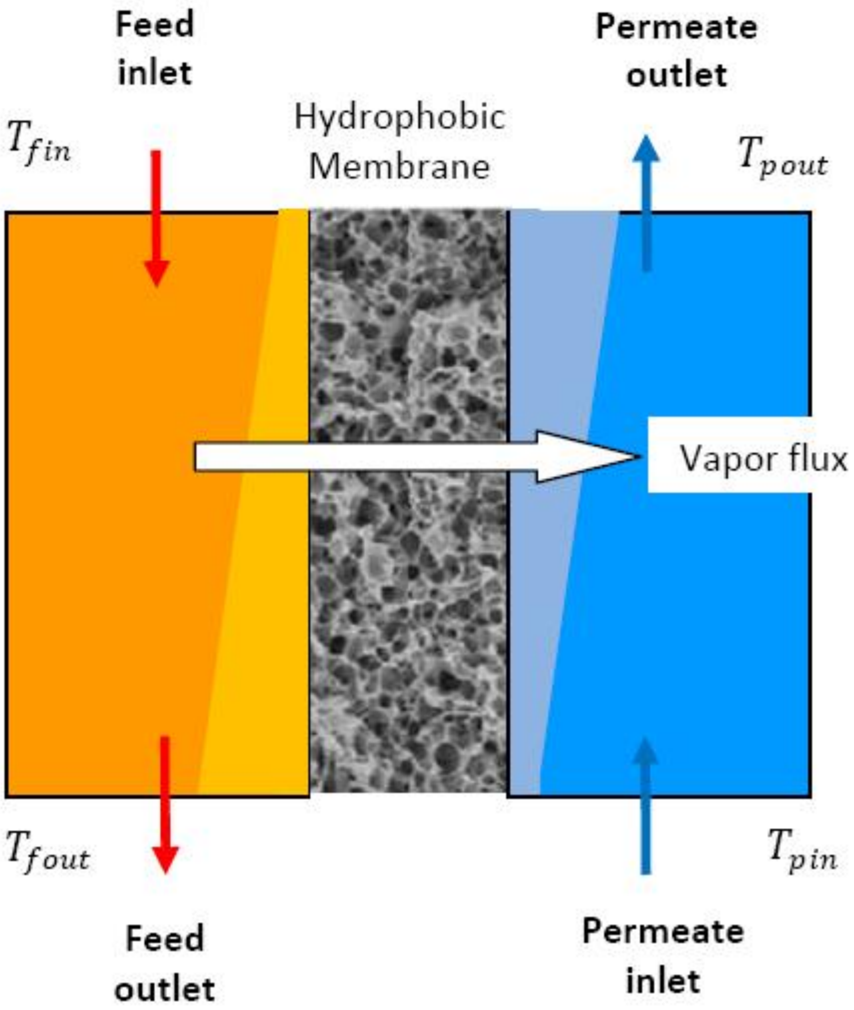




- MD is a thermal, phase change separation process
- Hydrophobic micro-porous membrane with pore size 0.1- 0.4 µm
- The driving force is the partial vapour pressure difference due to temperature difference across the hot and cold sides of the membrane

- Operates at low temperatures (50 - 70^{o}C) (Suitable for RE, waste heat)
- Possibility to desalinate feeds with very high salinity
- Produces high quality water
- Low hydrostatic pressure needed
- Resistive against fouling and scaling
- Modular and simple design
- Low investment cost
- No chemical pre-treatment of the feed water.

Direct Contact MD Configuration



- Simple system design and operation
- Higher permeate flux
- High heat losses

Parameters affecting DCMD flux and Energy efficiency of MD process

Process operating parameters

- Feed temperature
- Permeate temperature
- Feed flow rate
- Permeate flow rate
- Feed concentration
- Fouling and Scaling Control
- Pretreatment Method

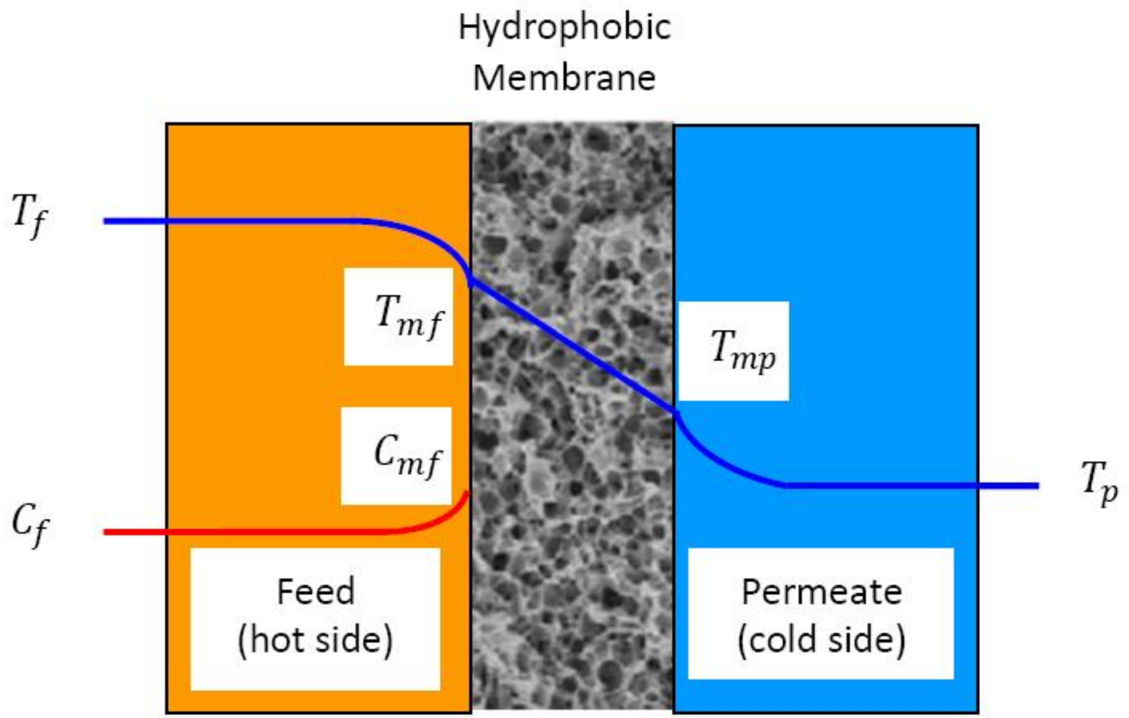
Polarization effects

- Temperature polarization
- Concentration polarization

Membrane and membrane module parameters

- Type of polymer
- Hydrophobicity (contact angle)
- Porosity
- Pore size
- Thickness
- Tortuosity
- Thermal conductivity
- Membrane module dimensions
- Membrane Area/Module

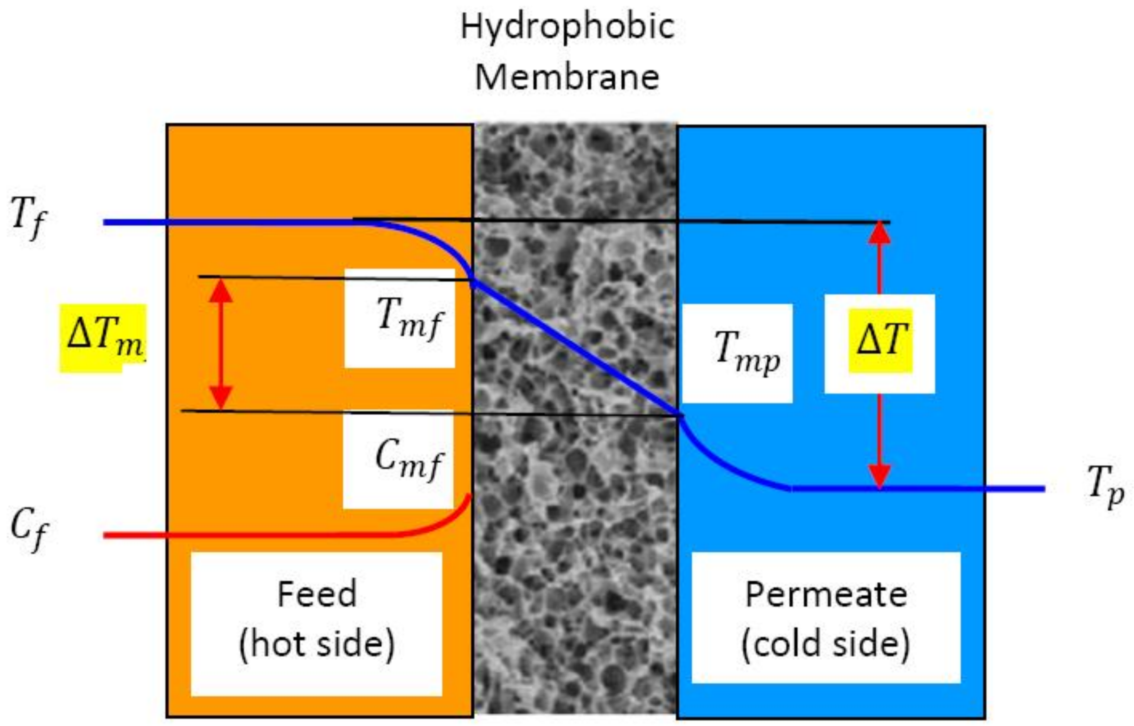
Temperature polarization phenomenon in MD



At both sides of the membrane the temperature at the membrane-liquid interface is not equal to the temperature in the bulk of the liquid

Negative effects of TP :
Reducing the overall driving force for vapor transfer from the feed side to the permeate side

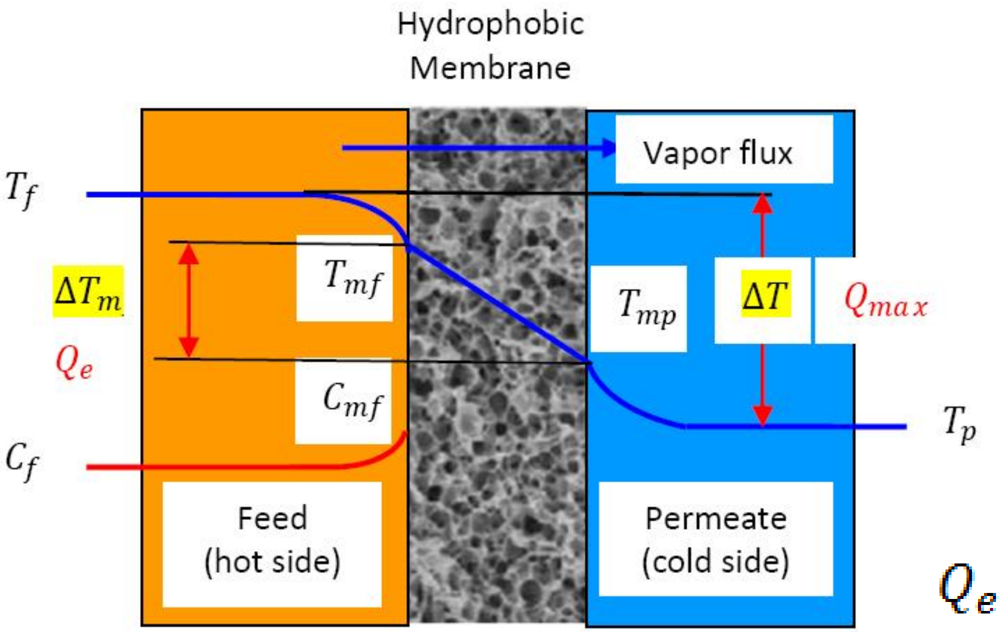
Temperature polarization coefficient (TPC)



TPC is defined as the ratio of the trans-membrane temperature gradient to the difference between the temperatures of the feed and permeate bulk streams

$$E = \frac{\Delta T_m}{\Delta T} = \frac{T_{fm} - T_{pm}}{T_f - T_p}$$

MD flux performance efficiency



Performance efficiency of the MD system is defined as the ratio of the measured vapor flux to the potential vapor flux

$$E_p = \frac{Q_e}{Q_{max}}$$

Q_e = Measured vapor flux ($kg.m^{-2}.h^{-1}$)

Q_{max} = Potential vapour flux ($kg.m^{-2}.h^{-1}$)

Based on Knudsen diffusion and Poiseuille viscosity flow models

$$Q_{max} = C(P_f - P_p)$$

C = Membrane distillation coefficient

P_f P_p = Saturation vapor pressure of pure water at the membrane surface-water interface on the feed side and permeate side, respectively

Saturation vapor pressure

- The saturated vapor pressure can be determined using the Antoine equation for pure water

$$P_w = exp\,(23.1964 - \frac{3816.44}{T - 46.13})$$

- In the case of saline feed , the calculated value of the saturated vapor pressure should be adjusted to account for the molar fractions of water and the solute

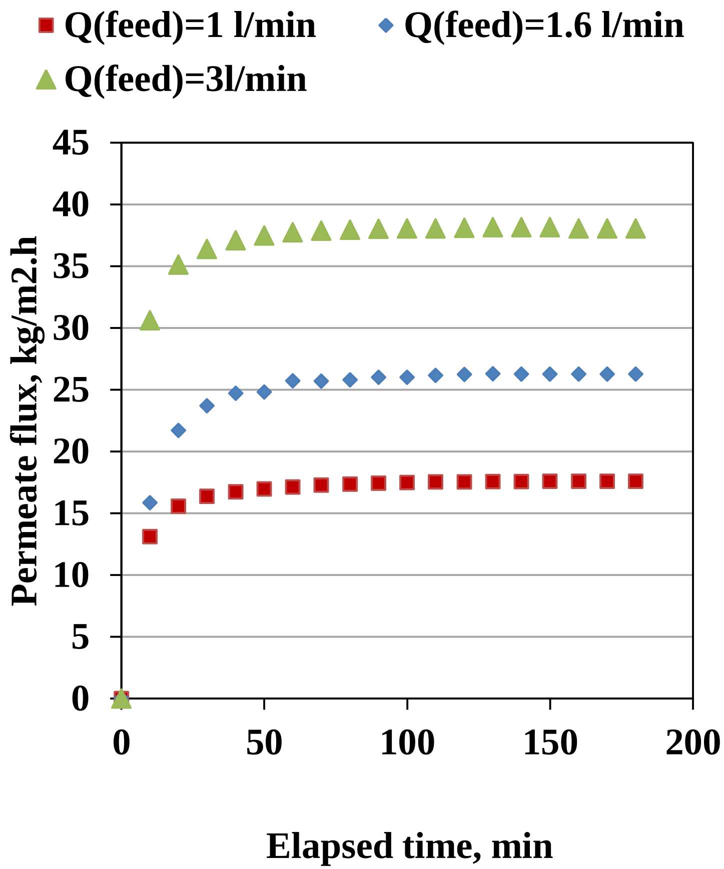
$$\mathrm{P_f} = \chi_w(1 - 0.5\,\chi_s - 10\chi_s^2)\mathrm{P_w}$$

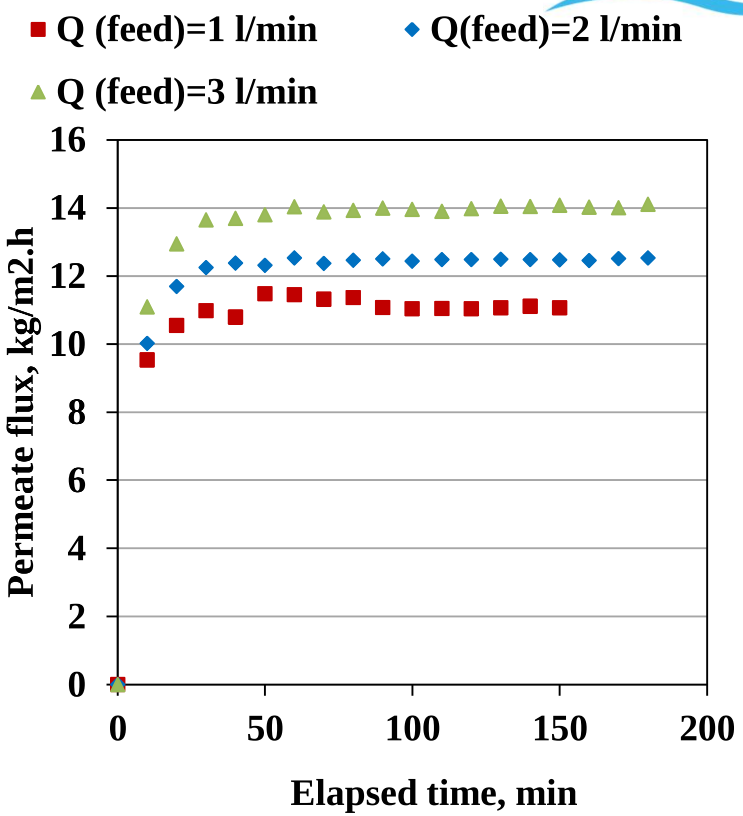
- For Millipore PVDF membrane with pore size of 0.22 µm the membrane distillation coefficient is 3.459 x 10^{-7} kgm^{-2} $s^{-1}Pa^{-1}$

Details of DCMD experiments

Experiments	Purpose	Process parameters			
		T_f ^0C	T_p ^0C	Q_f l/min	Q_p l/min
Set #1	Studying the effect of feed cross flow rates on the performance of commercial PVDF membranes using pure water as a feed	70	20	1	1.8
		70	20	1.6	1.8
		70	20	3	1.8
Set #2	Studying the effect of feed cross flow rates on the performance of commercial PVDF membranes using SWRO brine as a feed	56	20	1	1
		56	20	2	1
		56	20	3	1
Set #3	Four-factorial design experiment to establish the individual and combined effects of the operating parameters using SWRO brine as a feed	45	1	1	20
		65	1	1	20
		45	3	1	20
		65	3	1	20
		45	1	3	20
		65	1	3	20
		45	3	3	20
		65	3	3	20
		45	1	1	30
		65	1	1	30
		45	3	1	30
		65	3	1	30
		45	1	3	30
		65	1	3	30
		45	3	3	30
		65	3	3	30

Effects of feed salinity and cross flow rates on permeate flux

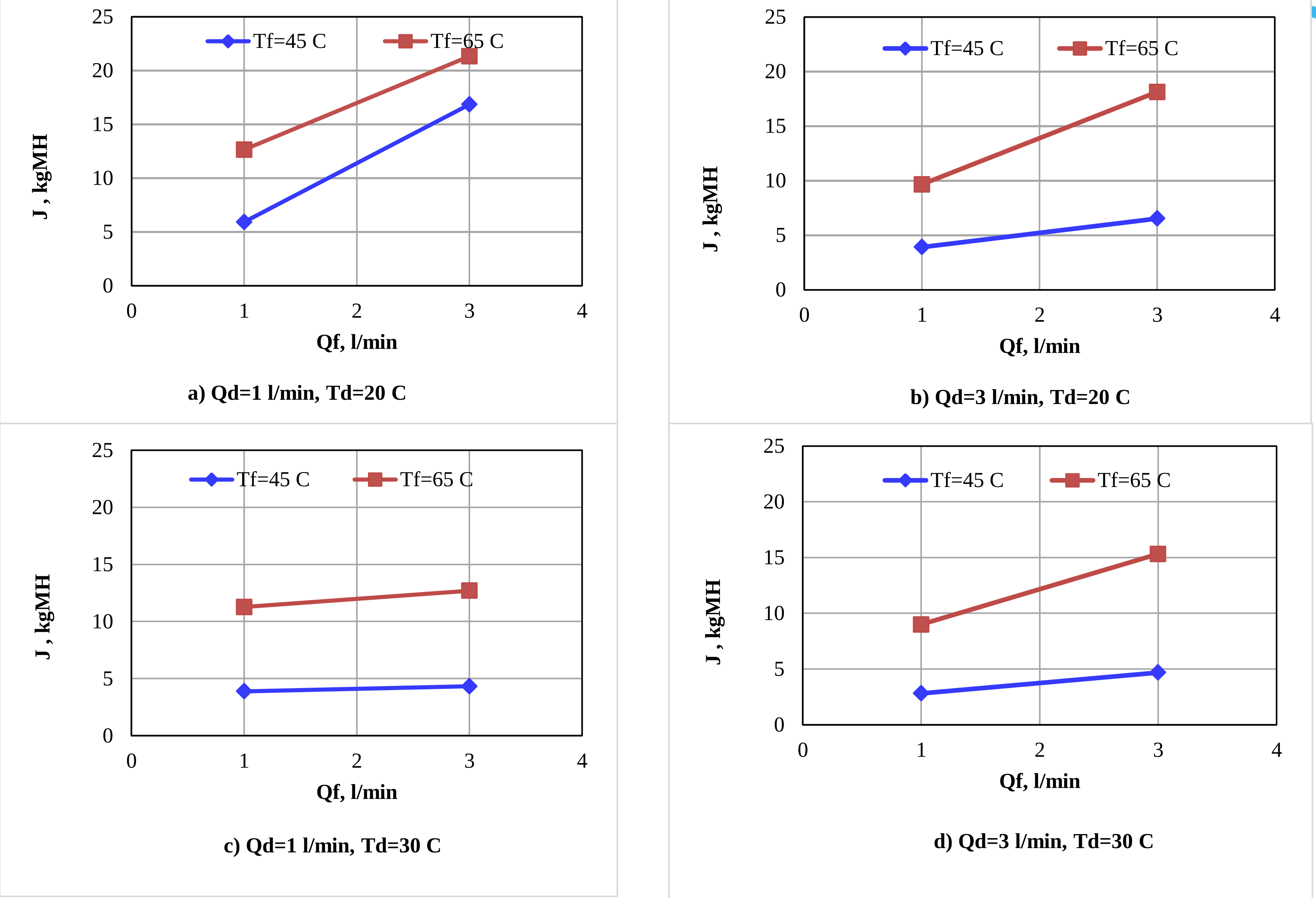




Type of feed water: Distilled water

Type of feed water: SWRO brine

Effect of operating parameters on DCMD permeate flux
type of feed water: SWRO brine



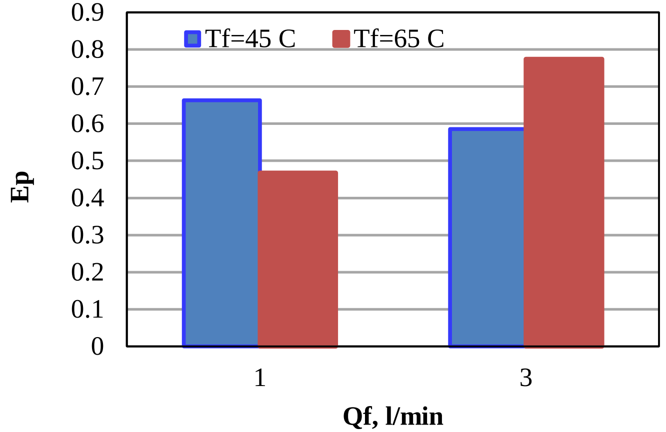
a) Qd=1 l/min, Td=20 C

b) Qd=3 l/min, Td=20 C

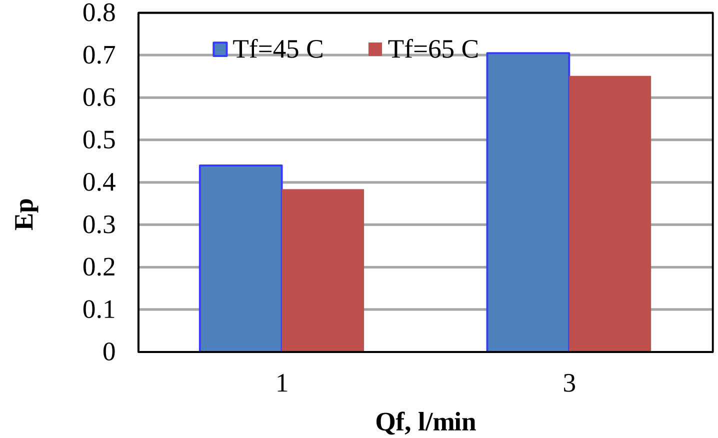
c) Qd=1 l/min, Td=30 C

d) Qd=3 l/min, Td=30 C

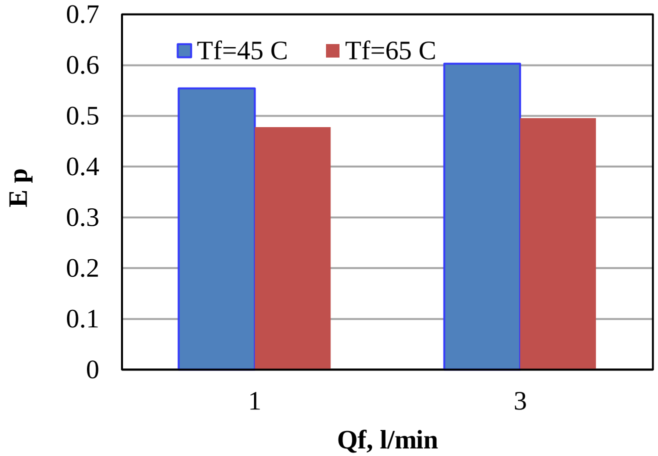
Effect of operating parameters on MD flux performance efficiency
type of feed water: SWRO brine



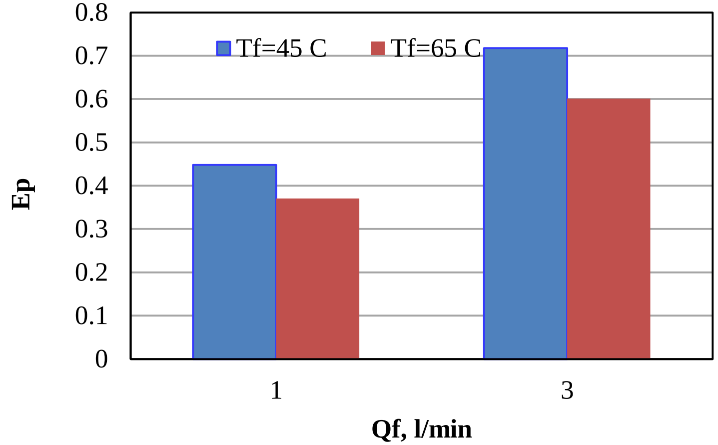
a) Qd=1 l/min, Td=20 C



b) Qd=3 l/min, Td=20 C

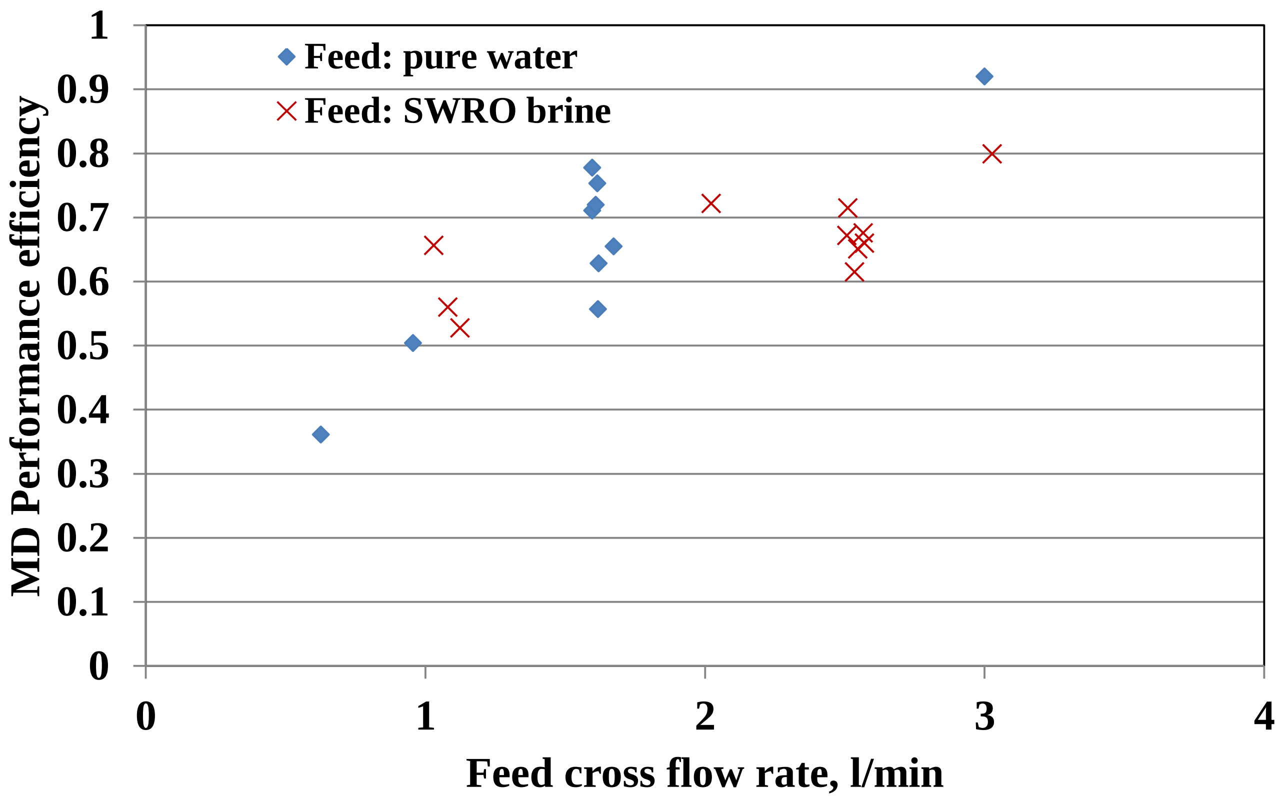


c) Qd=1 l/min, Td=30 C



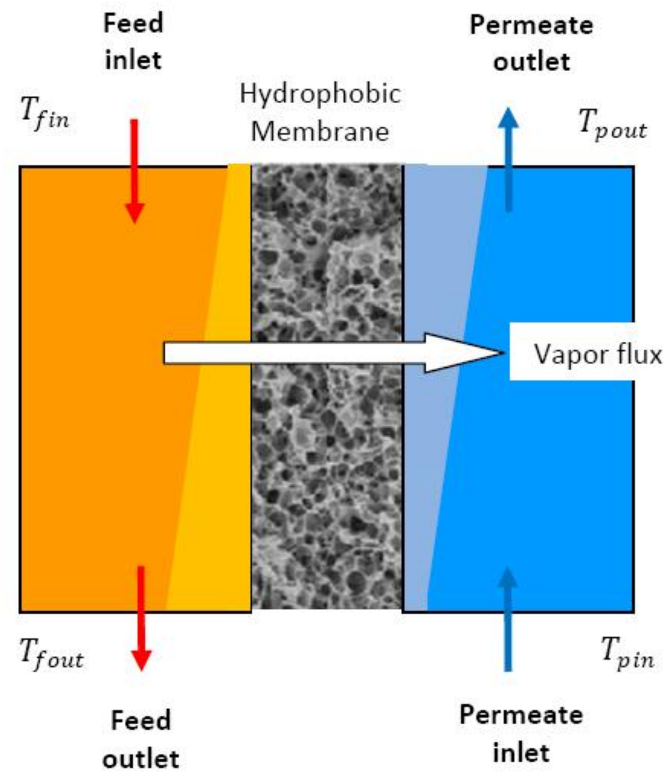
d) Qd=3 l/min, Td=30 C

Effect of feed cross flow rate on temperature polarization as expressed by the MD performance efficiency



How to control TP

- **Use modules with smaller length**
- **Limitations of module length: The temperature drop between the inlet and the outlet of either side of the membrane due to high heat loss by conduction should be minimized.**
- **The pressure drop between the inlet and the outlet of either side of the membrane should not exceed the LEP for the membrane**
- **Work at high cross flow velocity**
- **limitations cross flow velocity: the hydrostatic pressure should not exceed the LEP**
- **Use membranes with low thermal conductivity**
- **Use spacers to promote turbulent flow regime**



Current research efforts towards optimization of MD Desalination

- **Membrane development:** engineered polymers + improved membrane preparation techniques

  Aim: higher flux, lower fouling, lower wetting, improved rejection
- **Module design and optimization:** reduced temperature and concentration polarization and increased recovery ratio
- **Use of cost-effective heat sources:** Solar, boiler blowdown
- **MD System design:** lower energy use, higher performance, fouling and scaling control, wetting control

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Thank You