Novel Vacuum Membrane Distillation Configuration for Water Vapor Flux Enhancement

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

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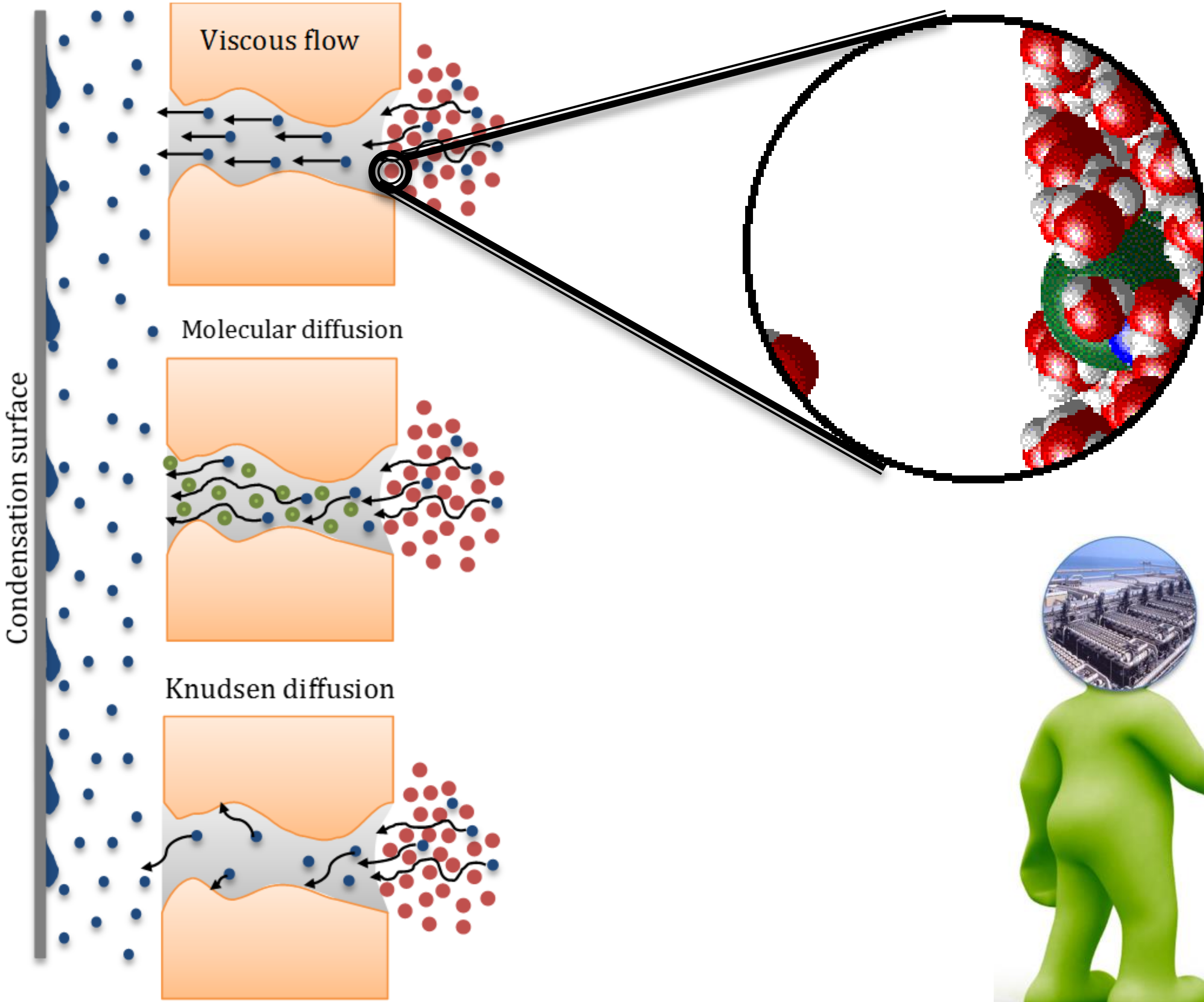
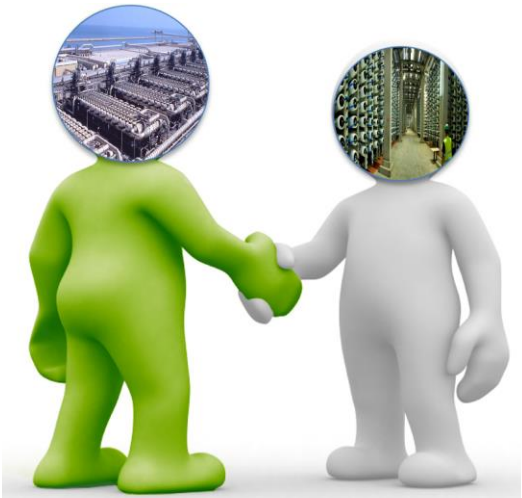
Membrane Distillation (MD)



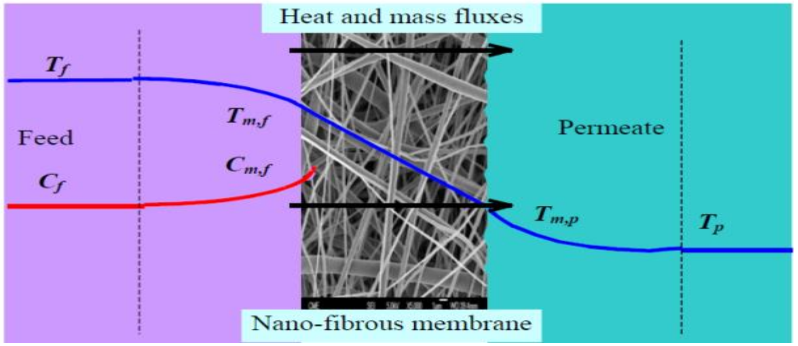
Due to non-equilibrium conditions between the two sides, the most volatile species escape the meniscus formed at pores inlet and flow through the porous membrane in a vapor state to reach the permeate side and condense



JMS 471 (2014) 138-148.

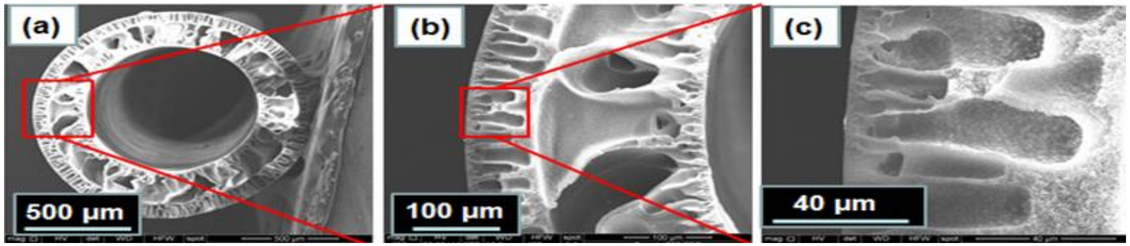
Parameters affecting the MD flux & energy efficiency

- Process conditions
  - ✓ Feed/coolant Temperatures
  - ✓ Feed water quality (salinity)
  - ✓ Flow velocity
- Polarization
  - ✓ Temperature polarization
  - ✓ Concentration polarization
- Membrane
  - ✓ Porosity
  - ✓ Pore size
  - ✓ Thickness
  - ✓ Tortuosity
  - ✓ Thermal conductivity



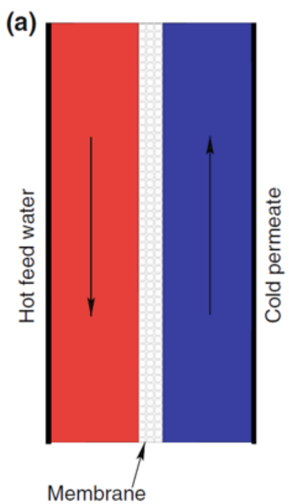
Heat transport through membrane Qm: HT due to flux Qn and HT due to conduction Qc (energy loss)

$$EE = \frac{Q_N}{Q_m} = \frac{Q_N}{Q_N + Q_c}$$

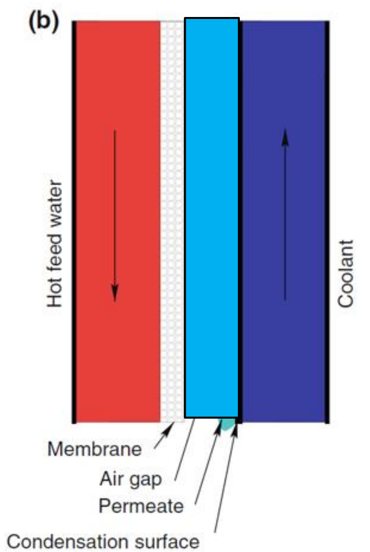


Configurations

Direct Contact Membrane Distillation

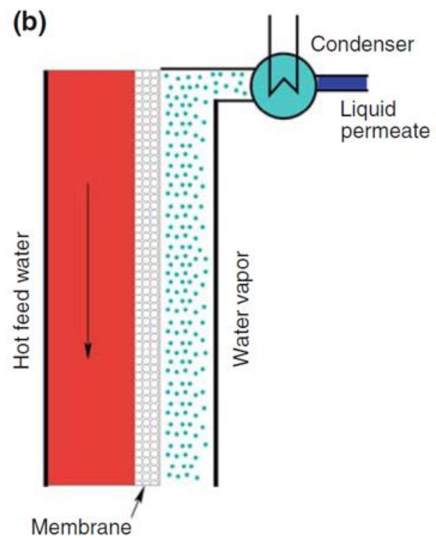


Air Gap Membrane Distillation

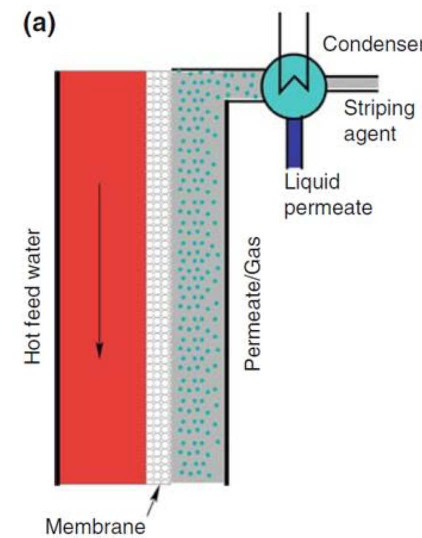


Water Gap, Material Gap, Conductive Gap Membrane Distillation

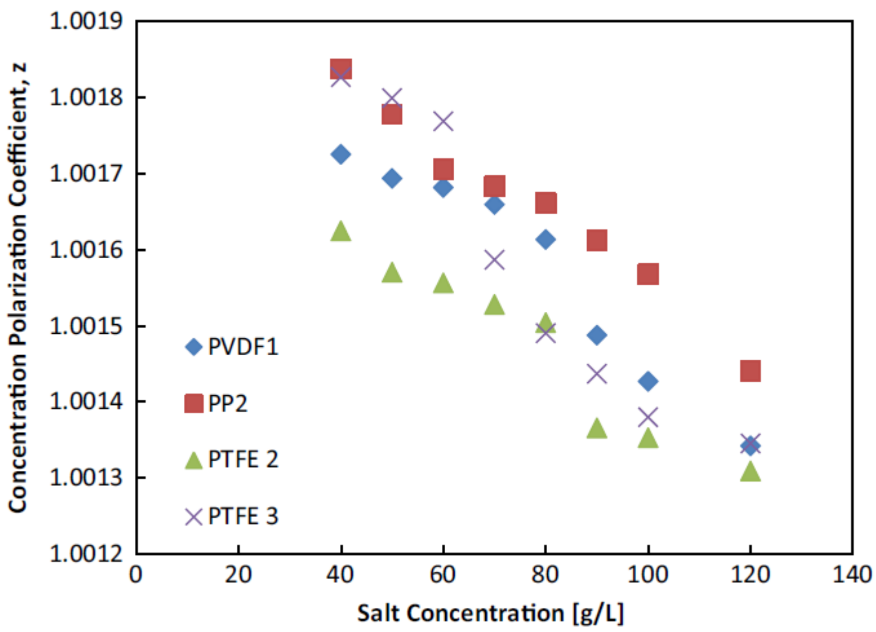
Vacuum Membrane Distillation

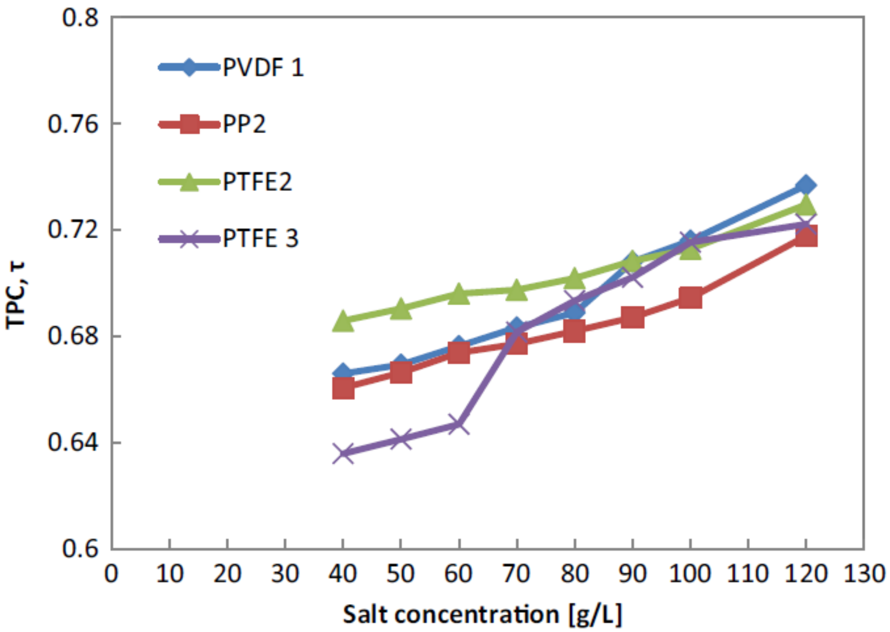


Sweeping Gas Membrane Distillation



Temperature polarization

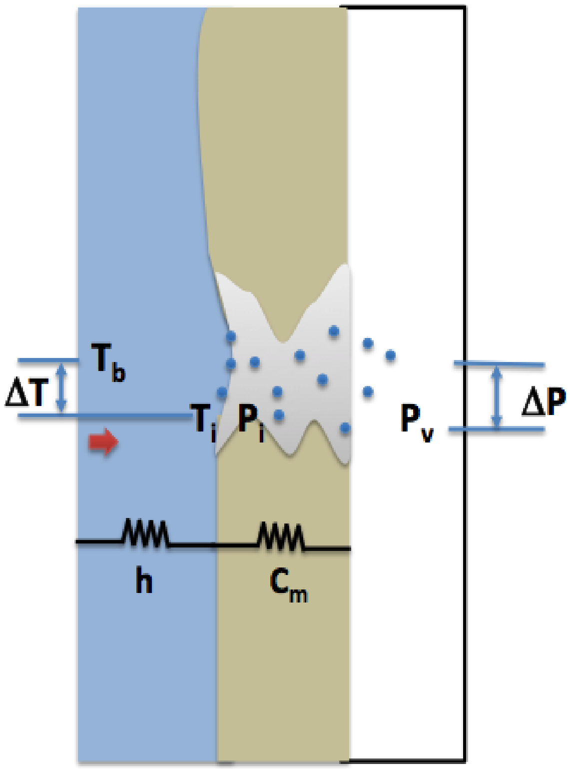




Temperature polarization effect is more significant than concentration polarization

Xu et al., J. Memb. Sci. 512 (2016) 73-82. 1-11.

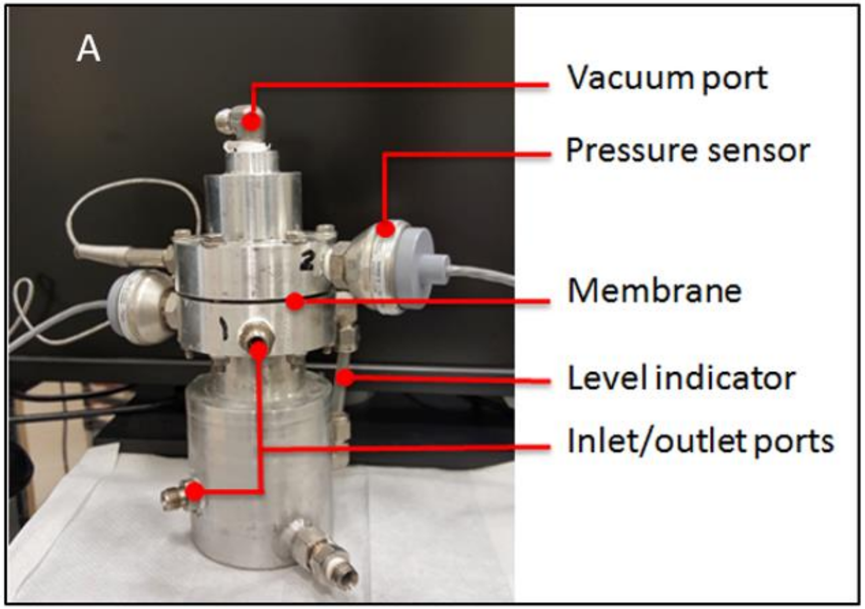
Main controlling resistances in VMD

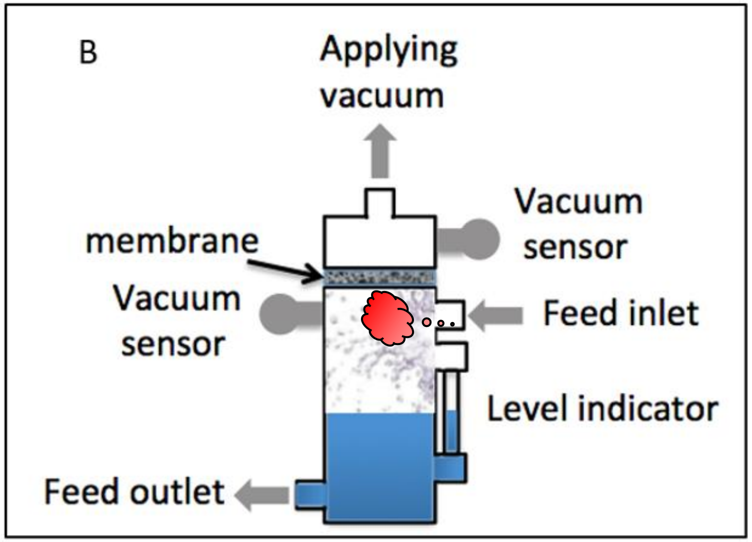


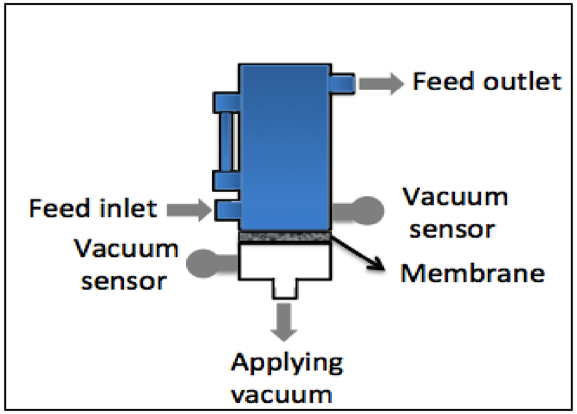
At low mass transfer resistance, the thermal separation process becomes heat transfer limited, and the opposite is true when the heat transfer resistance is lower

$$Q = h(T_b - T_i) = C_m(P_v - P_i)$$

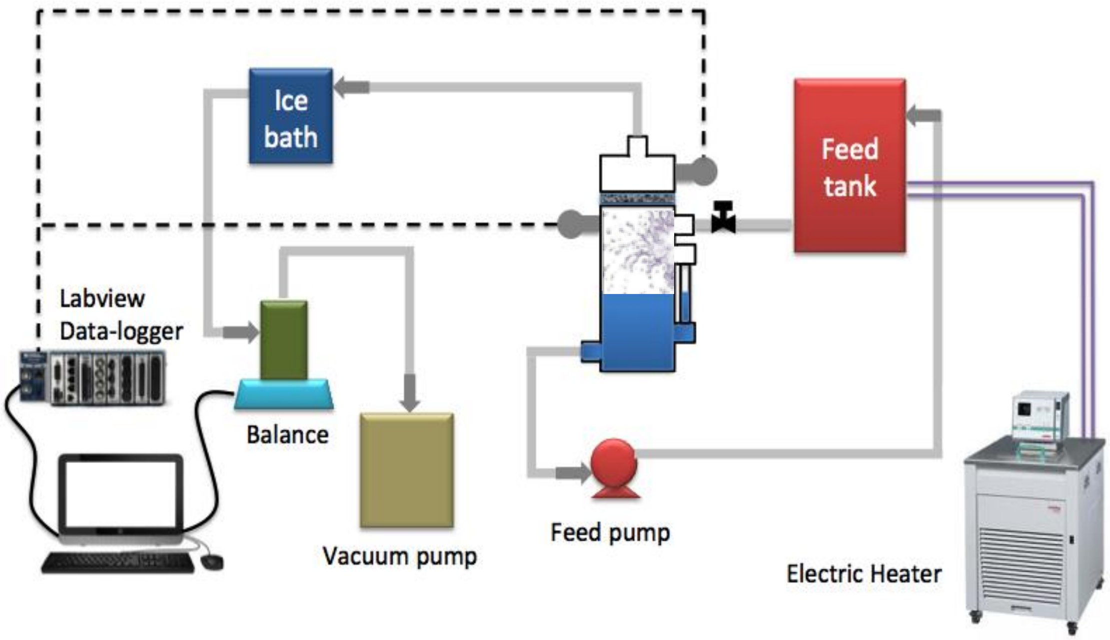
Custom-made VMD module

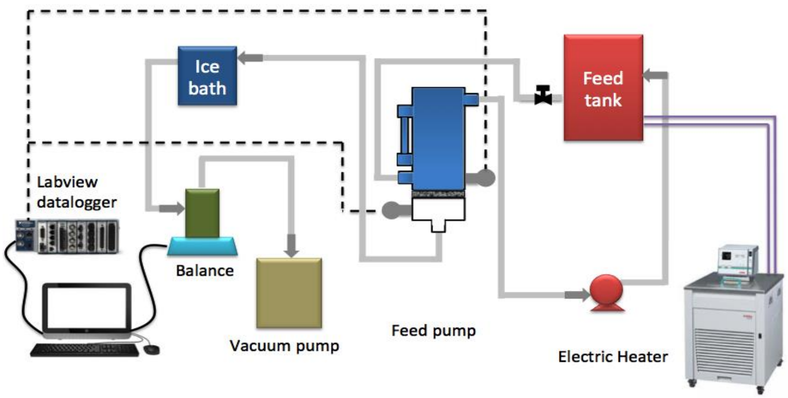




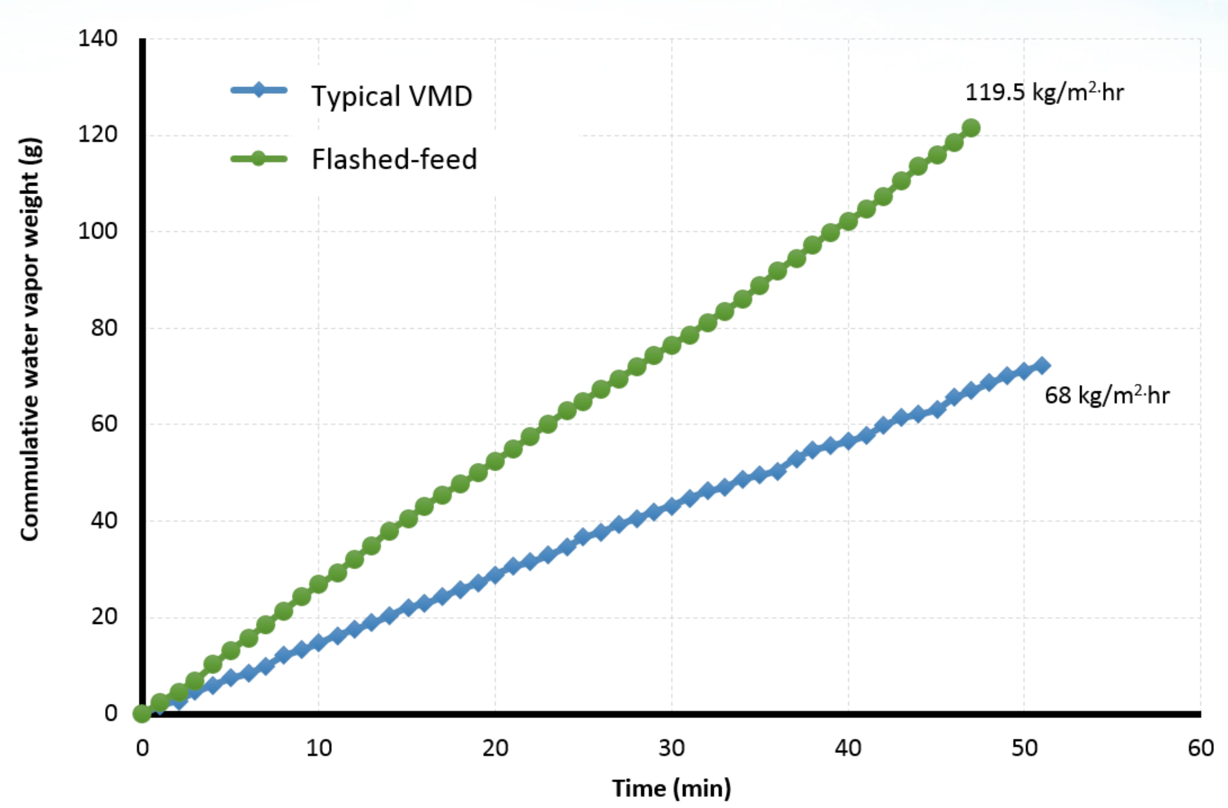


Experimental set-up





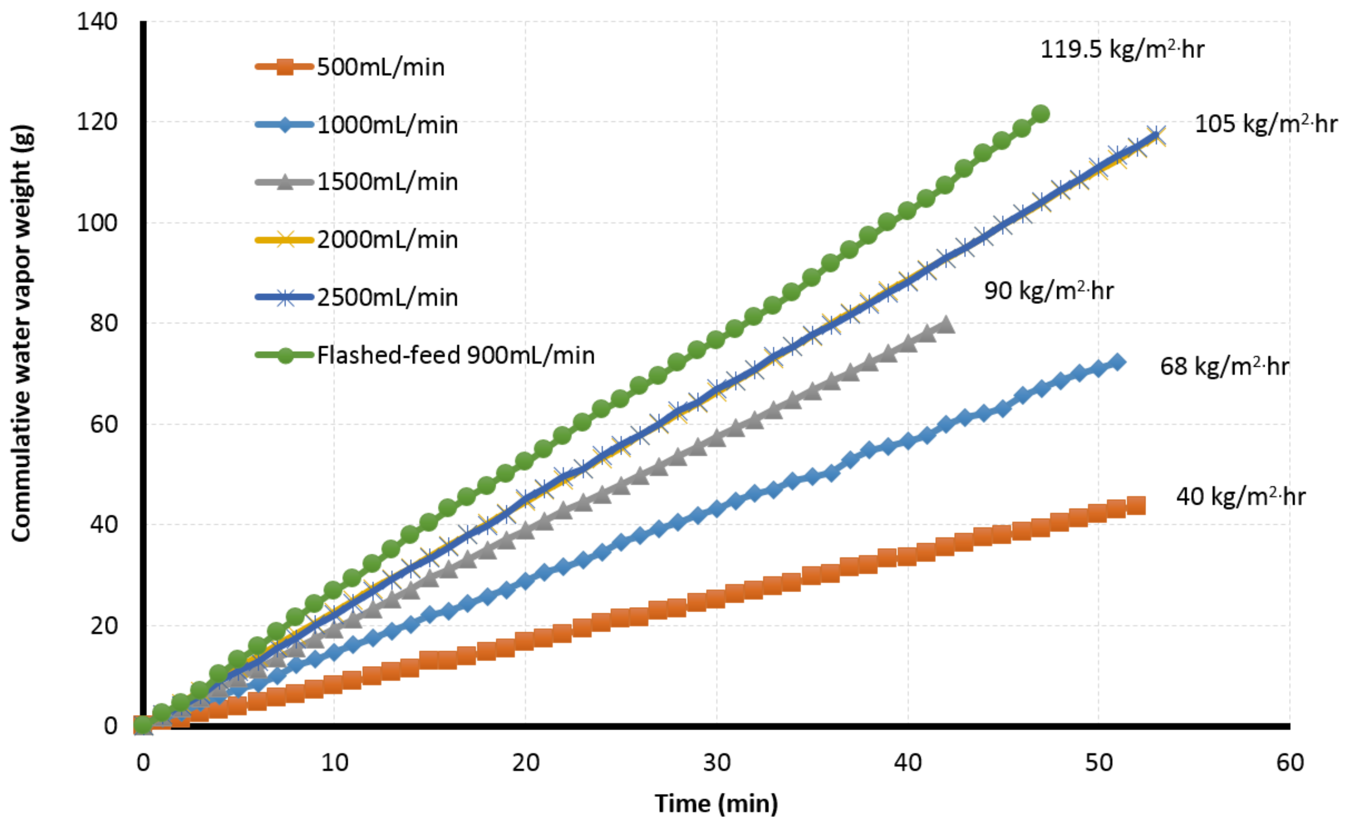
Effect of TP on water vapor flux



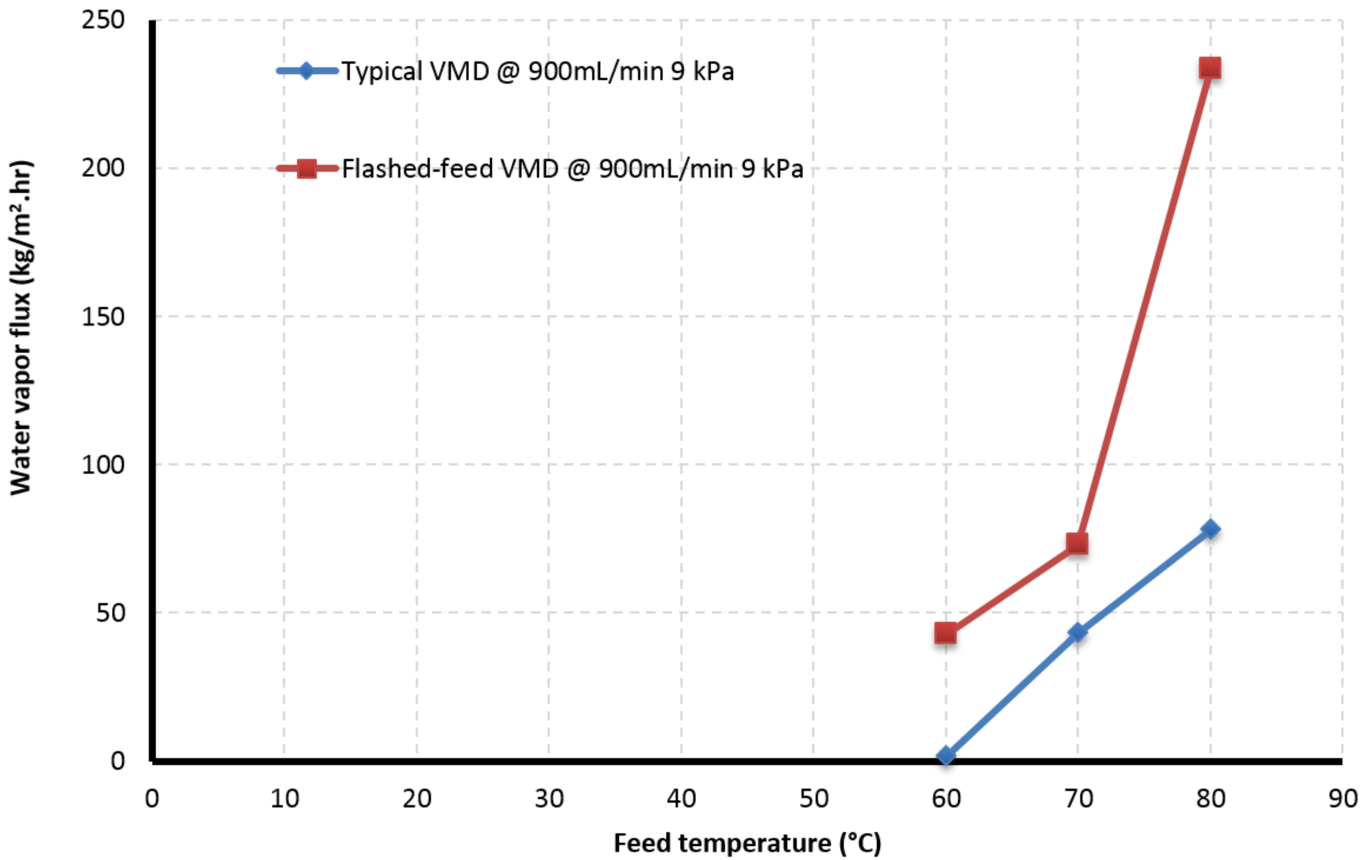
After eliminating temperature polarization effect membrane distillation flux is controlled by the heat transfer coefficient

Effect of TP on water vapor flux

Feed inlet temperature of 80 °C and 20 kPa

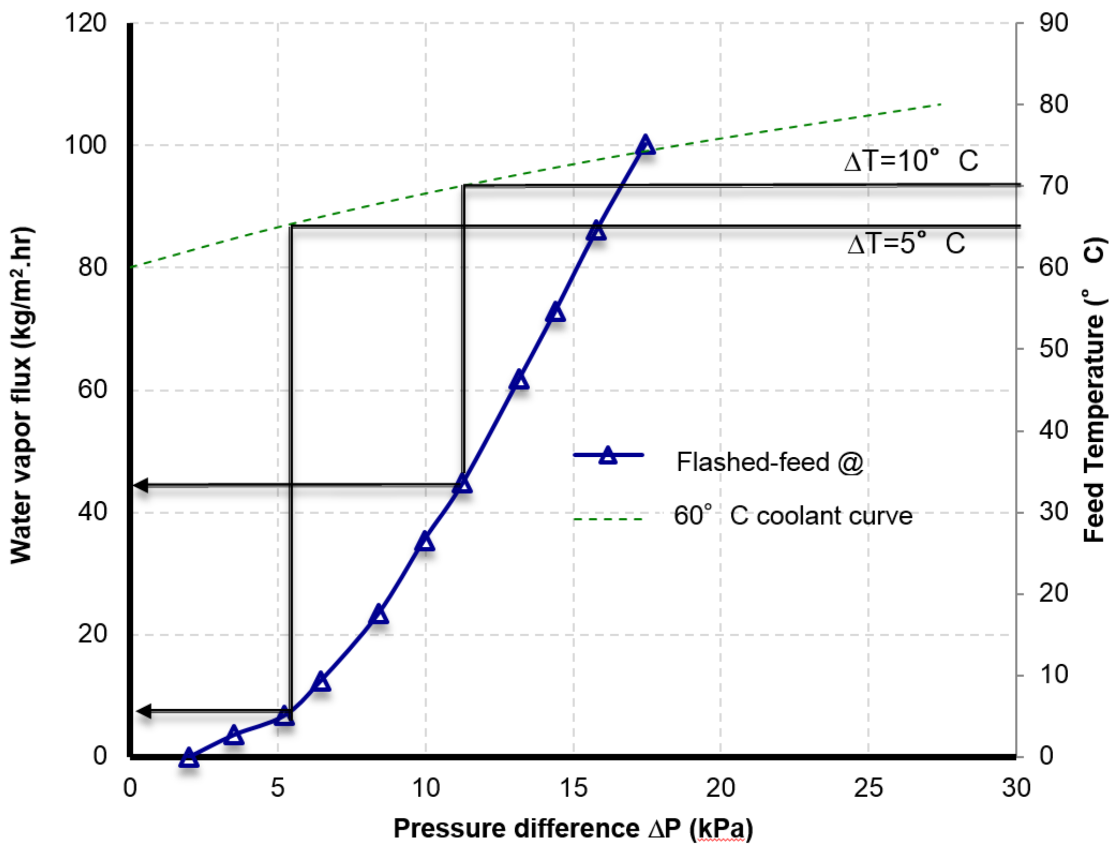


Feed temperature at membrane interface



Temperature polarization can reduce membrane distillation feed temperature by as much as 10 °C at a membrane surface relative to the bulk feed temperature

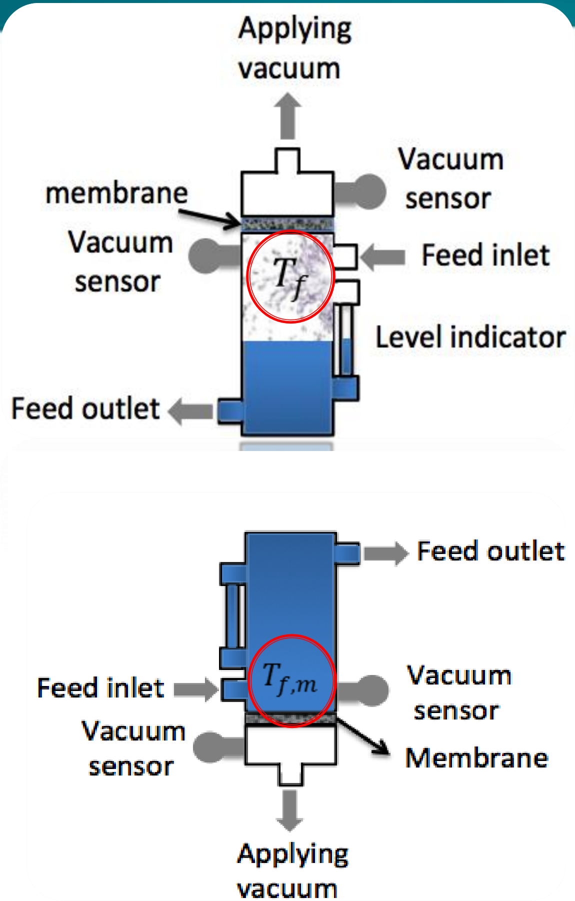
Membrane performance

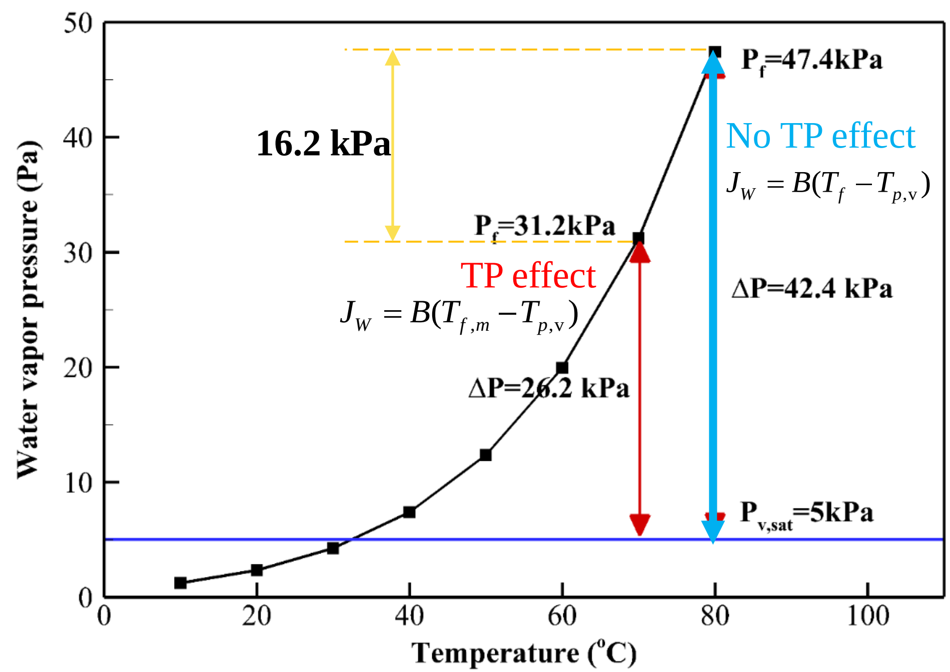


Estimating water vapor flux at different ΔP for feed flow rate of 900 mL/min and at temperature of 70 °C after eliminating TP effect

Calculation method deducted from JMS 471 (2014) 138-148.

Elimination of TP effect





$$T_{f,\mathrm{m}} = \frac{T_f h_f - J_W \Delta H + \frac{k}{\delta} T_{P,\mathrm{sat}}}{h_f + \frac{k}{\delta}}$$

Temperature polarization decreases the driving force by about 16.2 kPa

Conclusions

The coupling of heat and mass transfers in MD processes makes determining MD membrane MTC quite challenging due to the effect of TP. With our new concept:

- MD flux is controlled by the heat transfer coefficient.
- The currently available commercial membranes are good enough for scaling-up the process.
- TP can reduce MD feed temperature by as much as 10 ^{o}C at a membrane surface relative to the bulk feed temperature.
- Average water vapor fluxes of 9 kg/m^{2}.hr could be produced at ΔT of 5 ^{o}C.

Please find more details in:

A.S. Alsaadi, A. Alpatova, J.-G. Lee, L. Francis, N. Ghaffour, Flashed-feed VMD configuration as a novel method for eliminating temperature polarization effect and enhancing water vapor flux, ***J. Membr. Sci.*** **563 (2018) 175-182.**

Thank You

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