Analysis of salinity and membrane thickness influence on a Direct Contact Membrane Distillation module using the Dusty Gas model

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Abstract: Membrane distillation is an emerging technology for the separation of non-volatile inclusions in an aqueous feed stream. In this contribution, the effect of salinity and membrane thickness on flux and energy efficiency in direct contact membrane distillation (DCMD) is studied. The dusty gas model is used to describe the mass transfer inside the membrane and a Nusselt equation-based heat transfer submodel is used for the feed and permeate channels in DCMD. The analysis shows important interaction between the salinity and membrane thickness that strongly affect the flux and energy efficiency of the system, revealing large potential for system optimization.

Keywords: heat transfer; mass transfer; membrane distillation; optimization; simulation

Introduction

Membrane distillation (MD) is an upcoming technology mainly aimed at desalination, and the most commonly studied configuration is the direct contact membrane distillation (DCMD - Fig. 1). The vapour pressure difference is the driving force for the flux of the evaporated phase across the membrane. Large gradients of water vapour pressure can be created by using thin membranes, allowing MD to be operated at relatively low feed temperatures, potentially allowing reuse of waste heat at moderate temperatures from other nearby processes. However, most MD research claims that even though thin membranes lead to higher fluxes, the energy efficiency is negatively affected due to the increased conductive heat transfer through the membrane matrix (Khayet, 2011**)**. In this work, we argue that this is not always the case and suggest that a membrane with a specific thickness can be used to achieve optimal flux and energy efficiency depending on the case. The energy efficiency hereby represents the percentage ratio of energy that is used for flux transport and the total exchanged energy.

Model structure

The applied model is based on Nusselt equations for respectively the feed and permeate channels and is pre-calibrated experimentally using aluminium foil as described by Phattaranawik *et al.* (2003). The density and thermal conductivity of the fluid are corrected for the corresponding temperature and viscosity is corrected for the salinity and temperature. The flux of water vapour inside the membrane is predicted by the Knudsen-molecular transition form of the dusty gas model (DGM).

Results and discussion

Figure 2 shows that for clean water the flux is positively influenced by reducing the membrane thickness. However, when water with high salinity is used, an optimal thickness exists due to the reduced feed water activity that lowers the driving force (Figure 3). Indeed, smaller membrane thicknesses can induce negative fluxes as, even though a temperature difference exists, the vapour pressure on the feed side is smaller than the permeate side. The latter is due to the reduced activity and the overall result is that the flux is reversed. The simulation shows that for clean water the energy efficiency is constant over the range of considered membrane thicknesses (Figure 4). This can be explained by the fact that both the flux and heat conduction through the membrane increase with lower thicknesses and actually compensate, resulting in their ratio to be constant. However, for salt water the energy efficiency is severely diminished, especially at smaller membrane thicknesses, since the temperature drop across the membrane is too small to create a positive vapour pressure difference. Furthermore, it is noteworthy that the optimal membrane thickness is also a function of the membrane morphology and thermal conductivity.

Conclusion

The model analysis revealed that the energy efficiency is negatively affected by thin membranes for inflows with high salinity but proved to be completely insensitive for a clean water feed. This work suggests that there is no single best membrane thickness and an optimization for the flux and energy efficiency should be carried out for each inflow concentration and membrane type in order to achieve good system design.

References

Khayet,M. (2011). Membranes and theoretical modeling of membrane distillation: A review. *Adv. Colloid. Interfac.* **164**, 56–88.

Phattaranawik et al. (2003). Heat transport and membrane distillation coefficients in direct contact membrane distillation. *J. Membrane Sci.* **212,** 177-193.

Figures and Tables

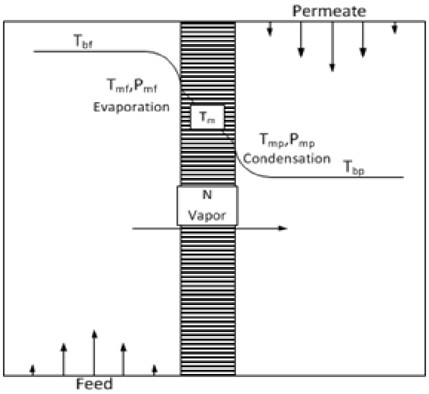

Figure 1 - Operation of direct contact membrane distillation

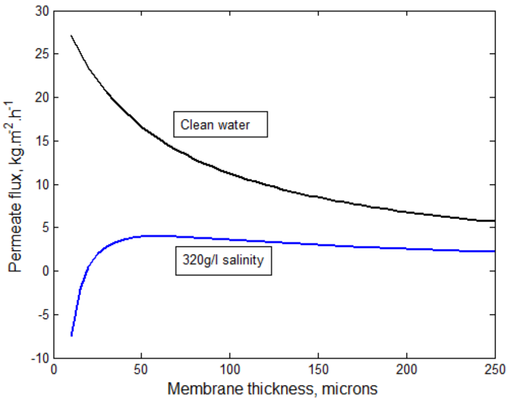

Figure 2 - Flux as function of membrane thickness

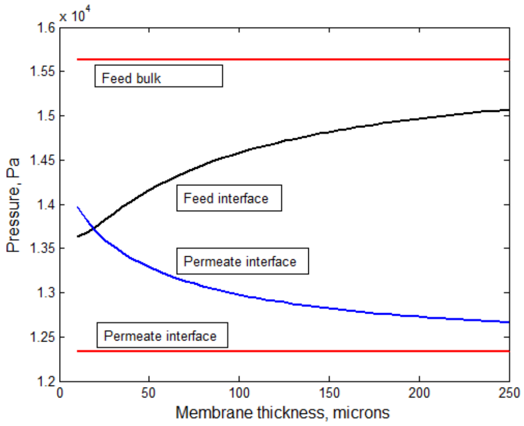

Figure 3 - Water vapour pressure in the system as function of membrane thickness at 320g/l salinity, with feed and permeate temperatures at 60 and 50˚C, respectively.

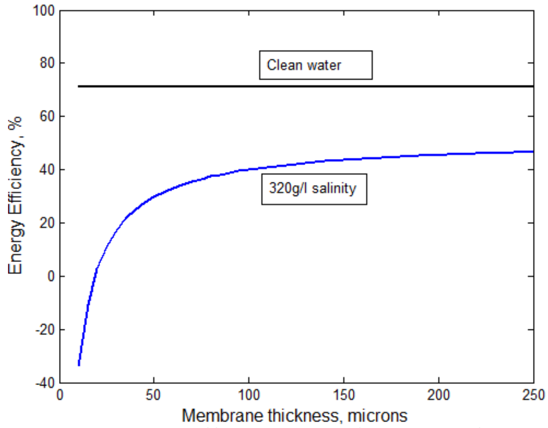

Figure 4 - Energy efficiency as function of membrane thickness.