Numerical modelling and performance evaluation of vacuum membrane distillation for energy-efficient seawater desalination: towards energy-efficient solutions	
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Abstract: Vacuum membrane distillation (VMD) is a compelling technique for desalinating water because it exhibits superior pure water permeability at lower operating temperatures compared to other membrane distillation technologies. This leads to reduced energy consumption, lower heat loss via conduction across the membrane surface, and minimal heat transfer through conduction due to the low pressure on the permeate side. Detailed modelling of heat and mass transfer in VMD is essential for optimizing the process as it provides valuable insights that contribute to the advancement and successful implementation of seawater desalination using VMD technology. The aim of this study is to establish a comprehensive numerical model that describes the water vapor transfer across a hydrophobic micro-porous membrane in single-stage and multi-stage VMD processes for seawater desalination. The numerical predictions were compared to experimental data in addition to numerical computations based on an existing literature database, and good agreement has been found. The investigation also conducted a sensitivity analysis of process variables and membrane specifications on the VMD performance, as well as an assessment of the impact of temperature and concentration polarization. The obtained results showed that the permeation flux reached 18.42 kg/m2·h at 35 g/L feed concentration, 65 °C feed temperature, 50 L/h feed flow rate, and 3 kPa vacuum pressure. Moreover, the findings revealed that the feed temperature was the most significant factor, while the feed flow rate was the least important in determining the permeation flux. Additionally, the findings suggested that the effectiveness of the VMD process heavily relies on the composition and permeability of the support materials. Finally, the results confirmed that temperature polarization had a more significant effect on the reduction of the permeate flux than the concentration polarization.