An Investigation into Hydrophobic Membrane Fouling in Desalination Using Membrane Distillation Technology

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Demand for freshwater supplies is continuously increasing globally to the extent where some parts of the world became highly water stressed. In particular, the Arabian Gulf states rely heavily on seawater desalination for their freshwater supply which is met using commercial seawater desalination technologies like thermal and reverse osmosis (RO) desalination processes. However, these technologies require considerable power input and actually do have a negative impact on the environment in terms of carbon footprint.

An alternative technology to the conventional desalination processes with potentially lower environmental impacts is the Membrane Distillation (MD) process. Membrane Distillation is a thermally-driven process that utilizes a hydrophobic micro-porous membrane and can utilize low grade heat and solar energy. The driving force of the process is the vapor pressure difference between the sides of the membrane that is induced by the temperature difference between the feed and distillate. However, one of the challenges facing the deployment of MD in large commercial scale desalination of seawater is membrane fouling.

The objective of this study is to investigate and compare the fouling characteristics of three different commercial membranes (PP membrane of 0.22 μm, PP membrane of 0.45 μm, and PTFE membrane of 0.22 μm) using two feed solutions (seawater from the Arabian Gulf and synthetic 100,000 ppm NaCl solution) using a bench-scale direct contact membrane distillation (DCMD) flat sheet module at hot water inlet temperature of 75 °C, cold water inlet temperature of 20 °C, and hot and cold water flow rate of 1.5 L/min. The study was performed by evaluating the distillate flux performance of the various membranes, measuring their contact angle before and after fouling, testing the quality of the distillate produced and examining the salt rejection, and interpreting membrane surface analysis using Scanning Electron Microscopy (SEM) coupled with Energy Dispersive Spectroscopy (EDS) in order to study the morphology and the composition of the fouling layer.

Initially, the average flux obtained was 50.5 L/m²h, 50.3 L/m²h, and 38.3 L/m²h for PP membrane of 0.22 μm, PP membrane of 0.45 μm, and PTFE membrane of 0.22 μm, respectively. Therefore, PP membrane generated a higher flux than PTFE membrane. In terms of membrane pore size, the results showed that a larger pore size membrane is more prone to fouling and flux decay. In terms of membrane material, PP membrane showed a more rapid flux decline than PTFE membrane. Moreover, the percentage of drop in the average flux was more than 60%, 97%, and 94% for PP membrane of 0.22 μm, PP membrane of 0.45 μm, and PTFE membrane of 0.22 μm, respectively, after almost 19 h, 30 h, and 25 h of operation, respectively.

In terms of feed solution, a lower flux was obtained with the higher salinity feed, the 100,000 ppm NaCl solution. However, the difference was not very large, indicating that initially salinity does not have a great impact on the distillate flux.

The results also showed that fouling/scaling causes the quality of the distillates to deteriorate and that membrane wetting has occurred. A salt rejection of more than 99.9% was achieved initially; however, with continuous operation, a salt rejection as low as 83.5% and 69.9% was achieved when the seawater and the 100,000 ppm NaCl solution were used, respectively. PP membrane of 0.22 μm gave a better salt rejection followed by PTFE membrane of the same size then by PP membrane of 0.45 μm.

The contact angle of a clean PP membrane of 0.22 μm, PP membrane of 0.45 μm, and PTFE membrane of 0.22 μm, was found to be 134.8°, 133.2°, and 136.7°, respectively. However, after fouling, the contact angle dropped to 40.5°, 36.1°, and 13.8° for PP membrane of 0.22 μm, PP membrane of 0.45 μm, and PTFE membrane of 0.22 μm, respectively, indicating significant loss of hydrophobicity.

SEM-EDS analysis showed that the salt layer formed on the membranes was not uniform and that the major foulants were CaCO₃ and CaSO₄. In addition, membrane pore blocking by salts and a cake layer formation (which was a result of the elevated feed temperature that resulted in the formation of temperature polarization) were observed.

The results of the study show that fouling needs to be more investigated in MD process to be practically implemented and considered as competitive to the conventional desalination technologies. An optimum temperature and flow rate should be explored; however, the results of the study urge the need for developing new membranes and improved membrane modules and MD configurations as well as finding optimum procedures for membrane cleaning.