Examining the role of internal and distillate-side membrane hydrophobicity to understand wetting and rejection in membrane distillation

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Abstract

Membrane distillation (MD) is a thermally driven separation process that can utilize waste heat and/or solar thermal energy to extract distillate-quality water from impaired water streams [1-3]. MD relies on a hydrophobic, unwetted membrane to achieve virtually complete rejection of dissolved solutes – a concept that appears simple, but encompasses numerous complexities and assumptions. Current MD research often implicitly assumes that feed-side membrane surface properties prevent wetting and therefore control rejection. While novel membrane materials, including composite hydrophobic-hydrophilic membranes, are increasingly being explored in the literature [5, 6], there have been very few studies of wetting of novel membranes, especially under scaling conditions. Furthermore, current research often assumes that membrane hydrophobicity can be fully restored by fully removing fouling/scaling deposits.

Our recent results have shown that these assumptions may not hold, especially when considering heterogeneous membranes and long-term operation under high-salinity conditions. Observation of both sides of a single-layer, symmetric membrane after long-term (100-day) bench-scale operation revealed that the feed-side contact angle was reduced by 56% and roughness by 92%. Perhaps more interestingly, the distillate-side contact angle was reduced by 26% and roughness by 57% (Table 1).

Table 1. Contact angles and roughness measured on virgin and used MD membrane before and after long-term (100-day) operation with 35 g/L NaCl feed solution and average feed and distillate temperatures of 63 and 40 °C measured at the module [4].

Membrane	***Side***	***Water contact angle***	***Root-mean-square roughness (nm)***
Virgin	Feed	140 ± 4.0°	31.0 ± 5.4
	Distillate	140 ± 3.6°	27.1 ± 7.58
Used	Feed	61 ± 9.1°	3.0 ± 0.88
	Distillate	104 ± 14°	14.5 ± 3.11

Although reductions on the feed side were associated with organic fouling deposits, the distillate side was free of external deposits; therefore, the hydrophobicity reduction was associated with changes to the surface of the membrane itself (Fig. 1).

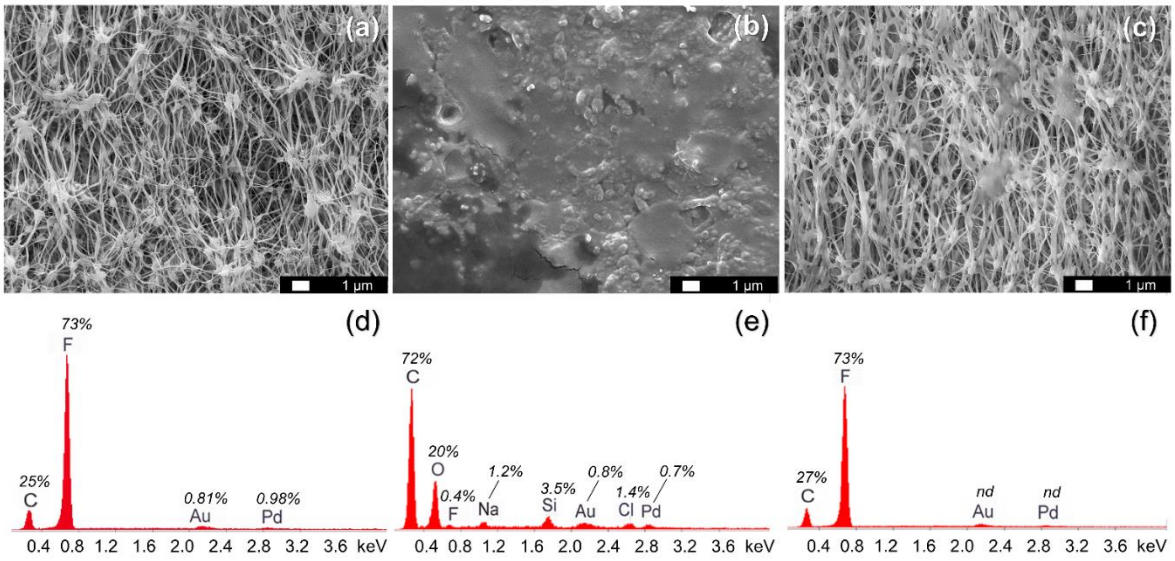


Figure 1. Representative images of **(a)** virgin membrane, **(b)** feed side of used membrane, and **(c)** distillate side of used membrane and energy dispersive x-ray spectra of **(d)** virgin membrane, **(e)** feed side of used membrane, and **(f)** distillate side of used membrane for a single-layer, symmetric PTFE membrane operated for 100 days with 35 g/L NaCl feed solution and average feed and distillate temperatures of 63 and 40 °C measured at the module [4].

Despite the significant reductions on the feed side of the membrane, which theoretically resulted in zero liquid entry pressure, distillate conductivity did not significantly increase (Fig. 2). These results clearly suggest that factors other than feed-side hydrophobicity significantly affect membrane wetting and rejection during long-term operation.

We also present, for the first time, measured internal contact angles of membrane materials. No researchers have yet reported measured internal hydrophobicity of membranes. Internal membrane hydrophobicity is characterized according to a method originally developed for porous fuel cell materials; briefly, the internal contact angle of a nonwetting liquid can be indirectly obtained from measurements with wetting liquids according to the Washburn method [7]. The role of internal and distillate-side membrane properties on wetting are systematically studied for commercial and composite hydrophobic-hydrophilic membranes, with and without scaling present. The results presented here provide fundamental insights relevant to MD membrane performance, longevity, and design.

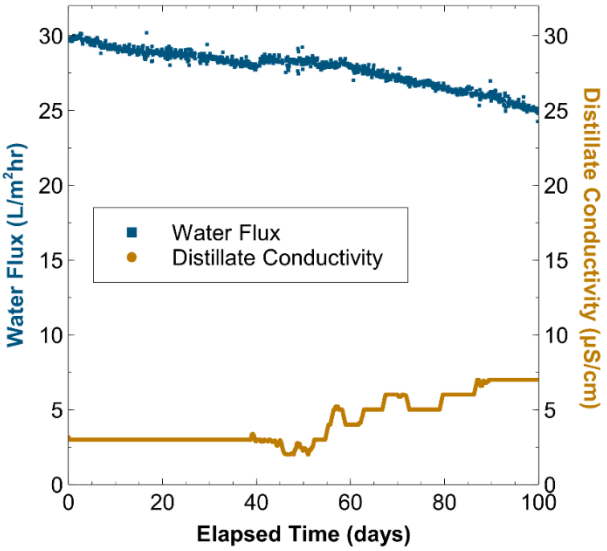


Figure 2. Performance results for long-term (100-day) operation of a single-layer, symmetric PTFE membrane with 35 g/L NaCl feed solution and average feed and distillate stream temperatures of 63 and 40 °C. Distillate conductivity is shown as a moving average [4].

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