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<th>Gypsum scaling and membrane integrity of osmotically driven membranes: The effect of membrane materials and operating conditions (Figures)</th>
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Figure 1. Membrane flux performance during FO scaling in the AL-FS orientation. Test conditions: FS contained 26.1 mM CaCl$_2$, 72 mM Na$_2$SO$_4$ and 10 mM NaCl (saturation index of 2.0) as scaling condition. 163 mM NaCl solution was used as FS for baseline tests. 1.9 M and 2.5 M NaCl DS was used for TFC and CTA membranes, respectively, to achieve a similar initial flux of 9 ± 1.5 L/m$^2$·h.
Figure 2. FESEM micrographs of the membrane active surfaces and cross-sections after scaling in the AL-FS orientation. (a) active surface of TFC membrane at low magnification (showing the damaged surface at the spacer niche); (b) active surface of TFC membrane with at higher magnification (away from the spacer); (c) cross section of TFC membrane; (d) active surface of CTA membrane at low magnification; (e) active surface of CTA membrane at higher magnification; and (f) cross section of CTA membrane. Scaling test conditions: FS contained 26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl (saturation index of 2.0) as scaling condition. 1.9 M and 2.5 M NaCl DS was used for TFC and CTA membranes, respectively, to achieve a similar initial flux of 9 ± 1.5 L/m²·h.
Figure 3. FO membrane flux performance during FO scaling in the AL-DS orientation. Test conditions: FS contained 26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl (saturation index of 2.0) as scaling condition. 163 mM NaCl solution was used as FS for baseline tests. 1.4 M and 1.9 M NaCl DS was used for TFC and CTA membranes, respectively, to achieve a similar initial flux of 9 ± 1.5 L/m²·h.
Figure 4. FESEM micrographs showing the membrane active surface and cross-section after scaling in the AL-DS orientation. (a) active surface of TFC membrane at low magnification; (b) active surface of TFC membrane at higher magnification; (c) cross section of TFC membrane; (d) active surface of CTA membrane at low magnification; (e) active surface of CTA membrane at higher magnification; and (f) cross section of CTA membrane. Scaling test conditions: FS contained 26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl (saturation index of 2.0) as scaling condition. 1.4 M and 1.9 M NaCl DS was used for TFC and CTA membranes, respectively, to achieve a similar initial flux of 9 ± 1.5 L/m²·h.
Figure 5. Flux reversibility check of TFC and CTA membranes after scaling. (a) Membrane flux after 18-h FO scaling (relative to the 18-h baseline flux). Scaling test conditions: initial flux was 9 ± 1.5 L/m²·h, crossflow velocity was 10 cm/s, FS contained 26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl (saturation index of 2.0) for scaling tests, while it contained 163 mM NaCl for baseline tests. (b) Percentage flux recovery (relative to clean membrane flux) after cleaning. The recovered flux (of scaled membrane after cleaning) and clean membrane flux (of fresh membrane) were both...
tested using 2 M NaCl DS and ultrapure water FS. All the tests were duplicated except for the flux recovery test for the case of CTA, AL-DS.
Figure A1. Schematic diagram of FO setup. The feed solution tank was placed on a magnetic stirrer. The draw solution tank was placed on a balance for water flux acquisition.

Figure B1. FESEM micrographs of clean membrane surfaces. (a) TFC membrane; and (b) CTA membrane.
TFC, AL-FS
with spacer

Normalized flux (-)

Time (h)

with spacer baseline

with spacer SI 2.0

with spacer SI 2.0 replicate

Normalized flux (-)

Time (h)

TFC, AL-FS
without spacer

without spacer baseline

without spacer SI 2.0

without spacer SI 2.0 replicate
Figure C1. Effect of feed spacer on TFC membrane scaling in the AL-FS orientation: (a) with feed spacer; and (b) without feed spacer. (c) Photo images showing the damaged membrane active surface after scaling tests. Scaling test conditions: the FS contained 26.1 mM CaCl$_2$, 72 mM Na$_2$SO$_4$ and 10 mM NaCl (saturation index of 2.0) for the scaling tests, and it contained 163 mM NaCl for the baseline tests. The initial water flux was 9 ± 1.5 L/m$^2$·h and the crossflow velocity was 10 cm/s.
Figure C2. The effect of the aged FS (saturation index of 2.0) on FO scaling in the absence of feed spacer in the AL-FS orientation. The aged FS was prepared by stirring the SI 2.0 solution for 6 h, during which the gypsum was precipitated out of the solution and resulted in a solution with high turbidity but without nucleation potential thereafter. During the FO scaling test, the aged FS was stirred well to ensure a homogeneous solution with suspended gypsum precipitates. Other test conditions: the SI 2.0 FS contained 26.1 mM CaCl$_2$, 72 mM Na$_2$SO$_4$ and 10 mM NaCl. The FS contained 163 mM NaCl for the baseline condition. The initial flux was $9 \pm 1.5$ L/m$^2$·h and the crossflow velocity was 10 cm/s.
Figure D1. Induction time of gypsum nucleation with and without antiscalant (AS). Three saturation indexes (SI) were evaluated: SI 2.0 (26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl), SI 2.3 (30 mM CaCl₂, 180 mM Na₂SO₄ and 171 mM NaCl), and SI 3.17 (40 CaCl₂, 240 mM Na₂SO₄ and 105 mM NaCl). The AS dosage was 2 ppm. The turbidity was measured using 2100AN IS Turbidimeter (HACH) at 22 ± 1 °C.
Figure E1. Effect of AS alone on the FO flux of TFC membrane in the (a) AL-FS orientation and (b) AL-DS orientation. The initial water flux was 9 ± 1.5 L/m²·h and the crossflow velocity was 10 cm/s. The FS contained 163 mM NaCl. 2 ppm AS dosage was applied.
Figure E2. Effect of AS on FO scaling. (a) TFC membrane, AL-FS; (b) CTA membrane, AL-FS; (c) TFC membrane, AL-DS; and (d) CTA membrane, AL-DS. Scaling test conditions: initial flux at 9 ± 1.5 L/m²·h, crossflow velocity at 10 cm/s, the FS contained 26.1 mM CaCl₂, 72 mM Na₂SO₄ and 10 mM NaCl (saturation index of 2.0) for the scaling condition, while it contained 163 mM NaCl for the baseline condition. 2 ppm AS dosage was applied.