Performance enhancement and scaling control with gas bubbling in direct contact membrane distillation

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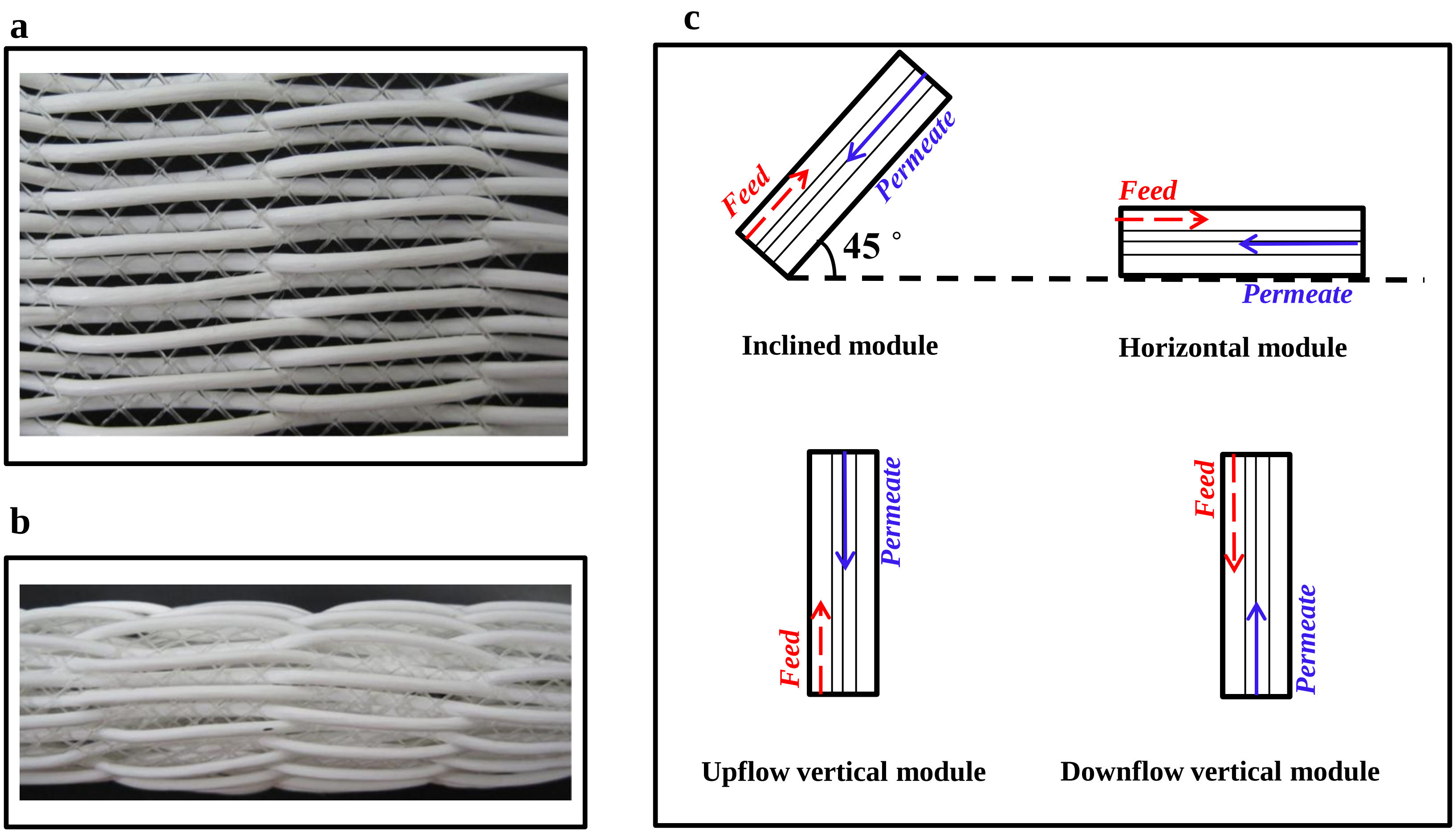

Figure 1. Several explanations for MD modules (a. Fibers knitted with spacers before packing; b. Hollow fibers in the membrane module after packing; c. Membrane module orientations).

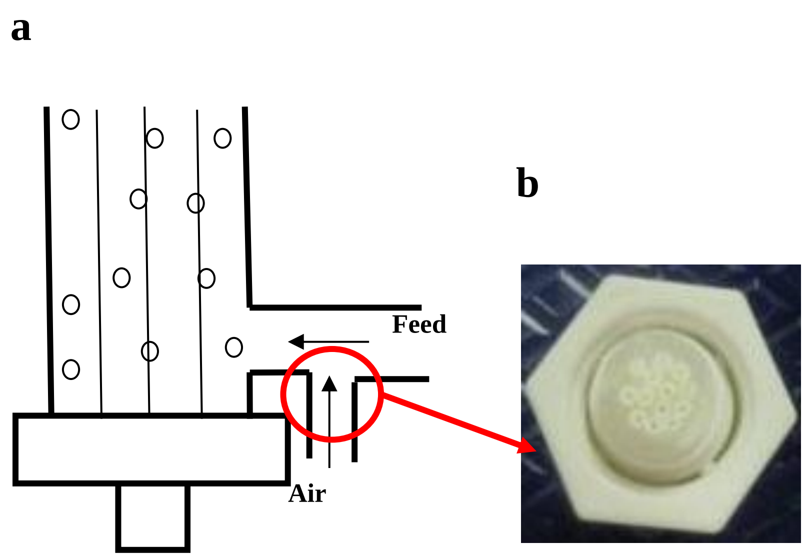

Figure 2. a. Air inlet connected to the membrane module; b. Air nozzle.

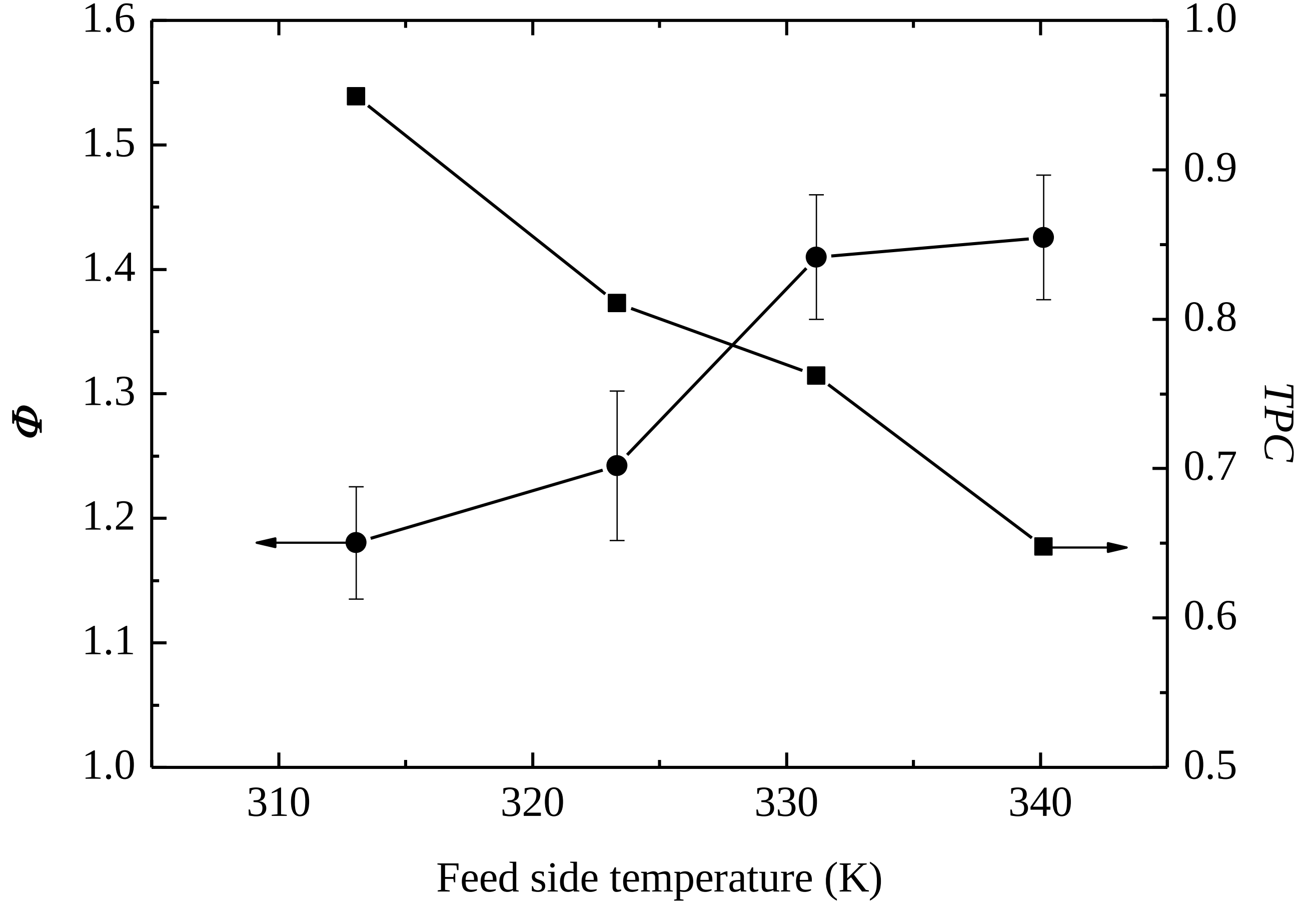

Figure 3. Effect of feed side temperature on *Φ* and *TPC*.
(3.5% NaCl solution as feed: Q_f = 0.3 L·min^{-1}; Q_p = 0.025 L·min^{-1} Q_g = 0.2 L·min^{-1}; T_p = 298 K)

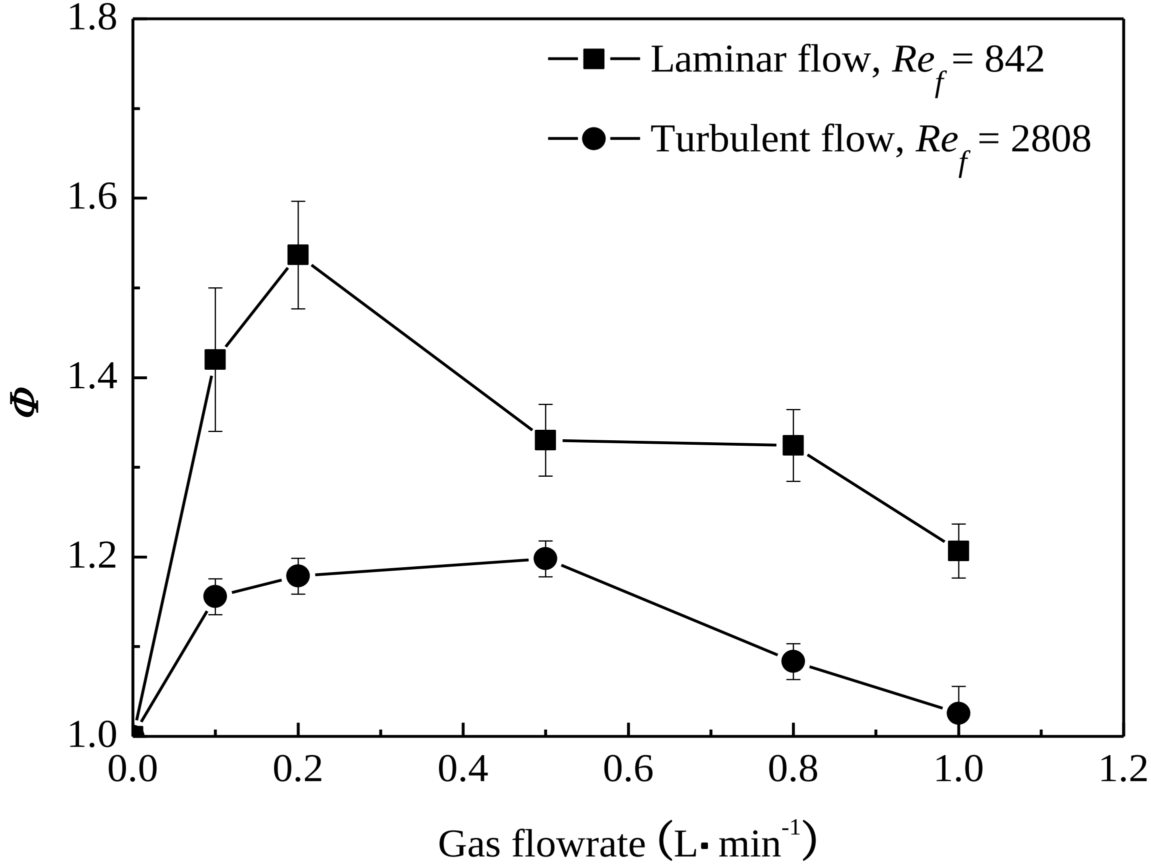

Figure 4. Effect of gas flowrate on Φ in laminar and turbulent flows.
(3.5% NaCl solution as feed; Re_p = 552; T_f = 333 K; T_p = 298 K)

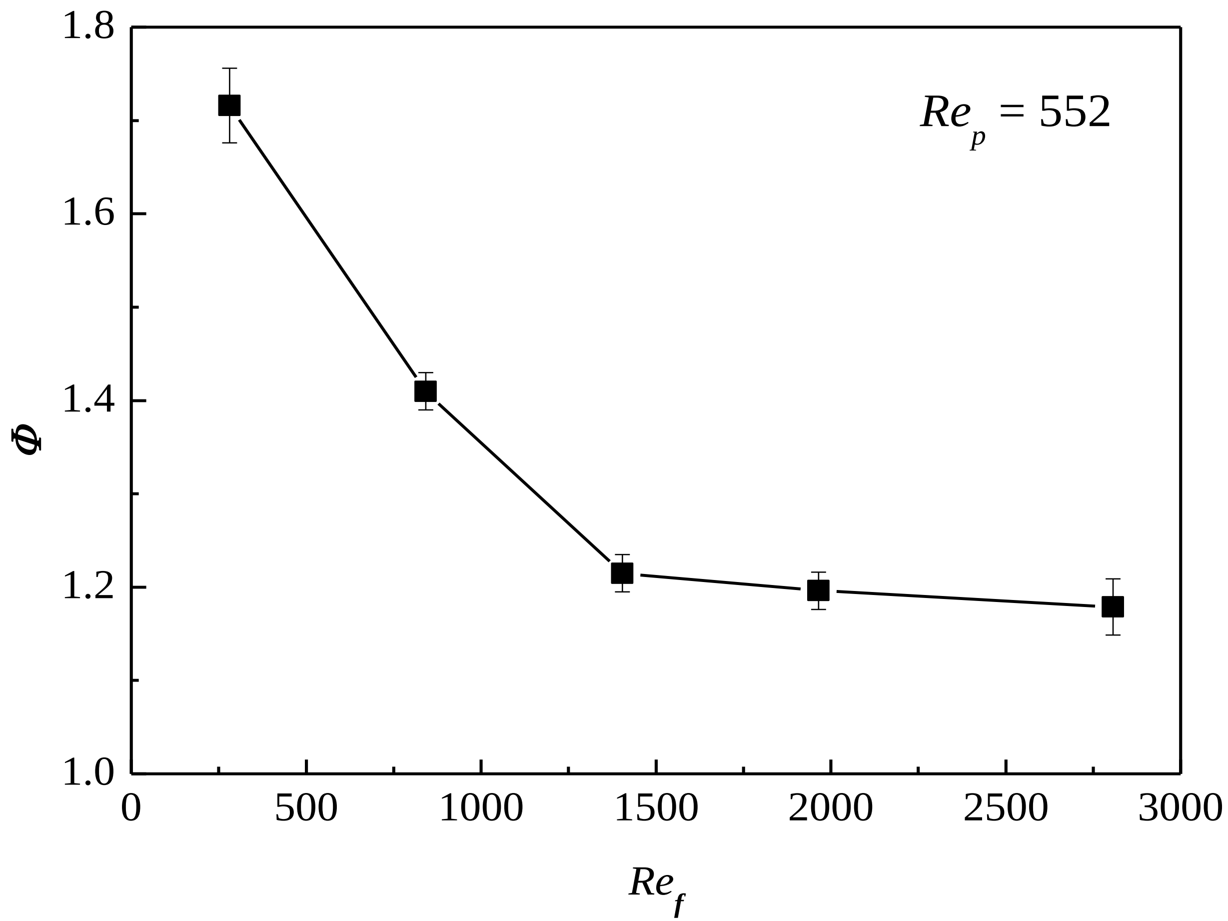

Figure 5. Effect of feed side Reynolds number on Φ.
(3.5% NaCl solution as feed; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K)

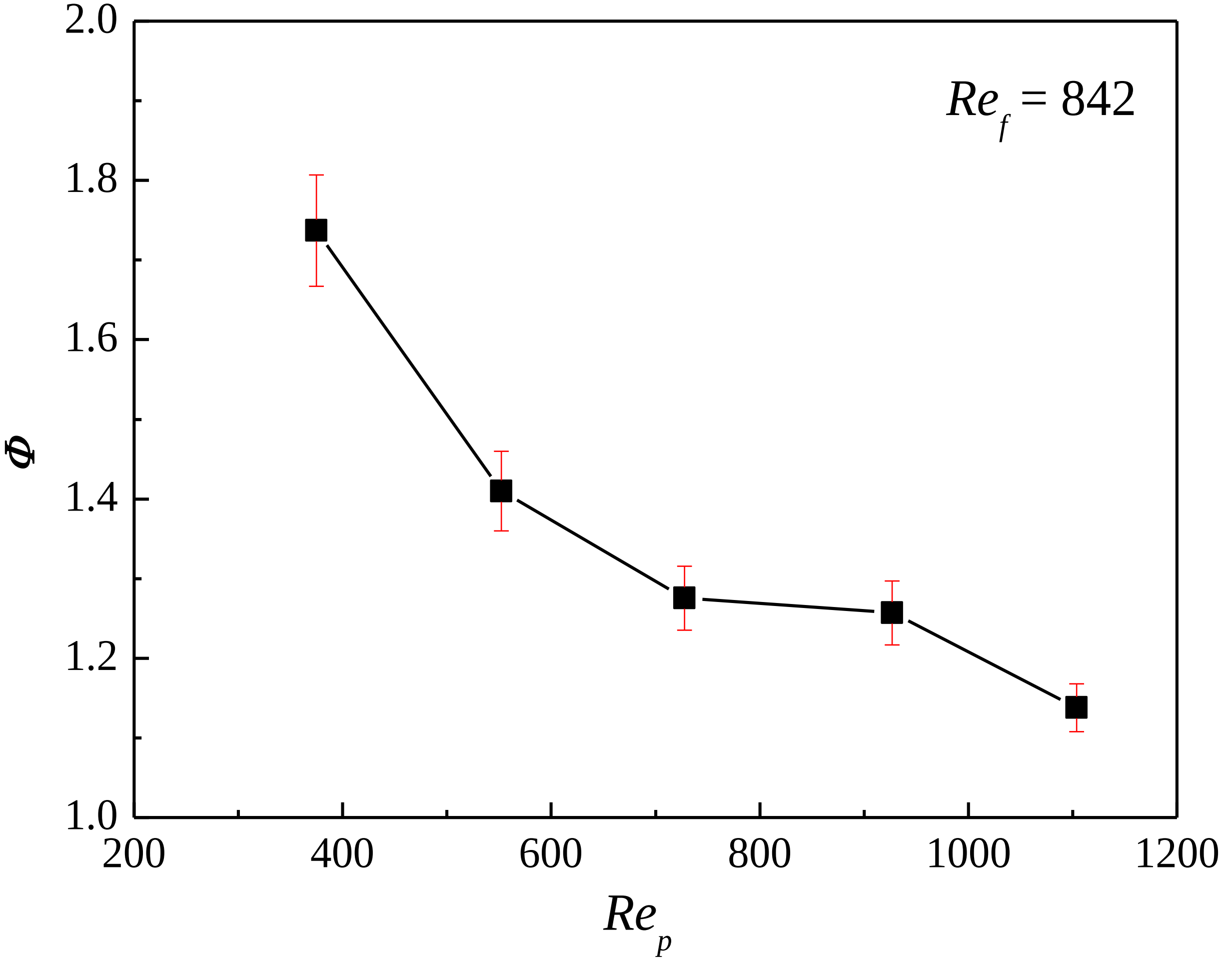

Figure 6. Effect of permeate side Reynolds number on Φ.
(3.5% NaCl solution as feed; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K)

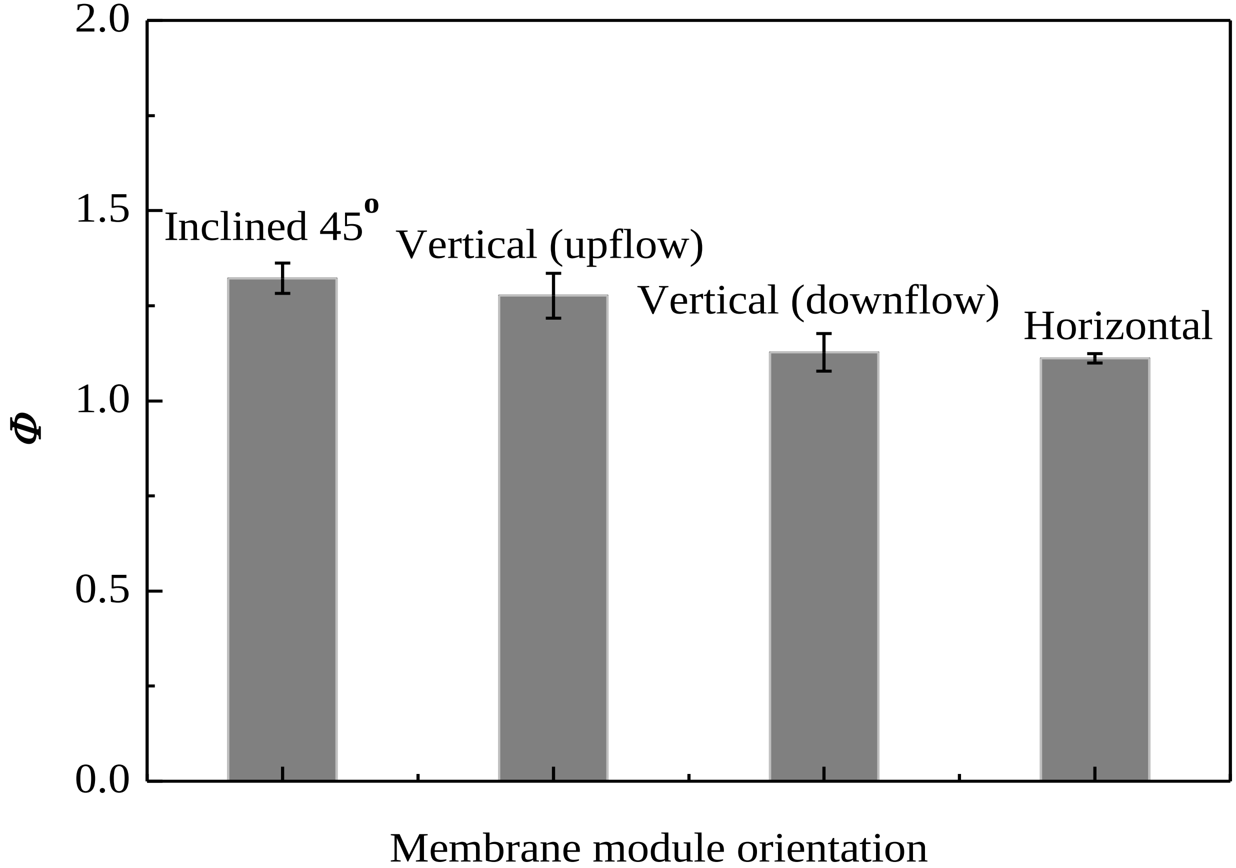

Figure 7. Effect of membrane module orientation on Φ.
(3.5% NaCl solution as feed: Q_f = 0.3 L·min^{-1}; Q_p = 0.025 L·min^{-1}; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K)

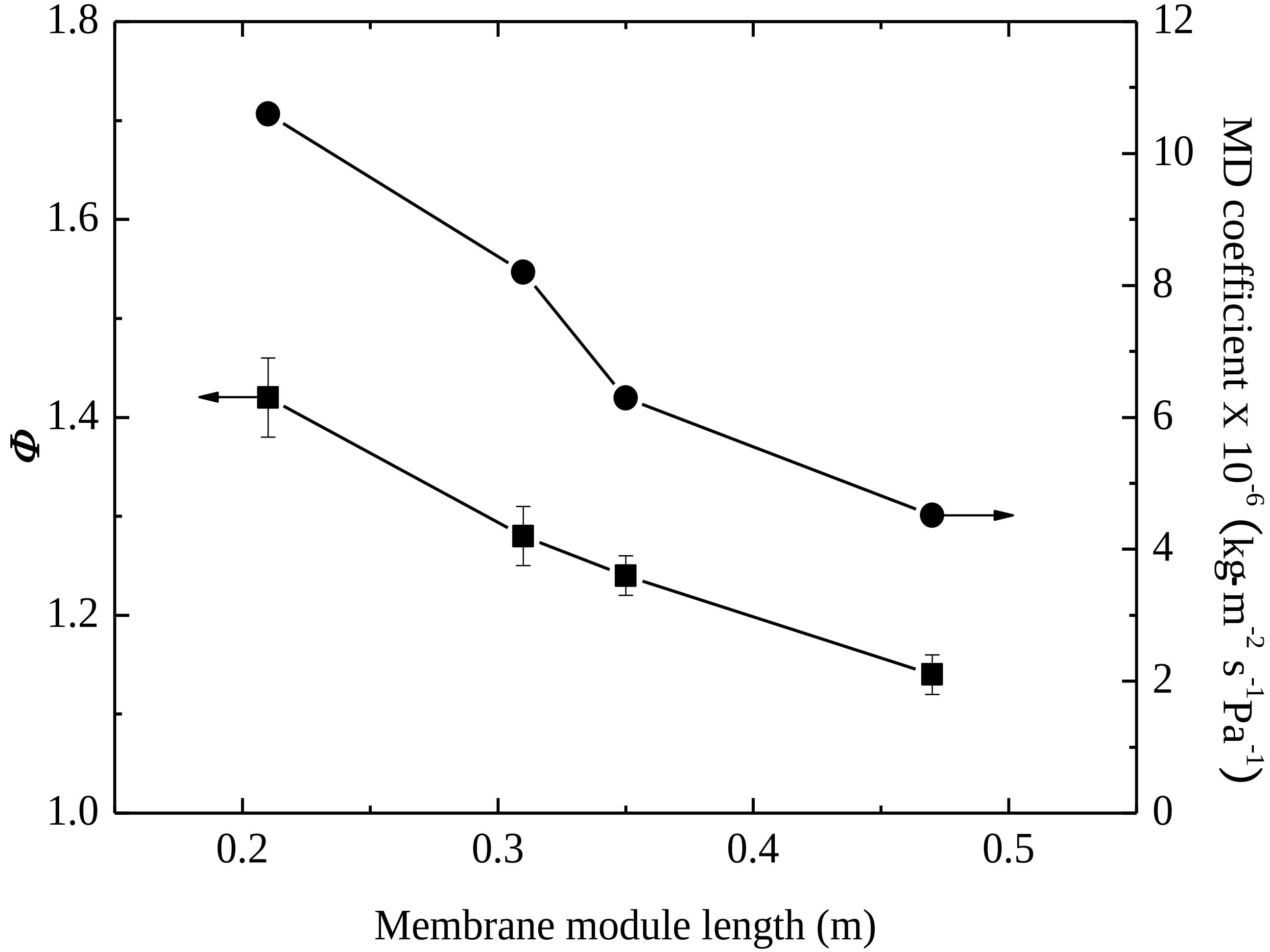

Figure 8. Effect of membrane module length on Φ.
(3.5% NaCl solution as feed: Q_f = 0.3 L·min^{-1}; Q_p = 0.025 L·min^{-1}; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K)

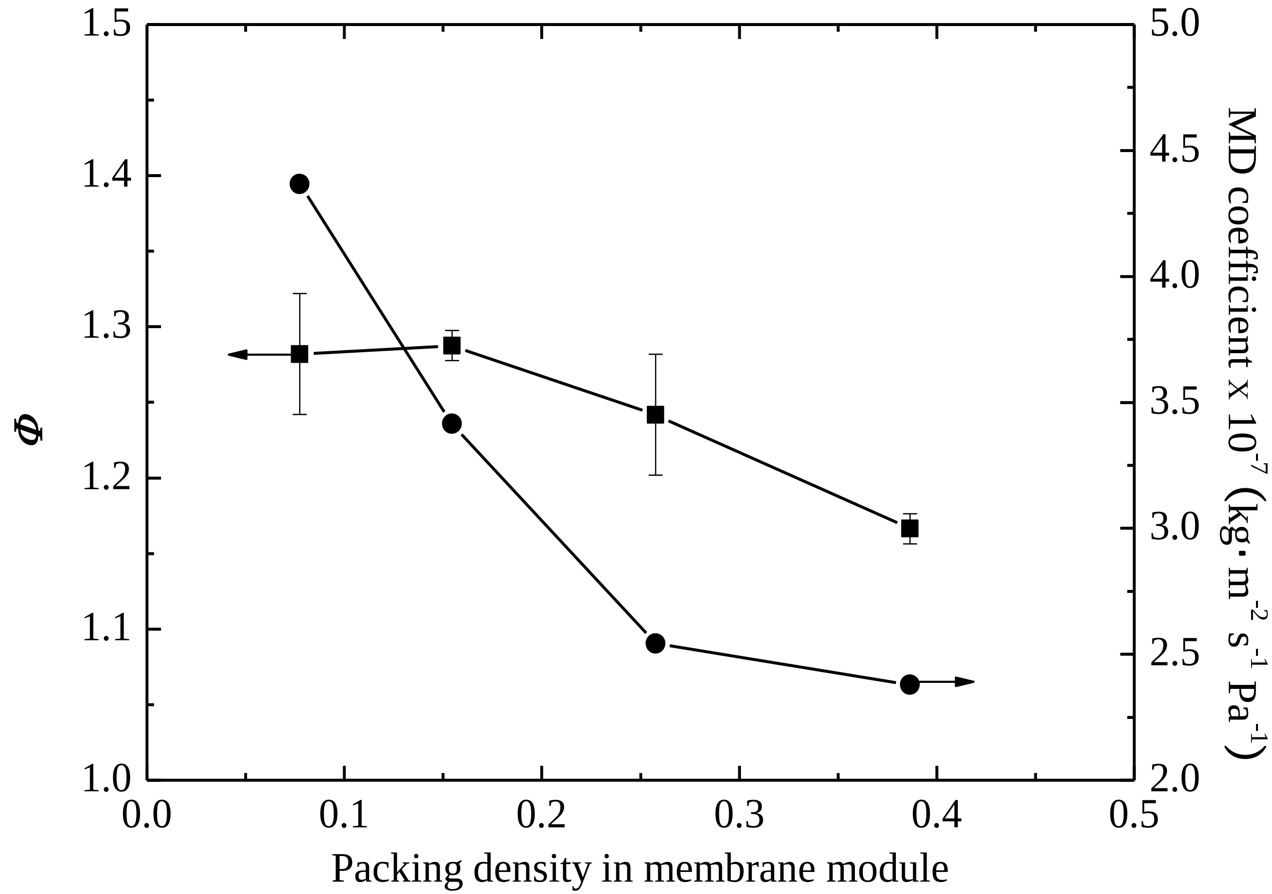

Figure 9. Effect of packing density in membrane module on Φ.
(3.5% NaCl solution as feed: Q_f = 0.3 L·min^{-1}; Q_p = 0.025 L·min^{-1}; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K)

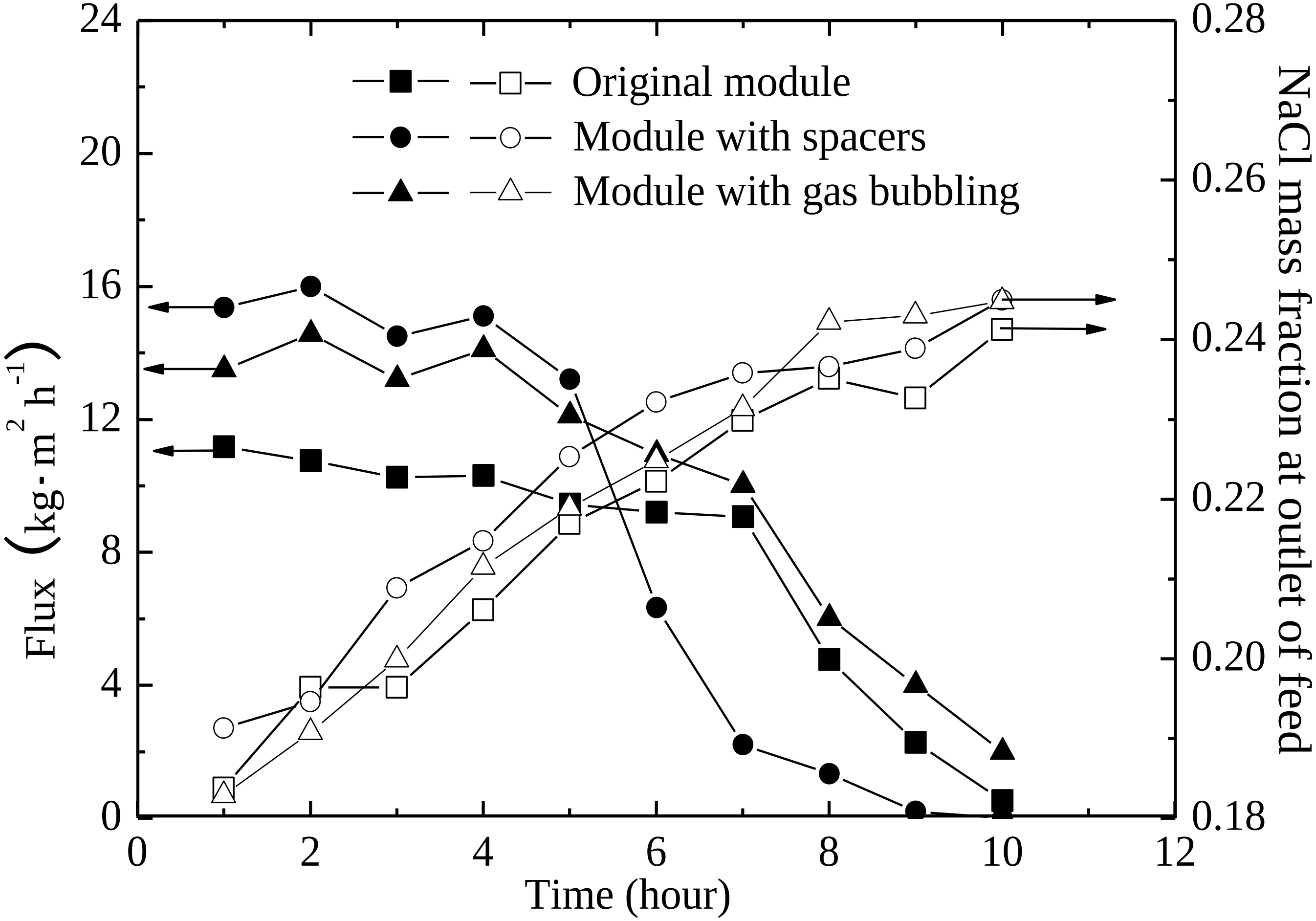

Figure 10. Flux and NaCl mass fraction at outlet of feed side vs time
(Q_f = 0.6 L·min^{-1}; Q_p = 0.15 L·min^{-1}; Q_g = 0.2 L·min^{-1}; T_f = 333 K; T_p = 298 K; initial feed volume: 4000 ml)

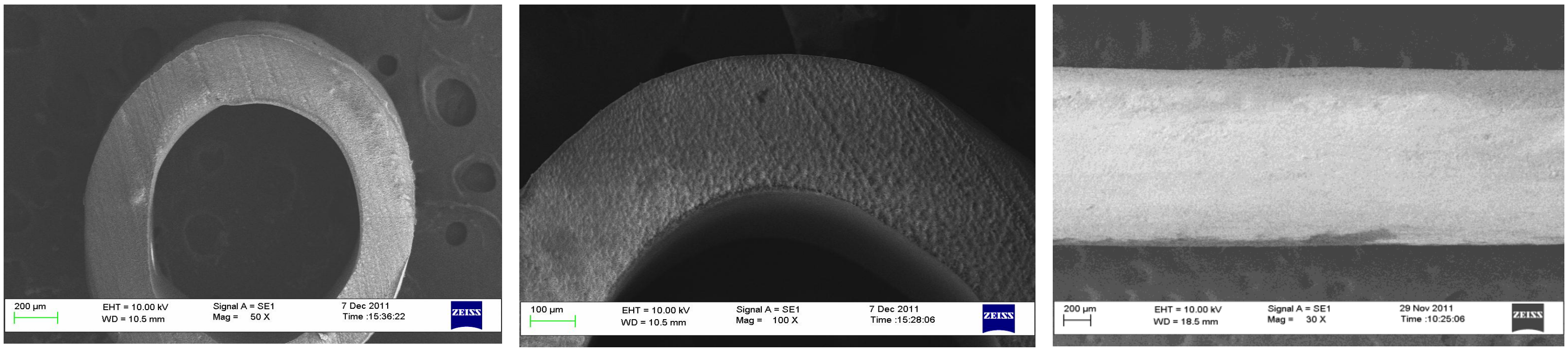

Figure 11(a). SEM images of cross section and membrane surface after 1 hour high concentration DCMD running

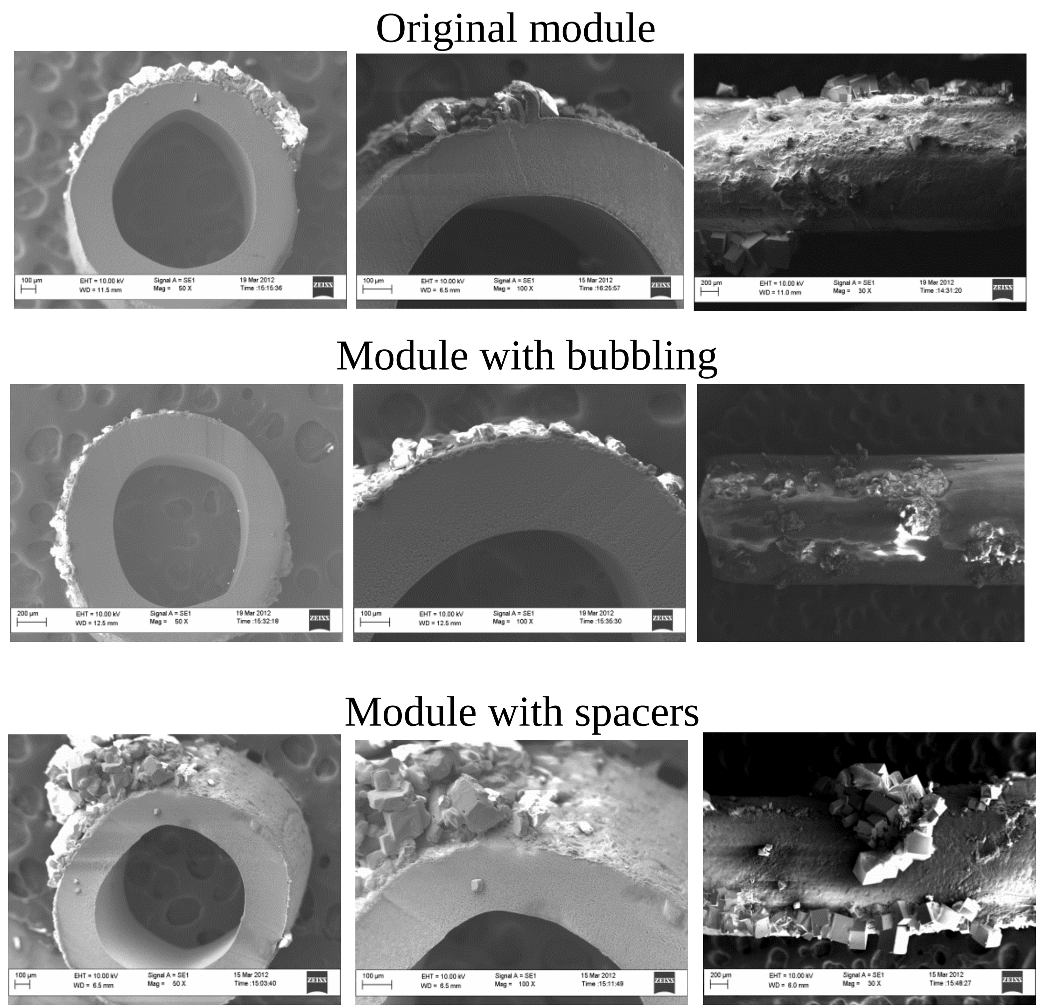

Figure 11(b). SEM images of cross section and membrane surface after 5 hours high concentration DCMD running

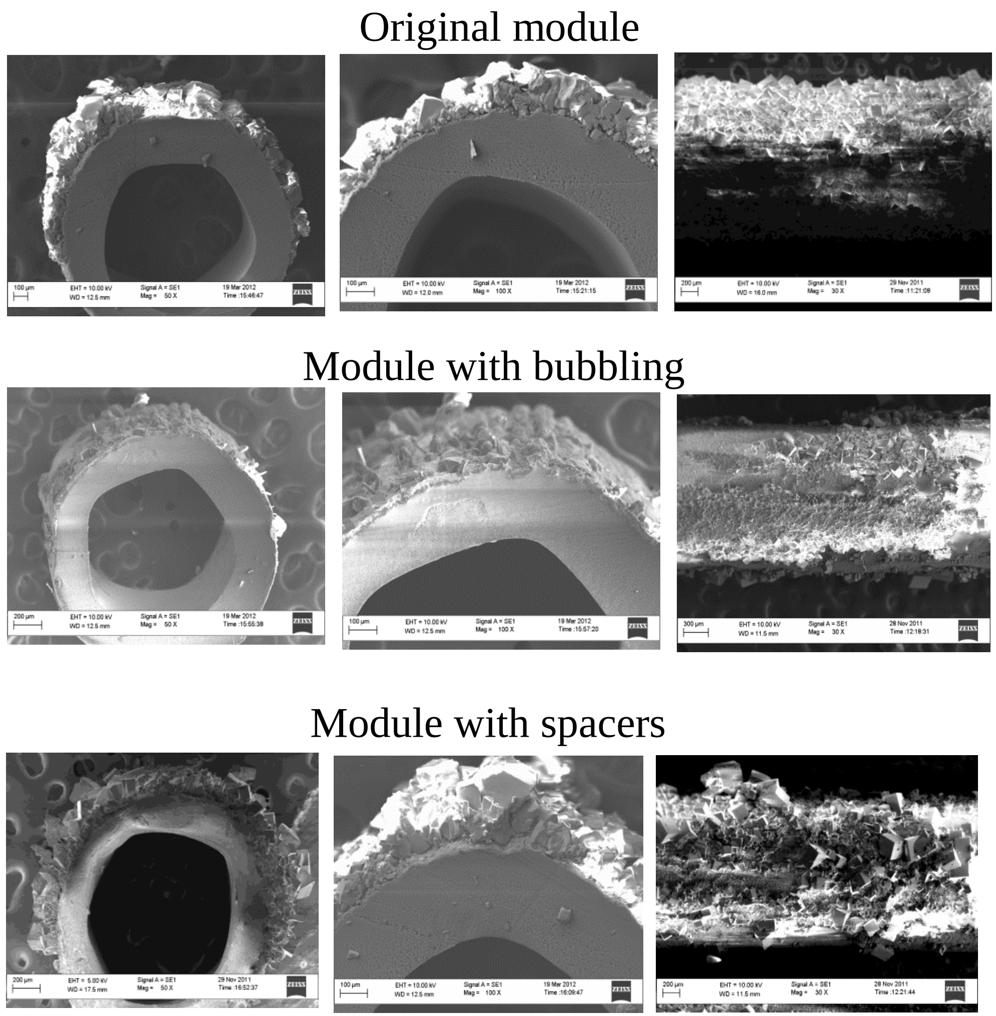

Figure 11(c). SEM images of cross section and membrane surface after 7 hours high concentration DCMD running

Table 1.PVDF membrane properties

Dimension	**Pore size (μm)**	**Contact angle (°)**	**Porosity ε (%)**	**LEPw (bar)**	**Tensile module E_t (MPa)**	**Strain at break δ_b (%)**
d_o: 1.525mm δ_m: 206.8 μm	r_{max}: 0.125 r_{mean}: 0.082	106-120	82-85	3.5	42.05	10.5

Table 2. Membrane module specifications

Experiment type	**Housing diameter, d_s(mm)**	**No. of fibers, n**	**Effective fiber length, L(mm)**	**Packing density, (%)**	**Membrane area, A(m^2)**
Module #1	6	1-6	210-480	8-49	0.001-0.006
Module #2 & #3	9.5	6	340	26	0.0098