

**VICTORIA UNIVERSITY**  
MELBOURNE AUSTRALIA

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

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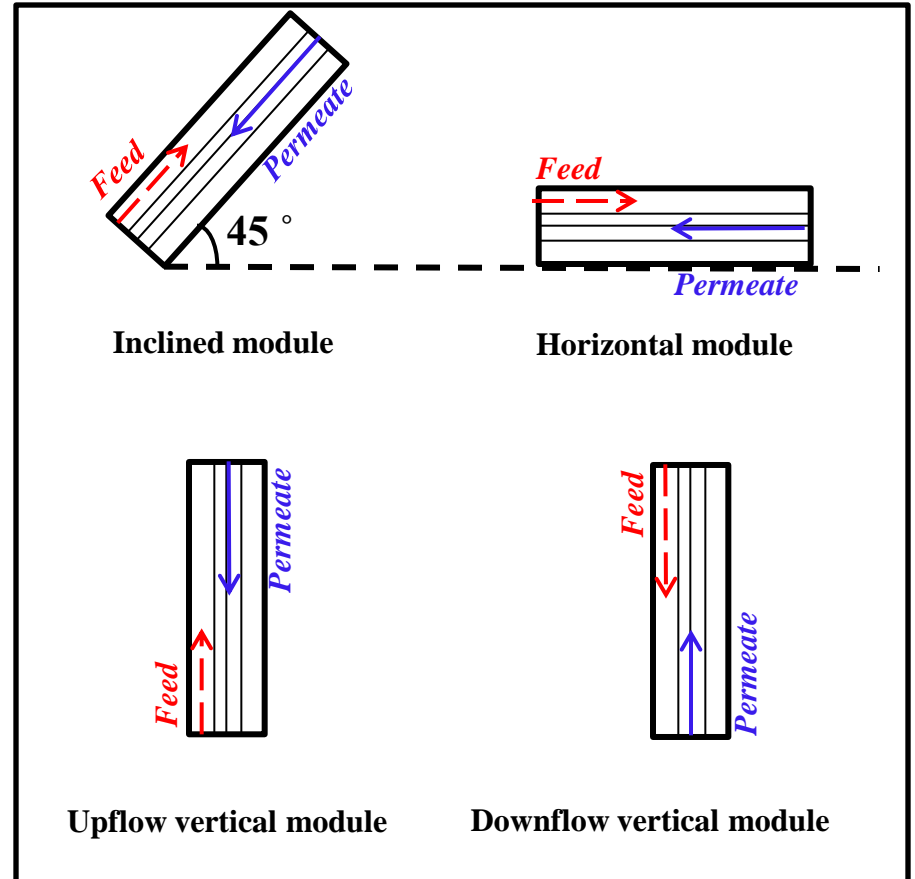
**a****b****c**

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).

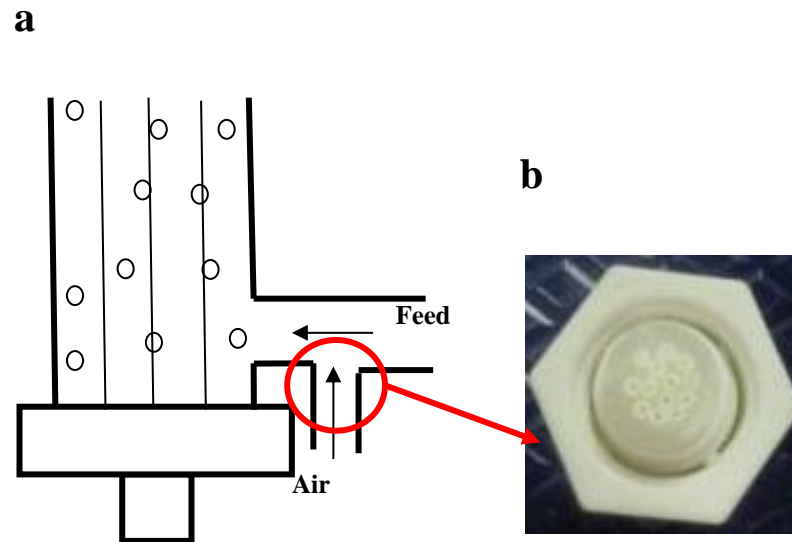


Figure 2. a. Air inlet connected to the membrane module; b. Air nozzle.

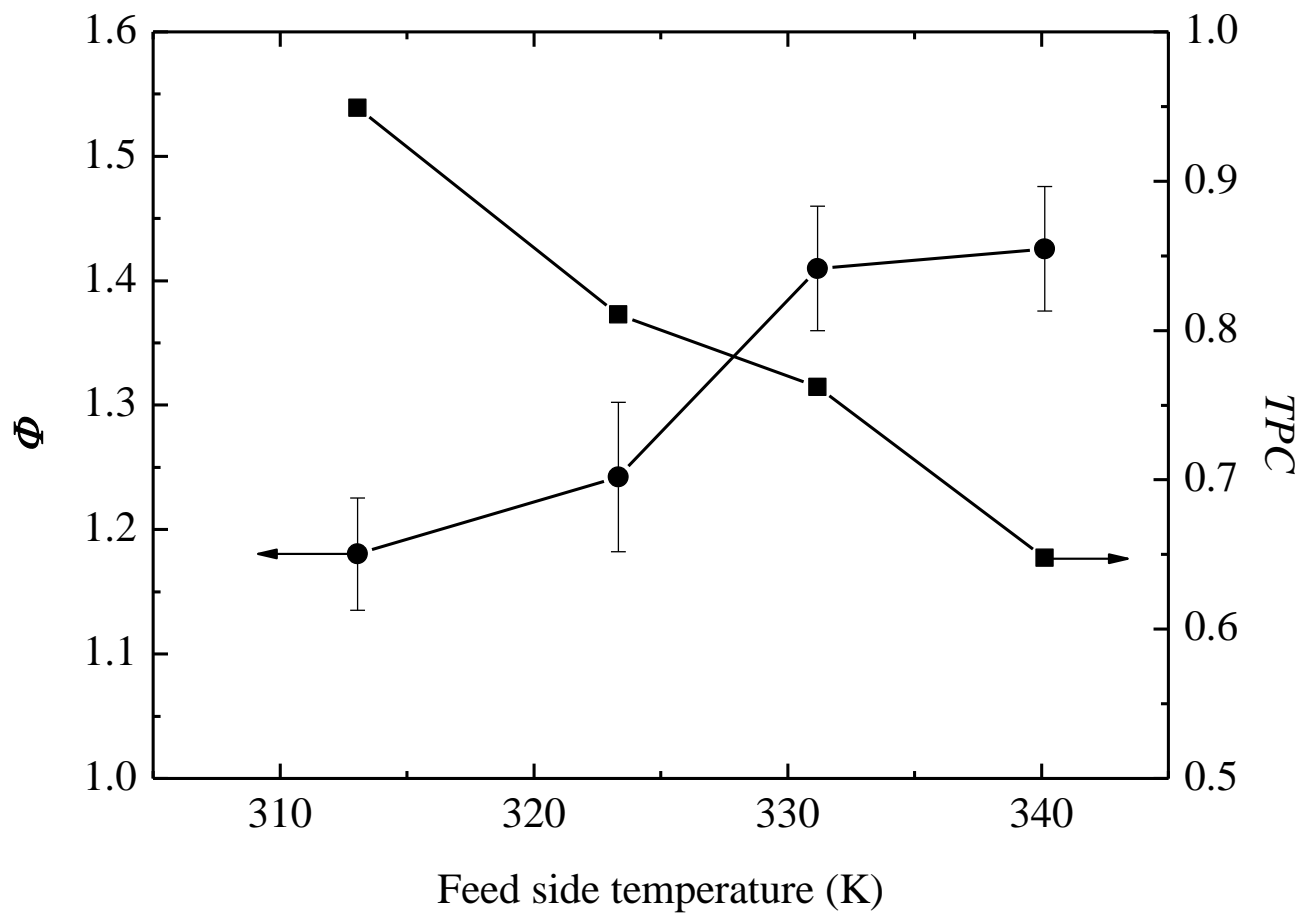


Figure 3. Effect of feed side temperature on  $\Phi$  and  $TPC$ .

(3.5% NaCl solution as feed:  $Q_f = 0.3 \text{ L} \cdot \text{min}^{-1}$ ;  $Q_p = 0.025 \text{ L} \cdot \text{min}^{-1}$   $Q_g = 0.2 \text{ L} \cdot \text{min}^{-1}$ ;  $T_p = 298 \text{ K}$ )

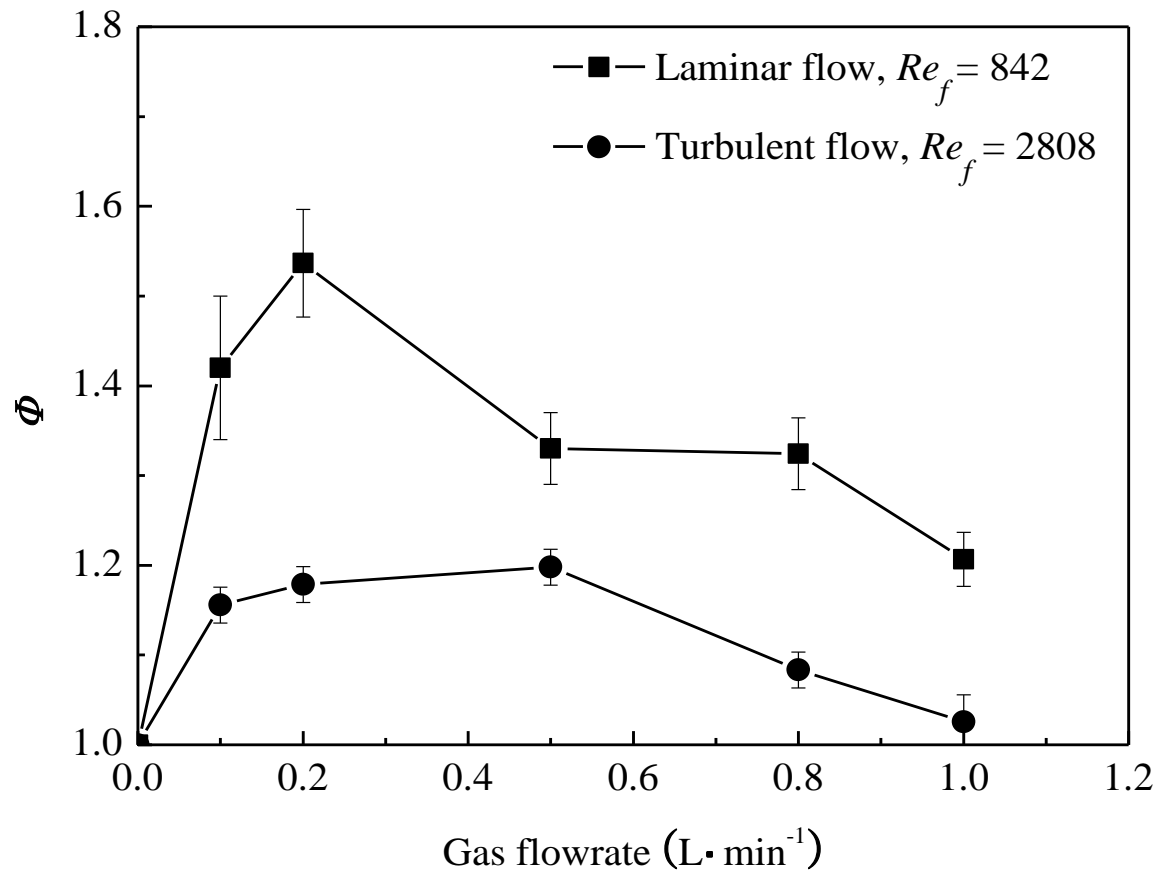


Figure 4. Effect of gas flowrate on  $\Phi$  in laminar and turbulent flows.  
(3.5% NaCl solution as feed;  $Re_p = 552$ ;  $T_f = 333$  K;  $T_p = 298$  K)

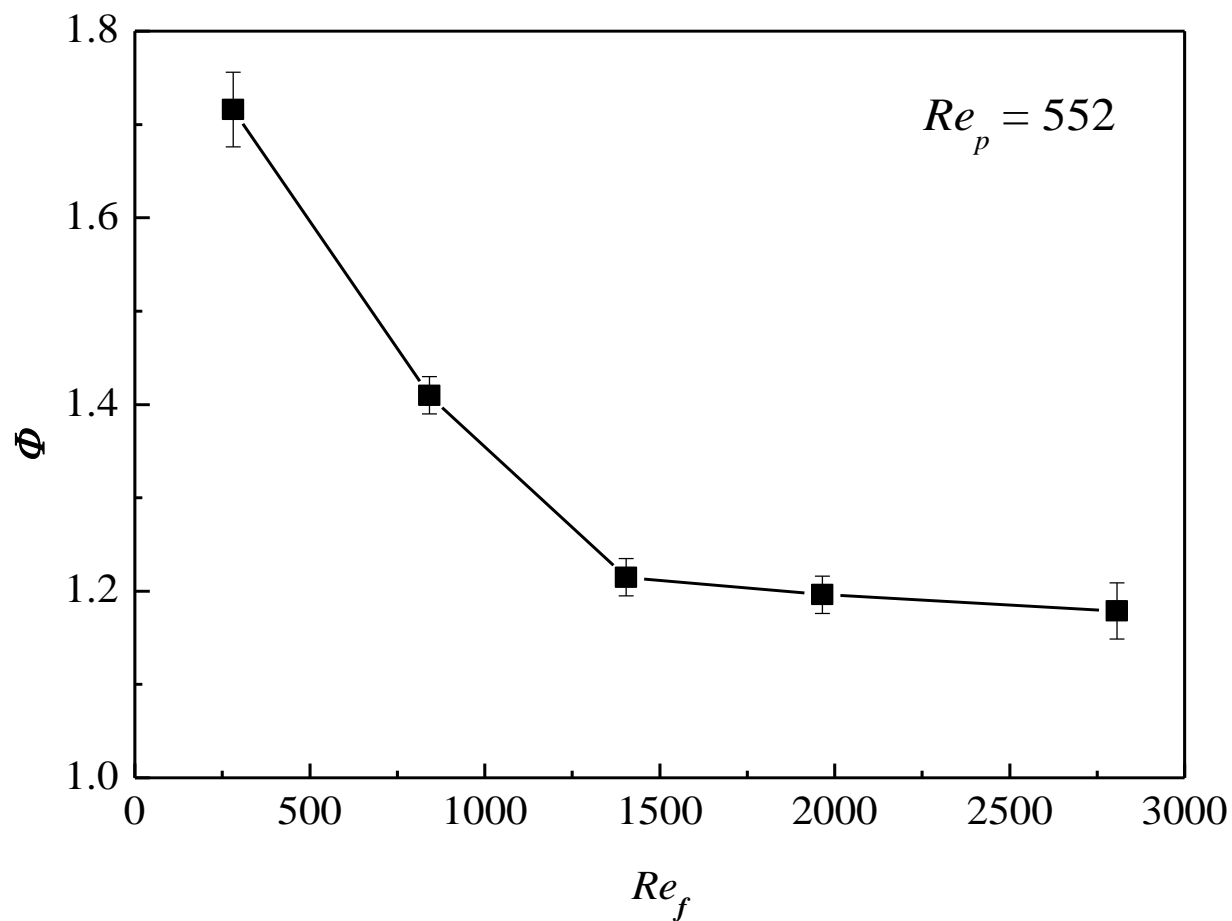


Figure 5. Effect of feed side Reynolds number on  $\Phi$ .  
(3.5% NaCl solution as feed;  $Q_g = 0.2 \text{ L} \cdot \text{min}^{-1}$ ;  $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ )

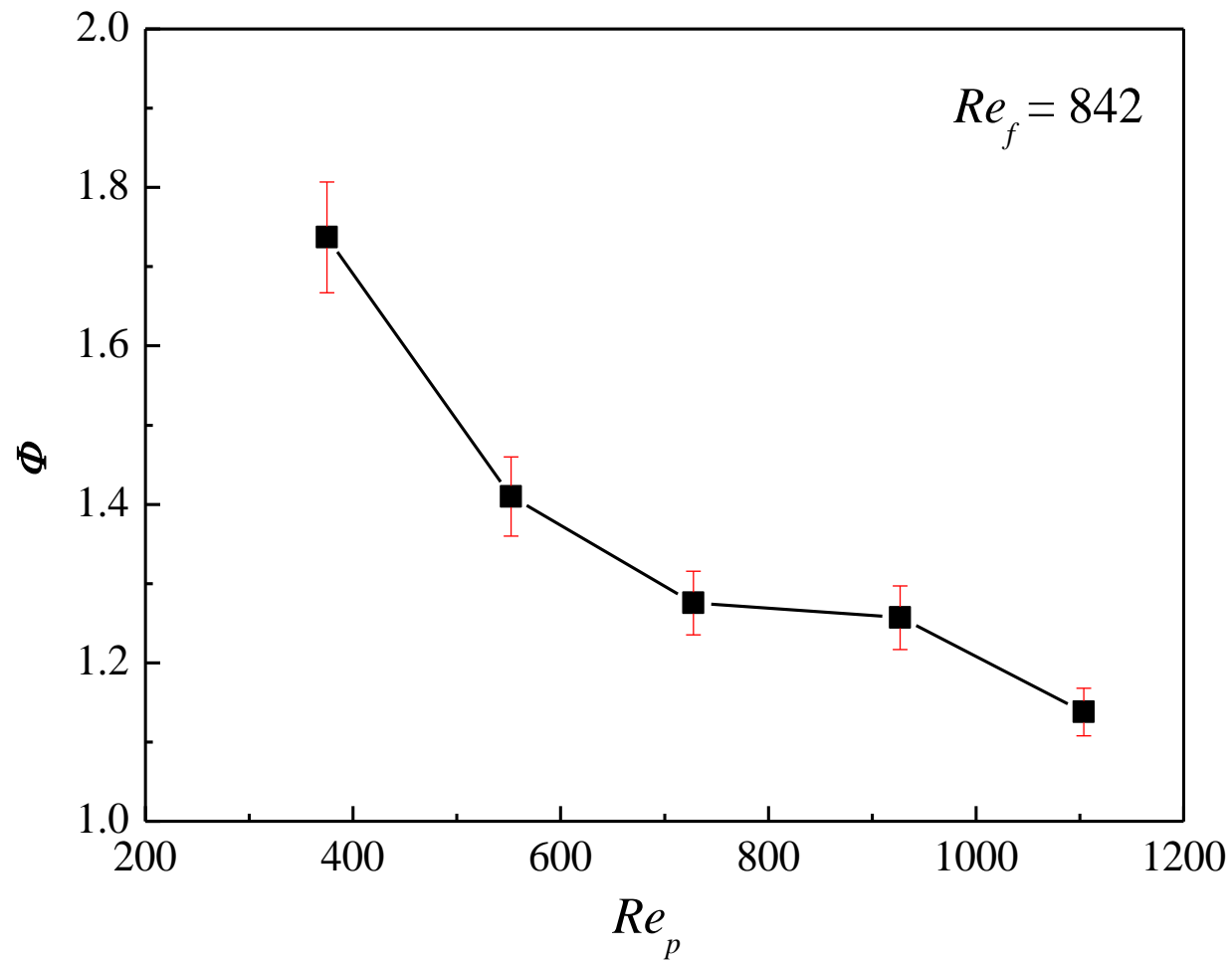


Figure 6. Effect of permeate side Reynolds number on  $\Phi$ .  
(3.5% NaCl solution as feed;  $Q_g = 0.2 \text{ L} \cdot \text{min}^{-1}$ ;  $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ )

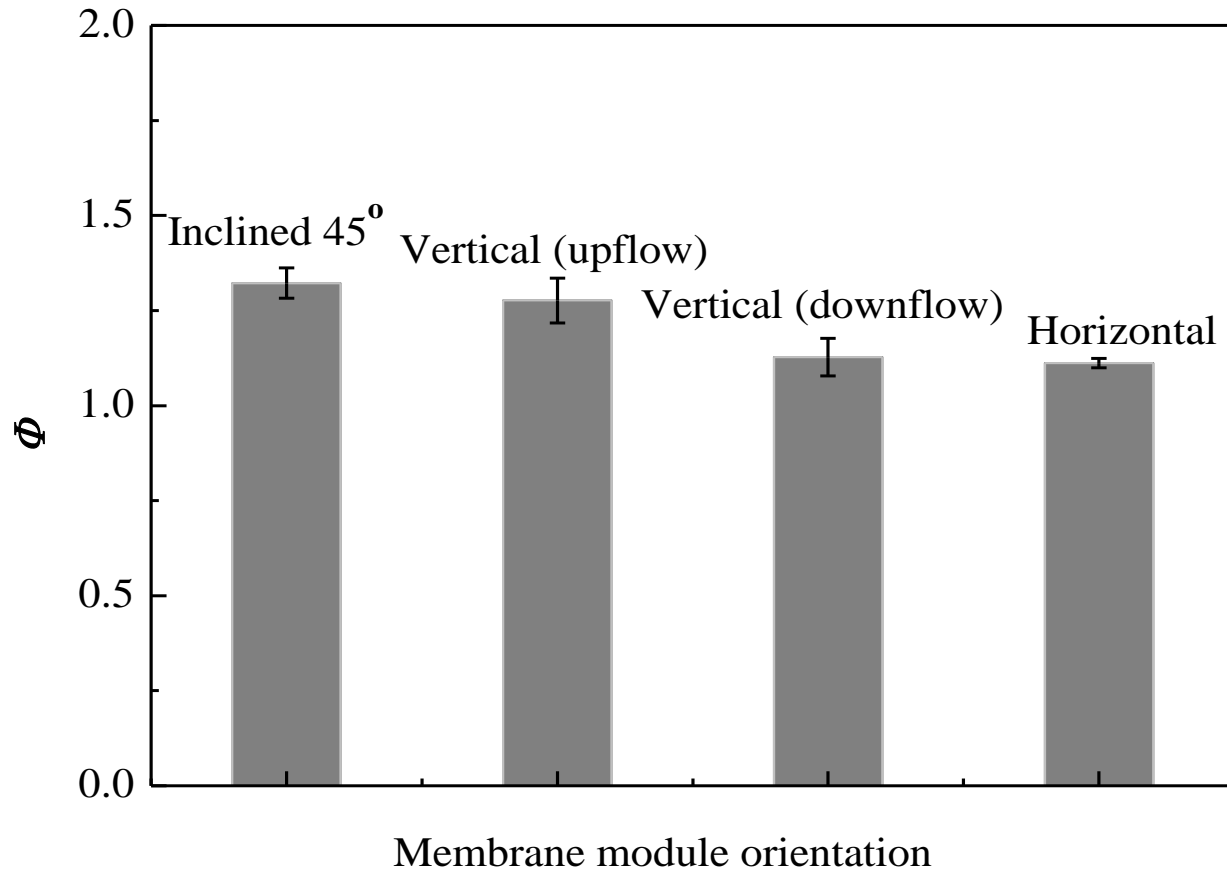


Figure 7. Effect of membrane module orientation on  $\Phi$ .  
 (3.5% NaCl solution as feed:  $Q_f = 0.3 \text{ L} \cdot \text{min}^{-1}$ ;  $Q_p = 0.025 \text{ L} \cdot \text{min}^{-1}$ ;  $Q_g = 0.2 \text{ L} \cdot \text{min}^{-1}$ ;  
 $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ )

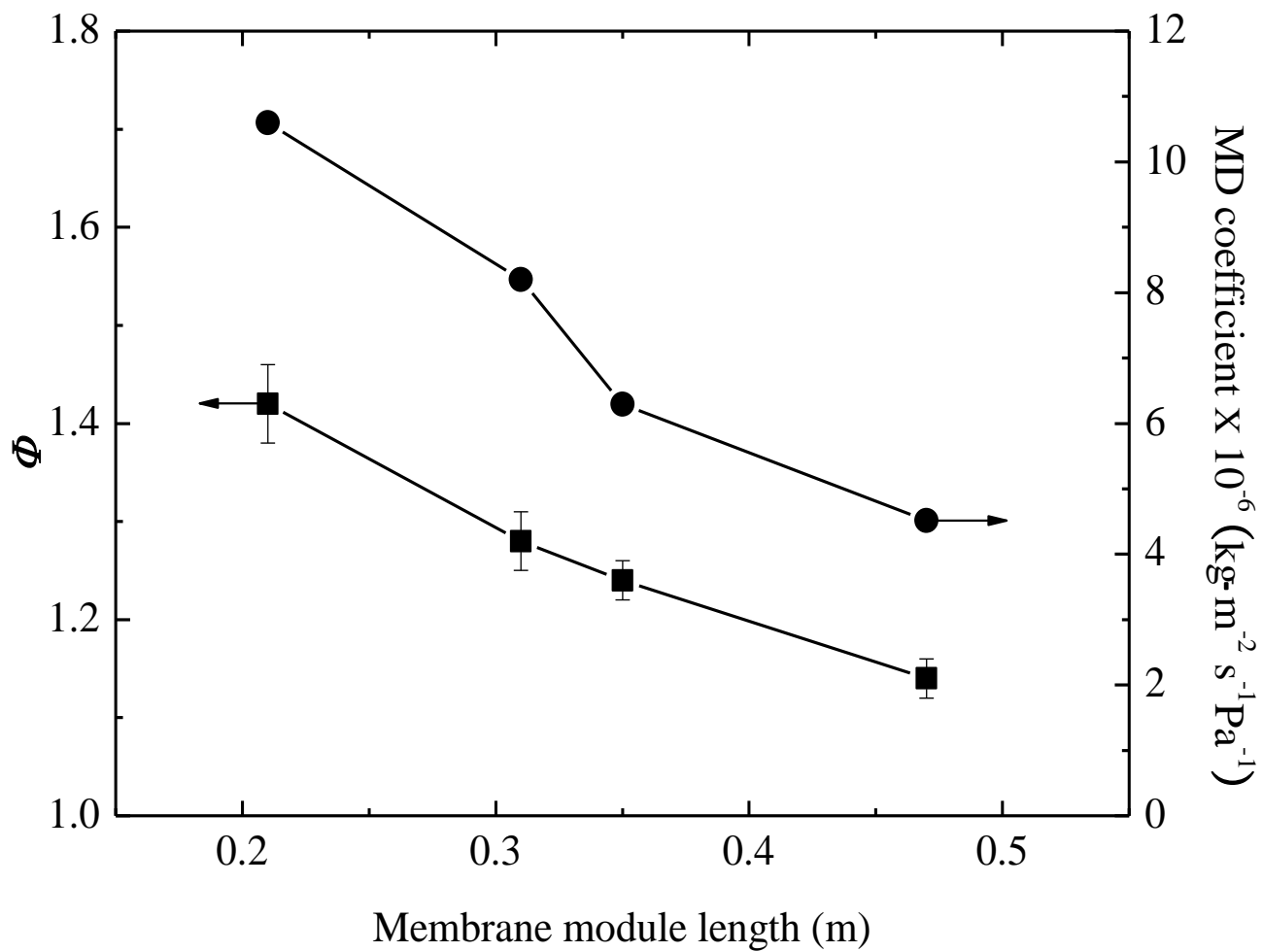


Figure 8. Effect of membrane module length on  $\Phi$ .  
 (3.5% NaCl solution as feed:  $Q_f = 0.3 \text{ L}\cdot\text{min}^{-1}$ ;  $Q_p = 0.025 \text{ L}\cdot\text{min}^{-1}$ ;  $Q_g = 0.2 \text{ L}\cdot\text{min}^{-1}$ ;  
 $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ )

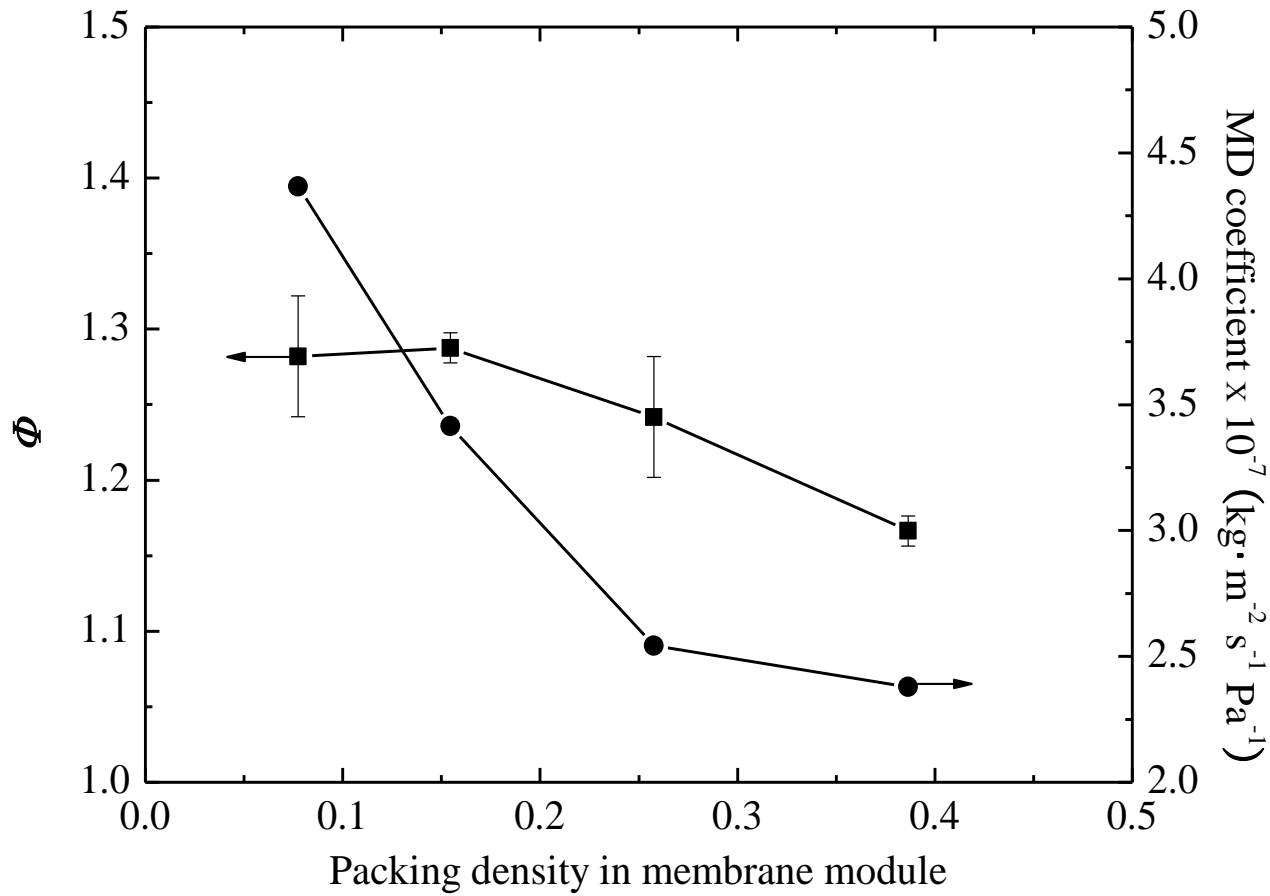


Figure 9. Effect of packing density in membrane module on  $\Phi$ .  
 (3.5% NaCl solution as feed:  $Q_f = 0.3 \text{ L}\cdot\text{min}^{-1}$ ;  $Q_p = 0.025 \text{ L}\cdot\text{min}^{-1}$ ;  $Q_g = 0.2 \text{ L}\cdot\text{min}^{-1}$ ;  
 $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ )

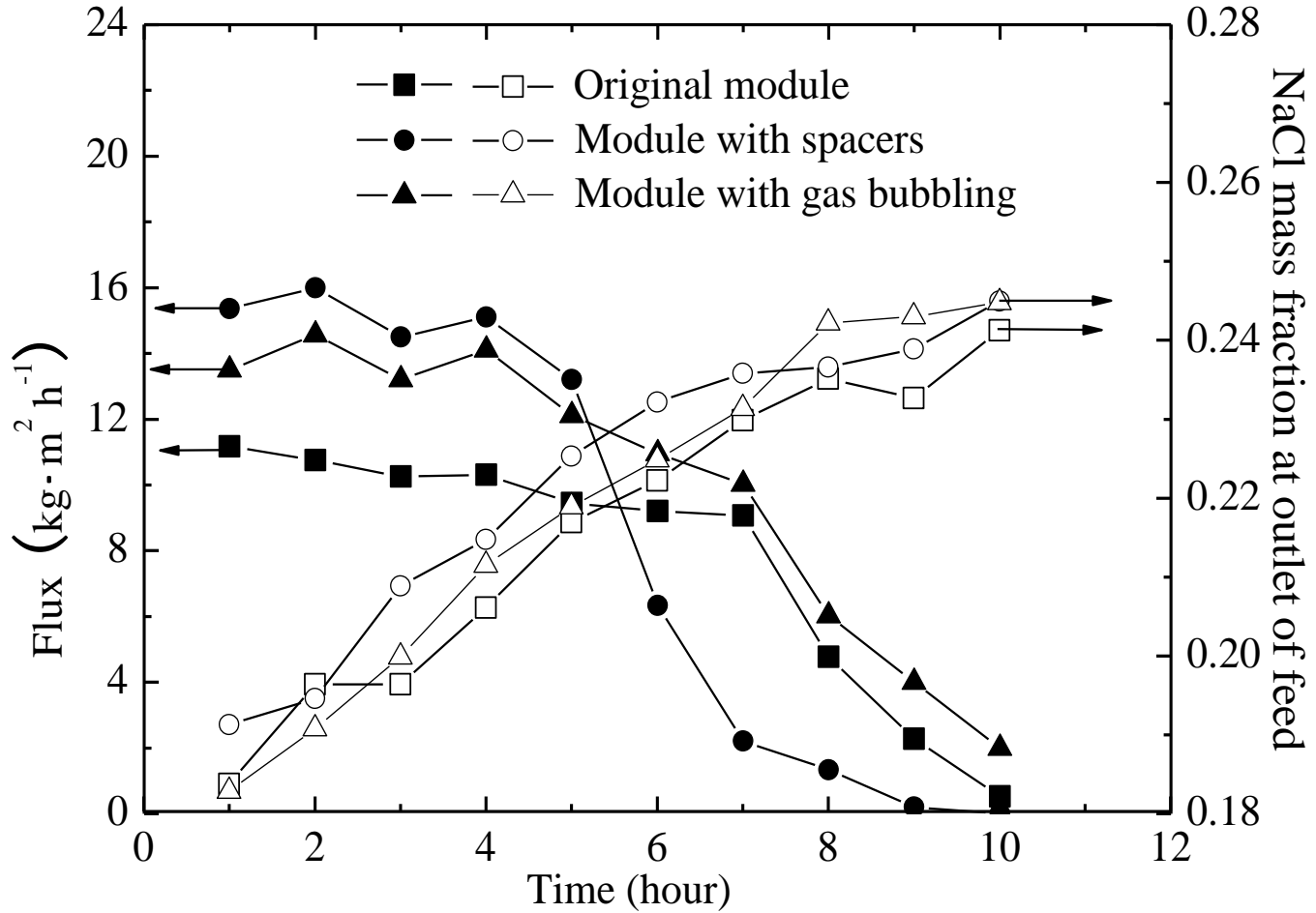


Figure 10. Flux and NaCl mass fraction at outlet of feed side vs time  
( $Q_f = 0.6 \text{ L} \cdot \text{min}^{-1}$ ;  $Q_p = 0.15 \text{ L} \cdot \text{min}^{-1}$ ;  $Q_g = 0.2 \text{ L} \cdot \text{min}^{-1}$ ;  $T_f = 333 \text{ K}$ ;  $T_p = 298 \text{ K}$ ;  
initial feed volume: 4000 ml)

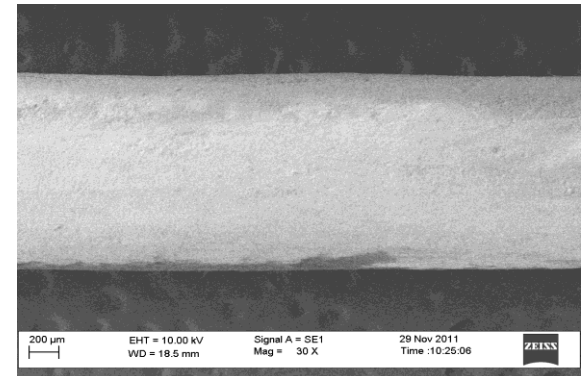
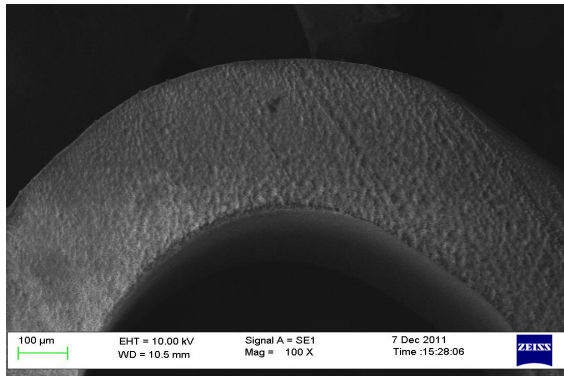
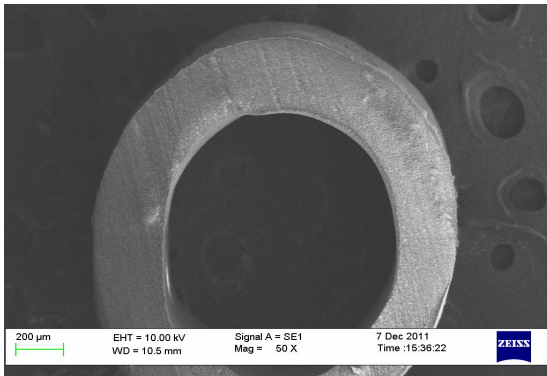
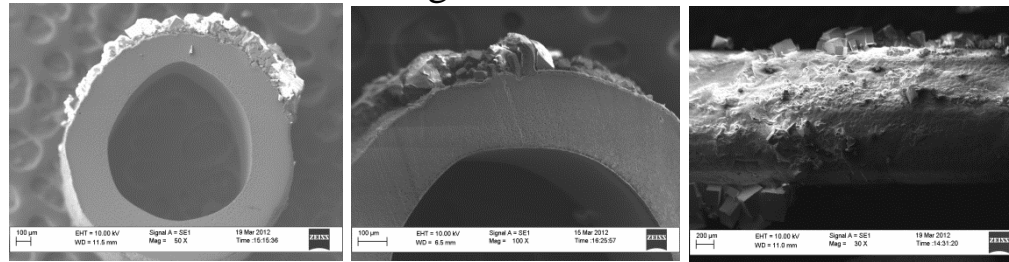
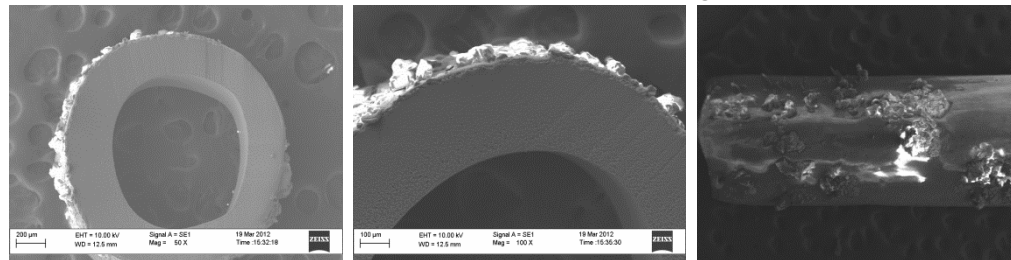


Figure 11(a). SEM images of cross section and membrane surface after 1 hour high concentration DCMD running

### Original module



### Module with bubbling



### Module with spacers

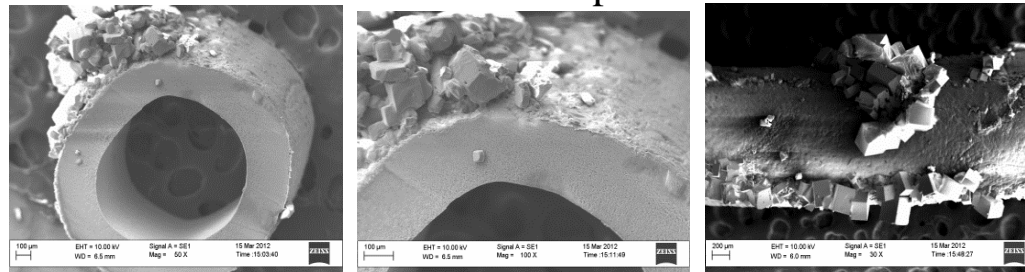
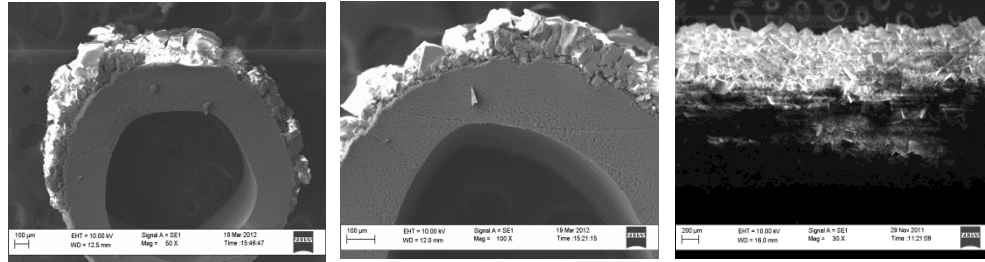
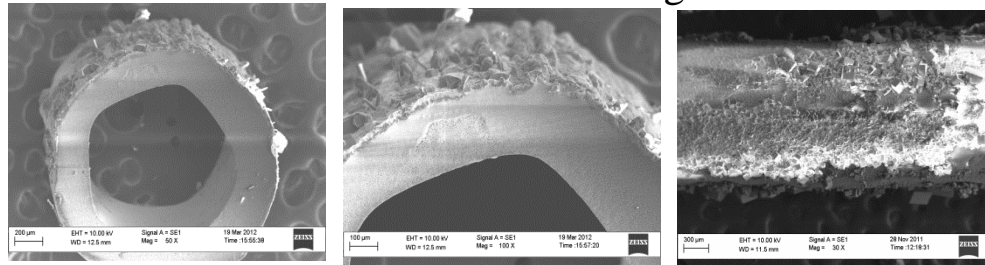


Figure 11(b). SEM images of cross section and membrane surface after 5 hours high concentration DCMD running

### Original module



### Module with bubbling



### Module with spacers

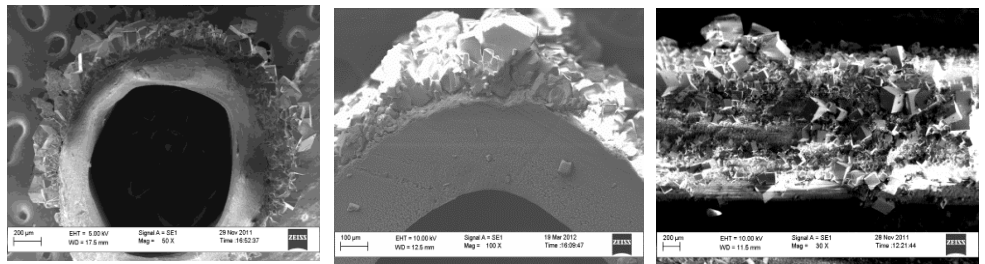


Figure 11(c). SEM images of cross section and membrane surface after 7 hours high concentration DCMD running

Table 1.PVDF membrane properties

Dimension	Pore size ( $\mu\text{m}$ )	Contact angle ( $^{\circ}$ )	Porosity $\varepsilon$ (%)	LEPw (bar)	Tensile module $E_t$ (MPa)	Strain at break $\delta_b$ (%)
$d_o$ : 1.525mm	$r_{max}$ : 0.125	106-120	82-85	3.5	42.05	10.5
$\delta_m$ : 206.8 $\mu\text{m}$	$r_{mean}$ : 0.082					

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 <sup>2</sup> )
Module #1	6	1-6	210-480	8-49	0.001-0.006
Module #2 & #3	9.5	6	340	26	0.0098