Performance improvement of PVDF hollow fiber-based membrane distillation process

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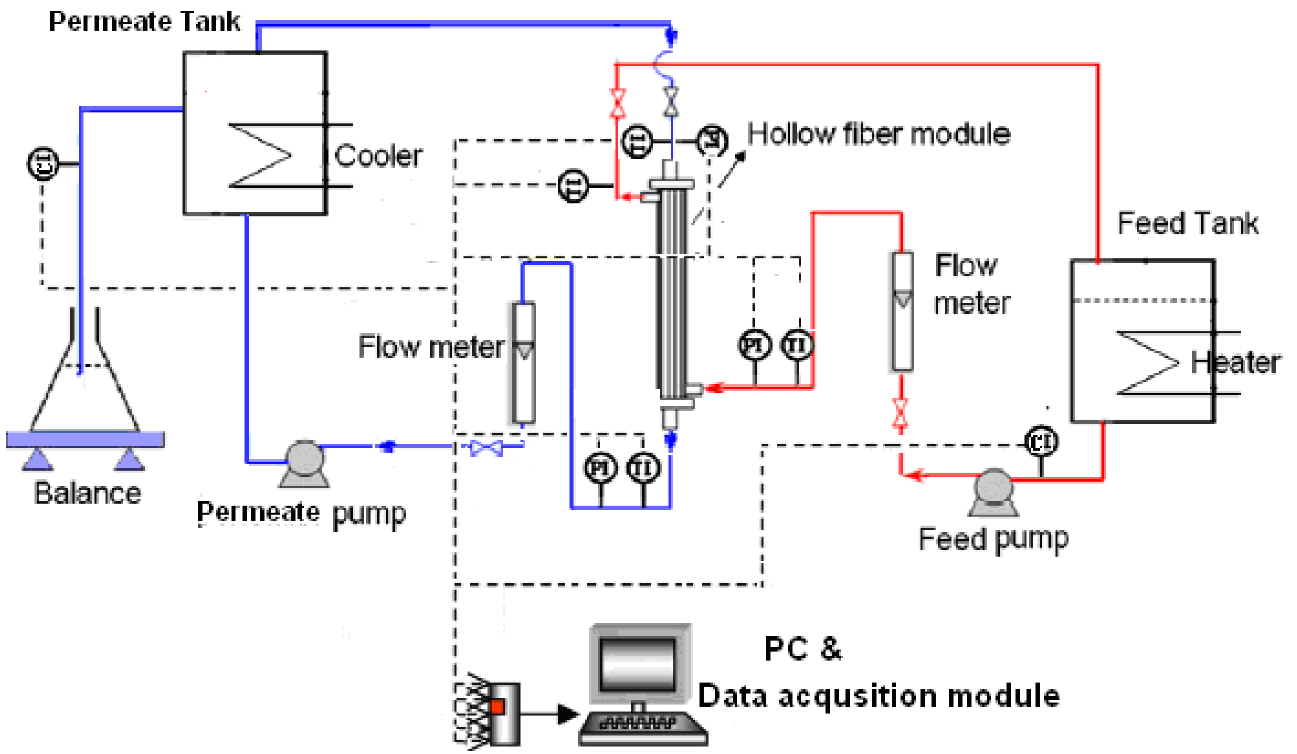
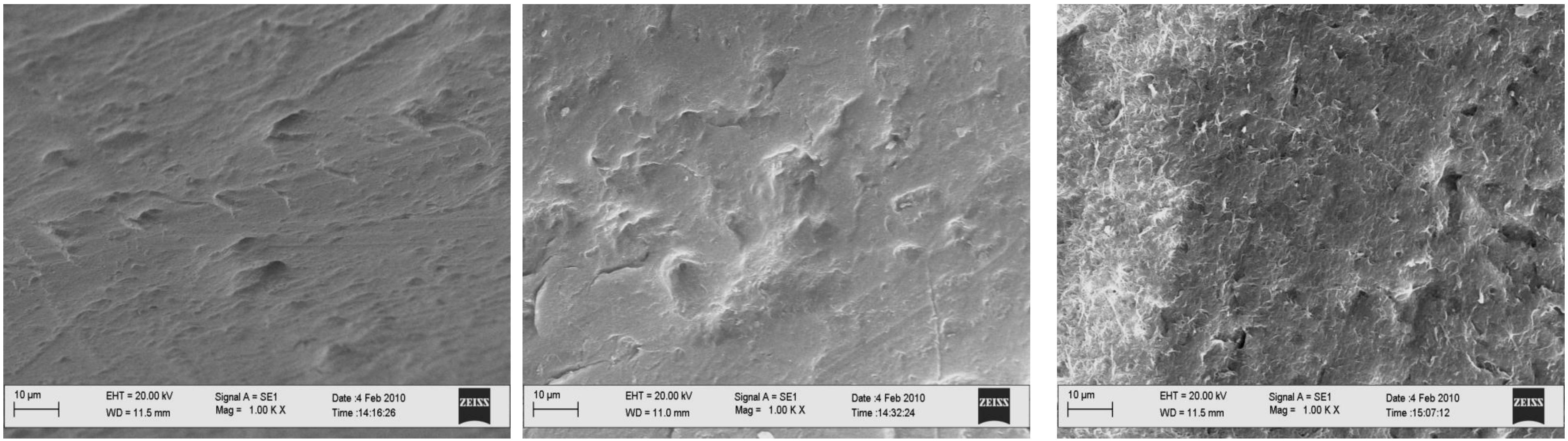
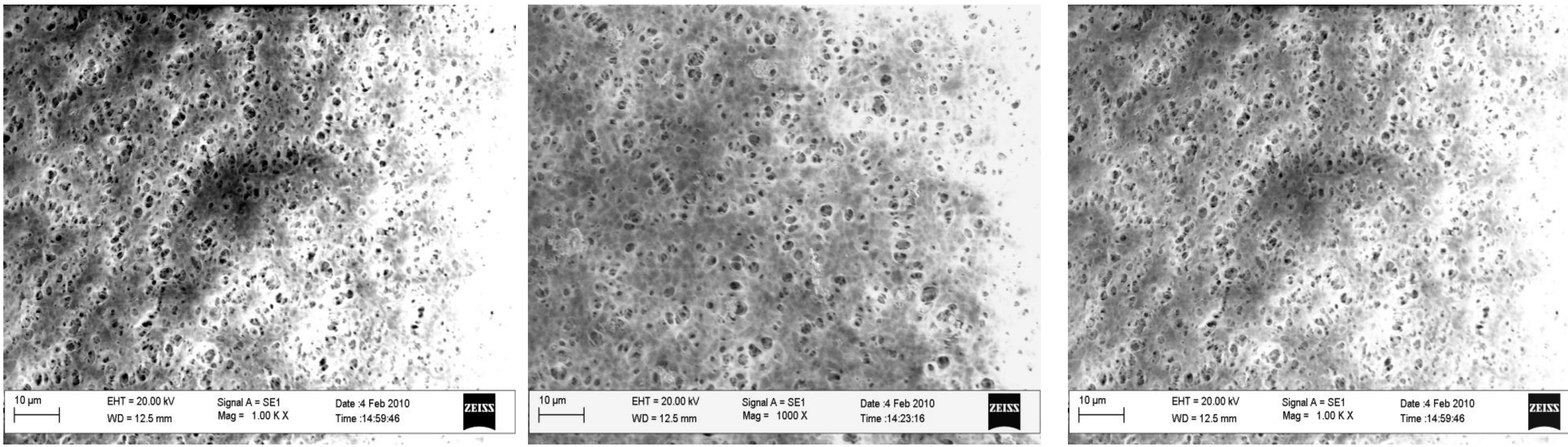


Fig. 1. DCMD experimental set-up



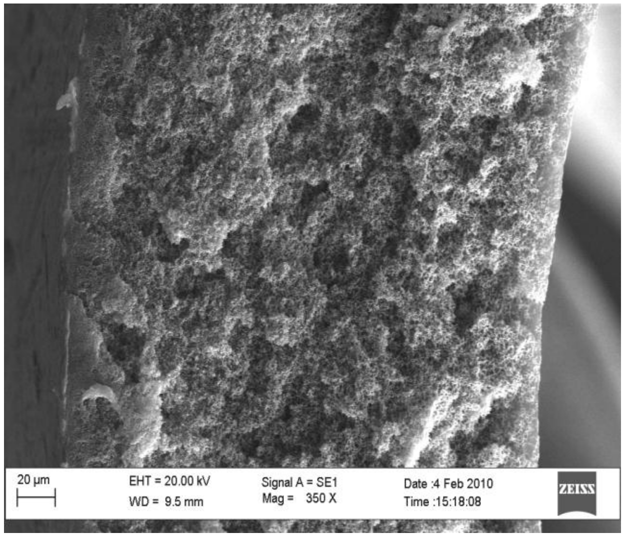
Original PVDF Plasma modified Chemically modified

(a) Outer surface 1000x

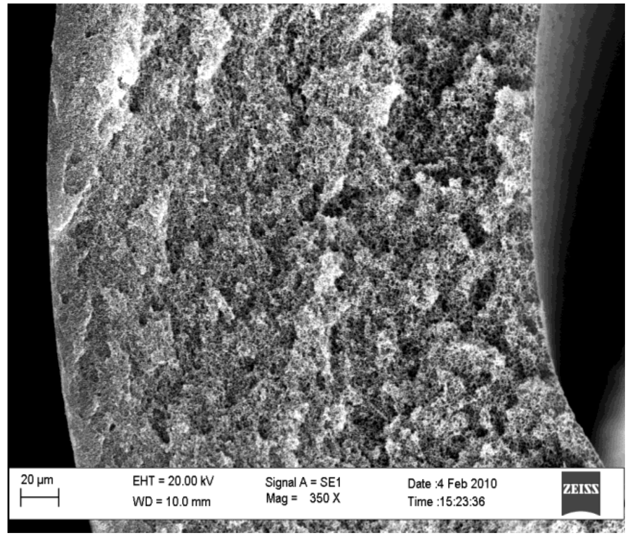


Original PVDF Plasma modified Chemically modified

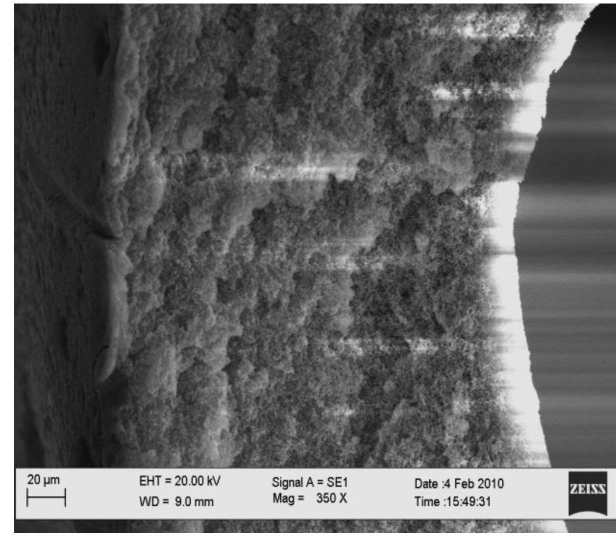
(b) Inner surface 1000x



Original PVDF



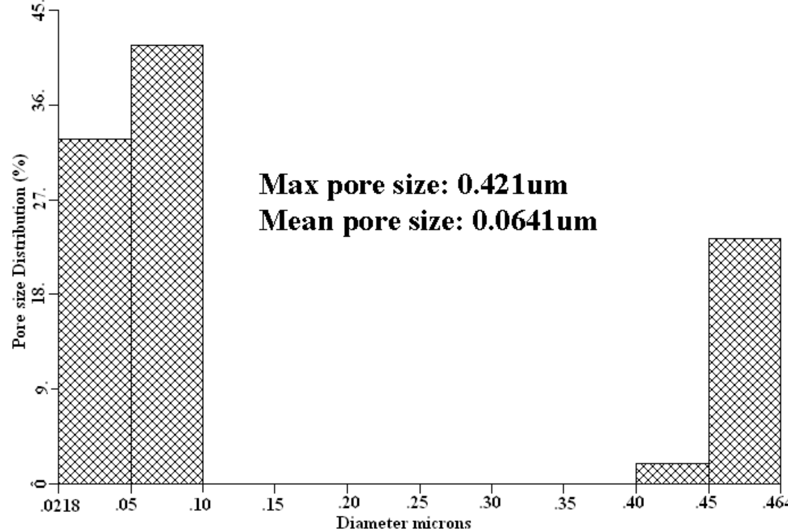
Plasma modified



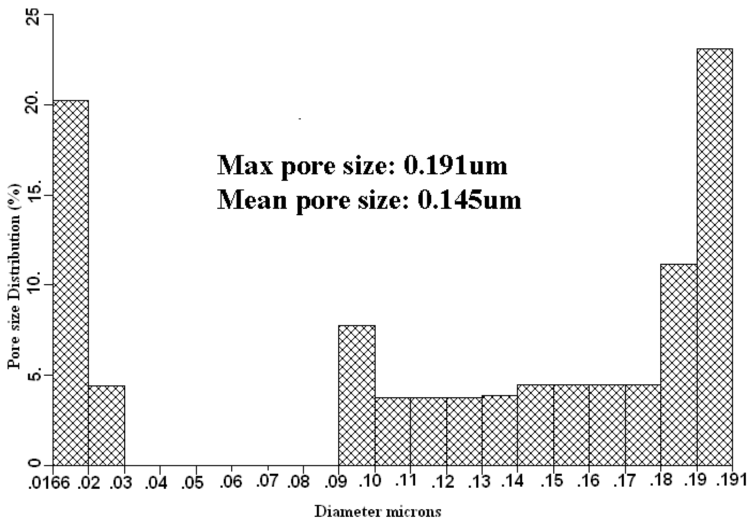
Chemically modified

(c) Cross-section 350x

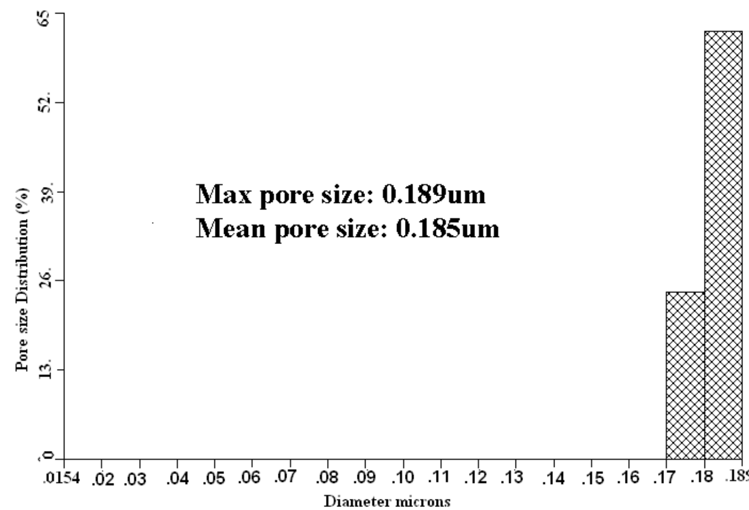
Fig. 2. SEM pictures of the original and modified PVDF membranes:
(a) Outer surface; (b) Inner surface; (c) Cross-section



(a) Original PVDF



(b) Plasma modified



(c) Chemically modified

Fig. 3. Pore size/pore size distribution of the original and modified membranes: (a) Original PVDF membrane; (b) Plasma modified membrane; (c) Chemically modified membrane

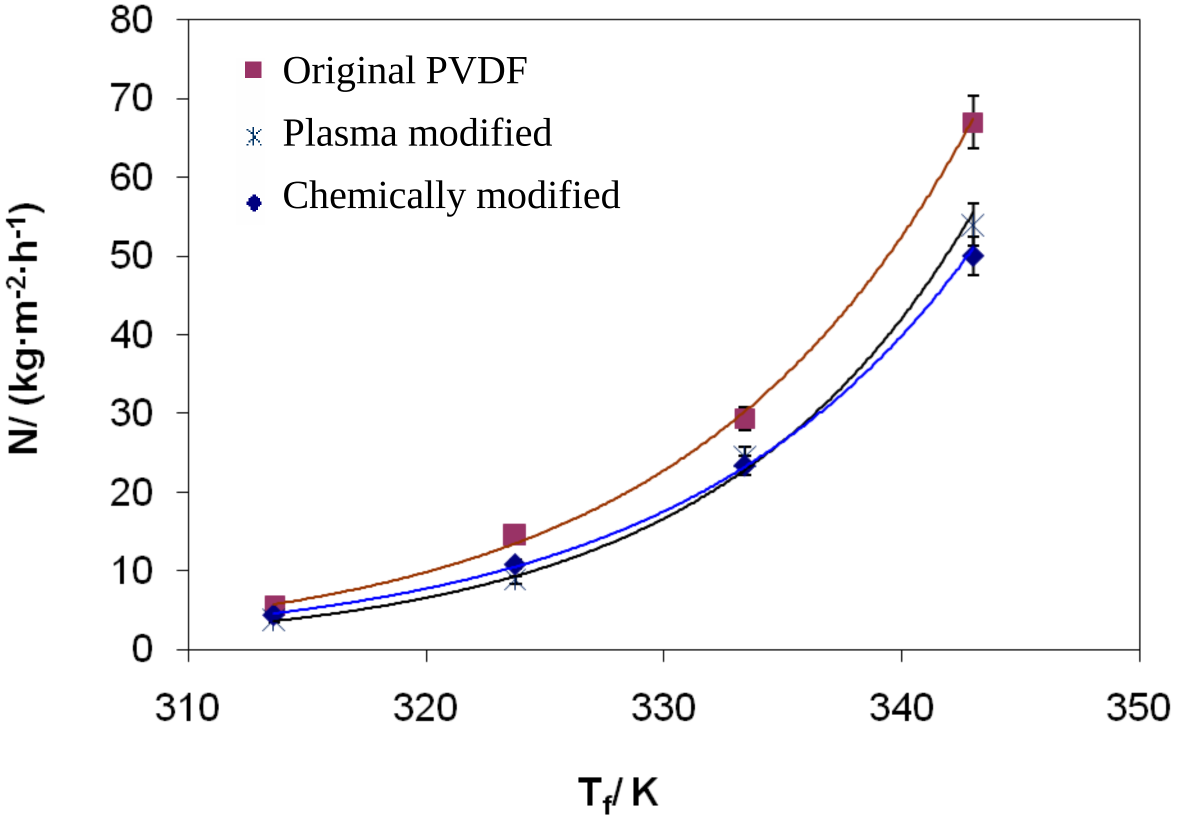


Fig. 4. Permeation flux vs. feed temperature

(3.5 % NaCl solution as feed, Q_f=2.5 L·min^{-1}, Q_p=0.4 L·min^{-1}, T_p=298K. T_f=313–343K)

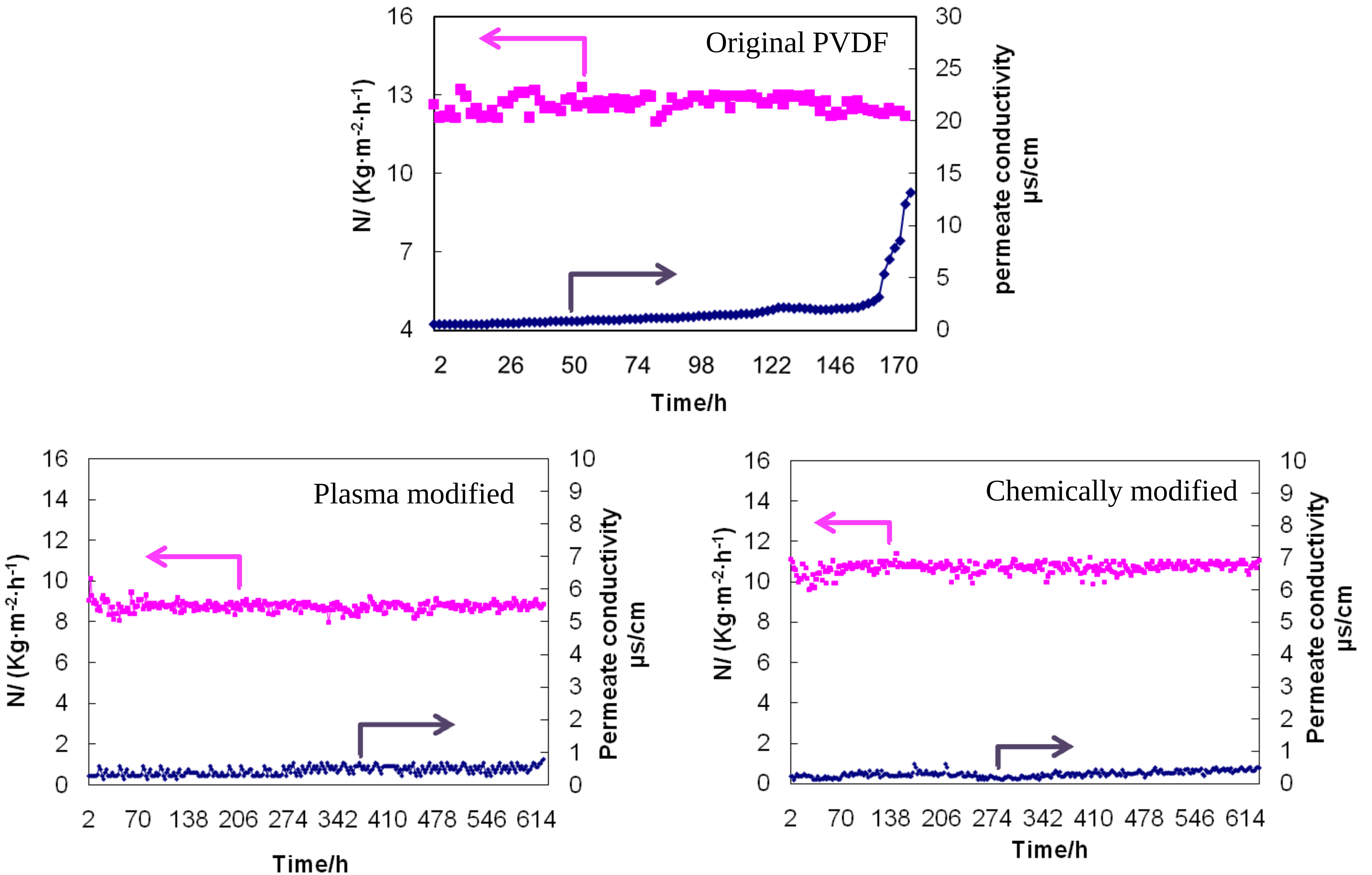


Fig. 5. Long-term performance of the original and two modified PVDF membranes (3.5 % NaCl solution as feed, Q_f=2.5 L·min^{-1}, Q_p=0.4 L·min^{-1}, T_p=298K. T_f=323K)

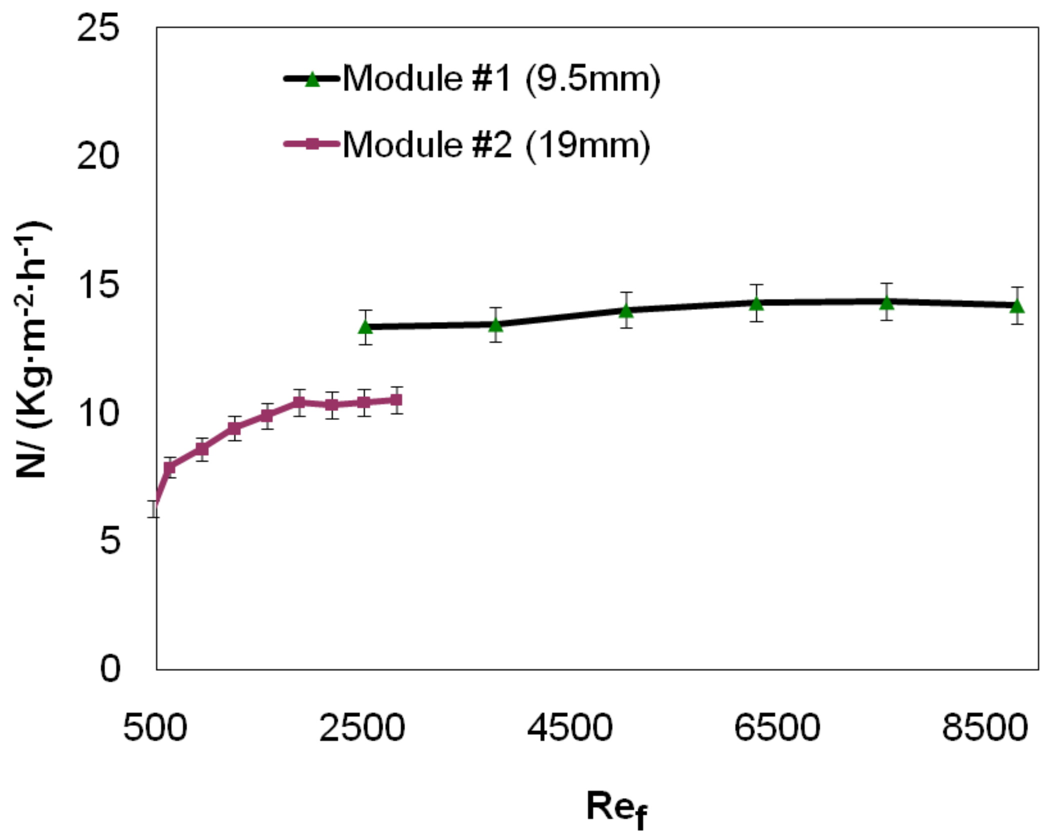


Fig. 6. Effect of feed circulating velocity on permeation flux (3.5 % NaCl solution as feed, v_f =0.82–3.06 m·s^{-1} (module #1) and 0.17–1.05 m·s^{-1} (module #2), v_p =0.17 m·s^{-1}, T_p =298K, T_f =323K)

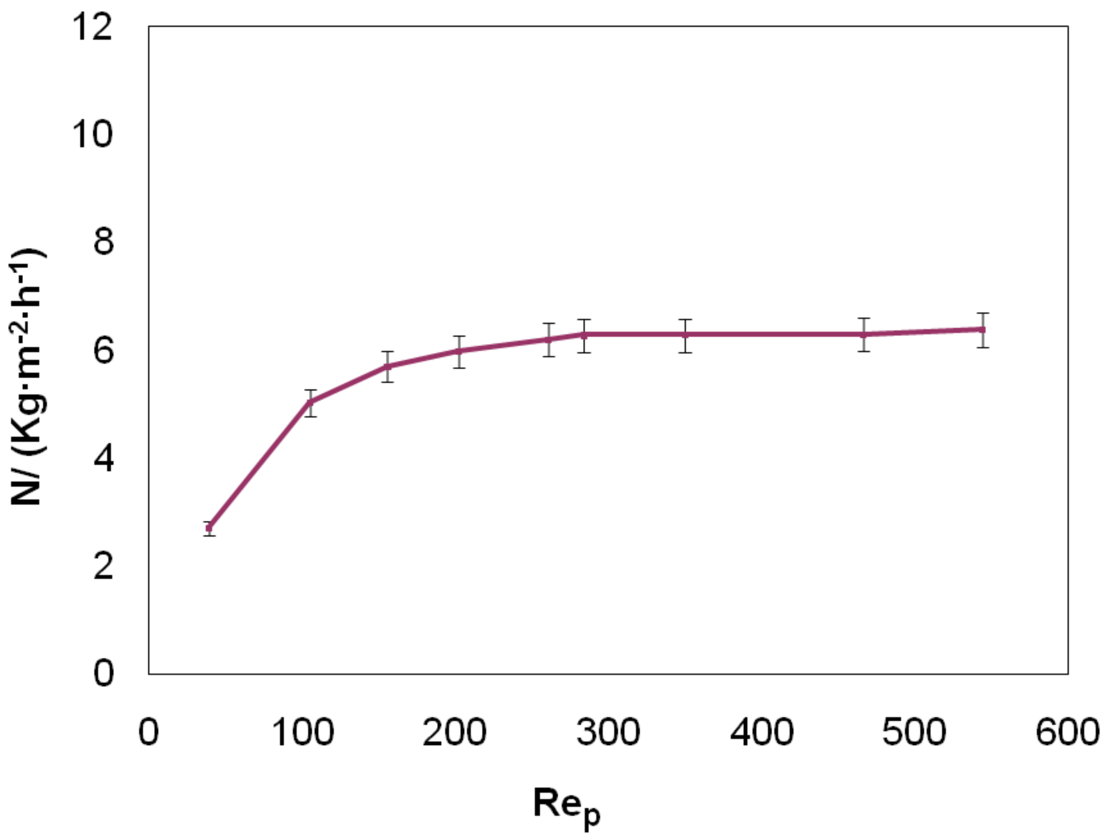


Fig. 7. Effect of permeate circulating velocity on permeation flux
(3.5% NaCl solution as feed v_f =0.2 m·s^{-1} v_p=0.04~0.61 m·s^{-1}, T_p =298K, T_f =323K)

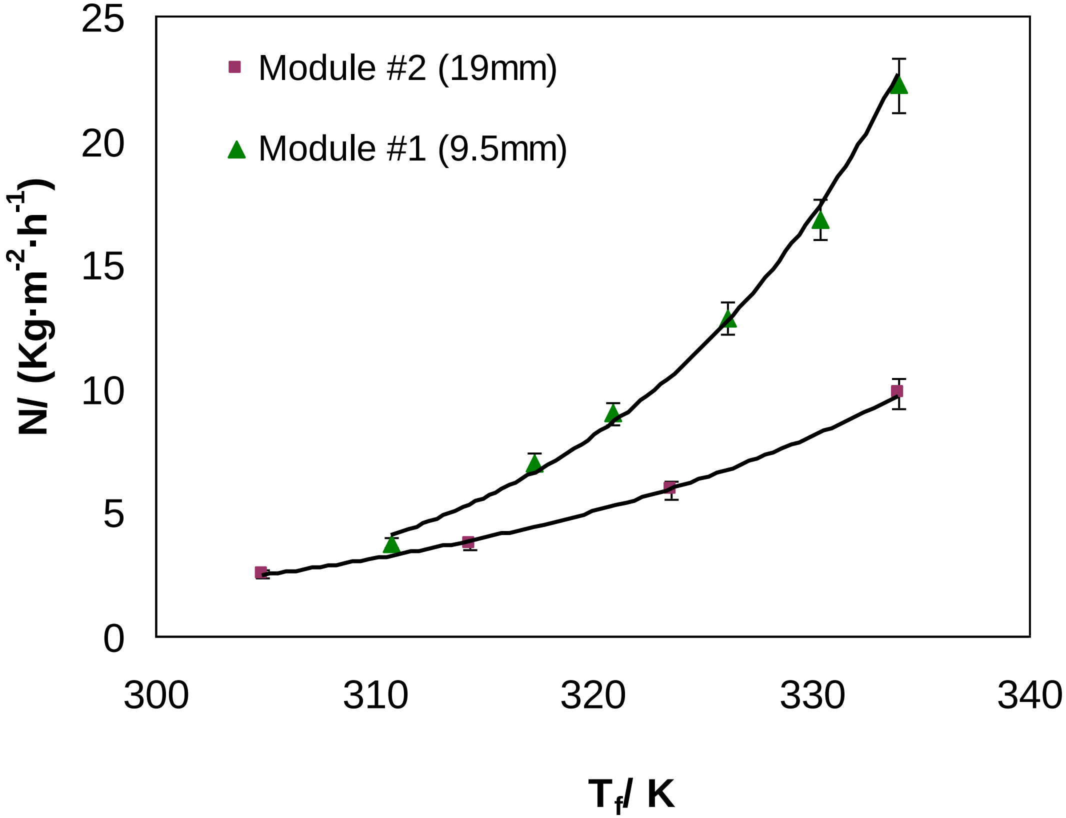
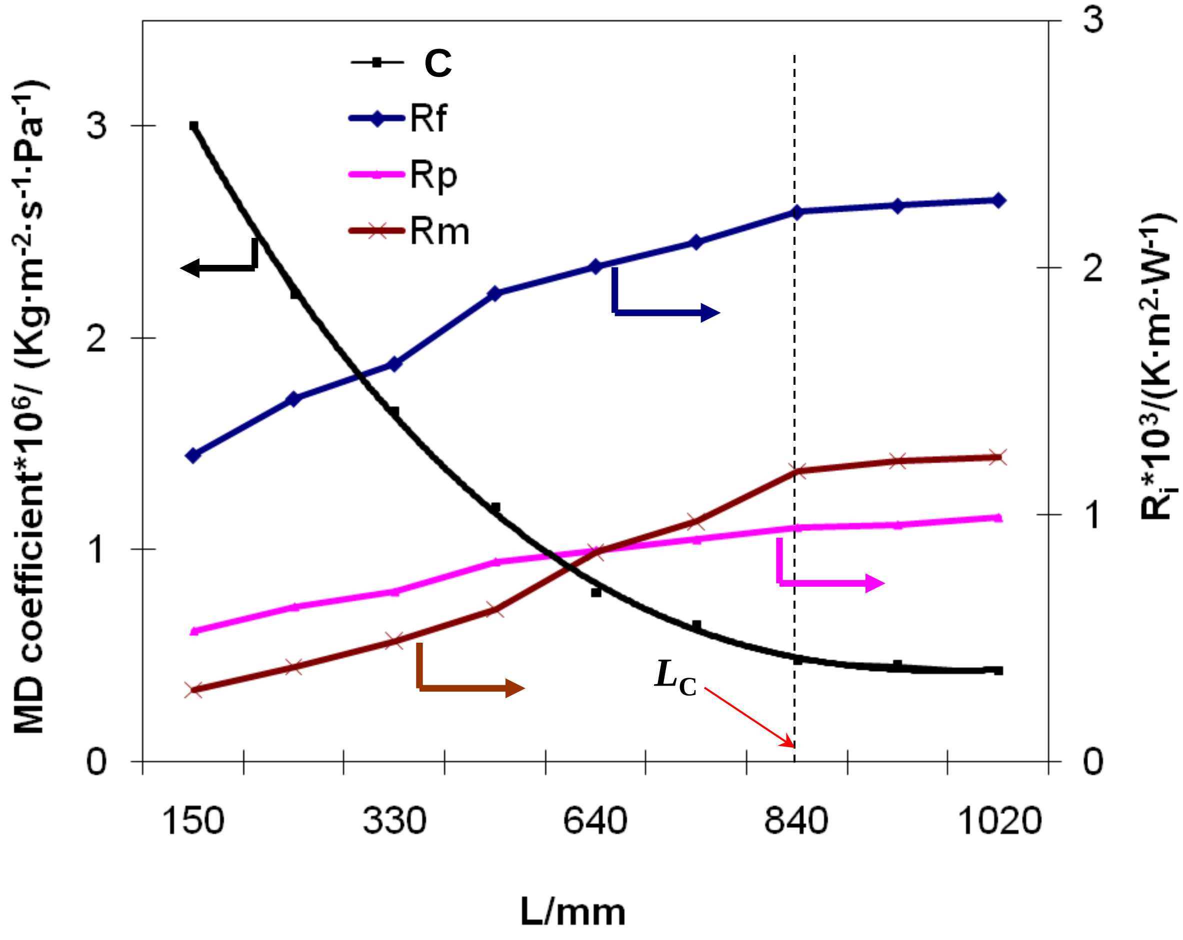
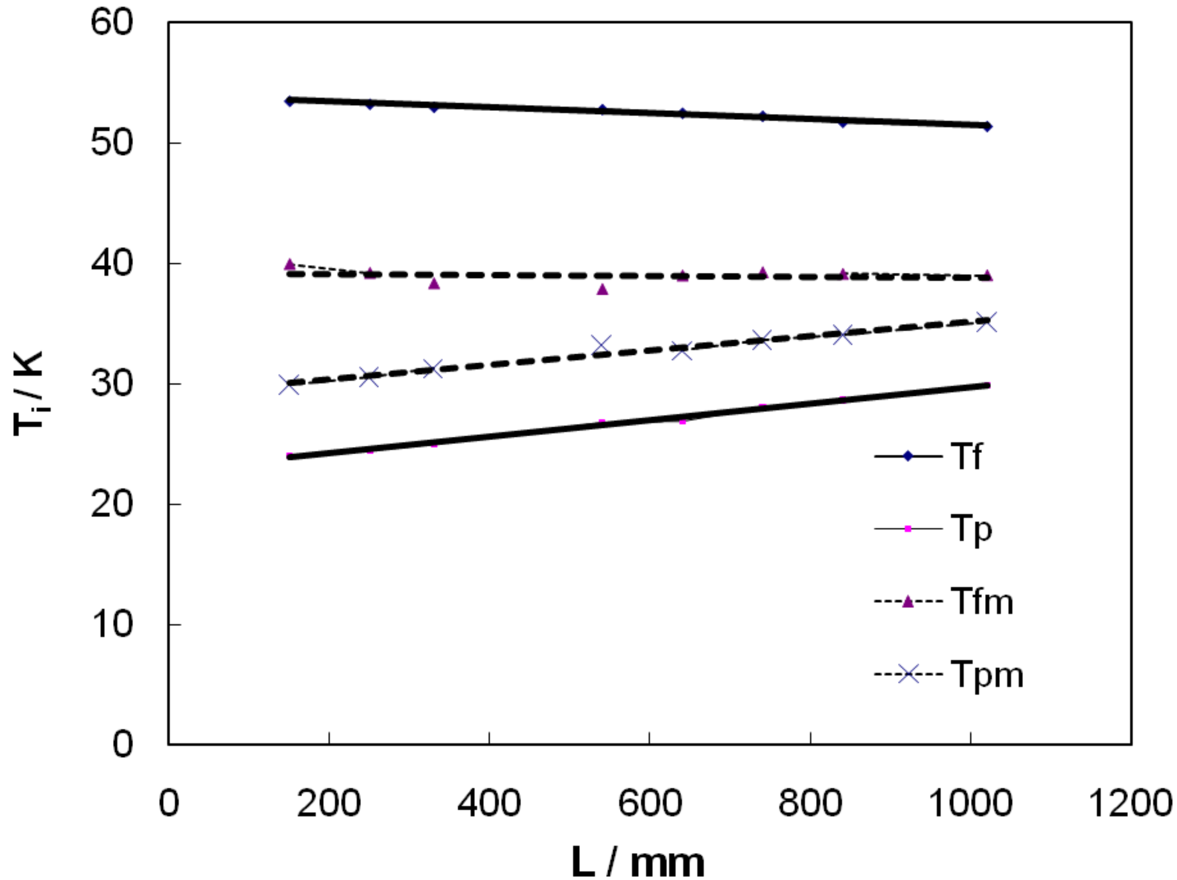


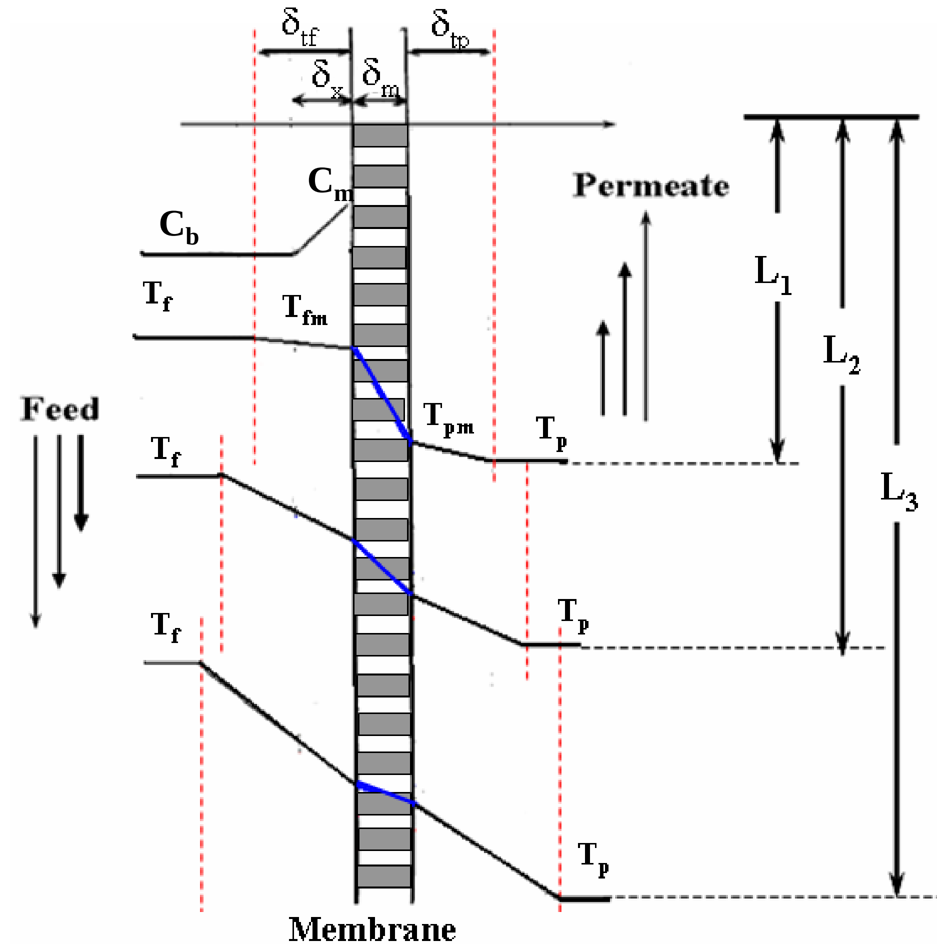
Fig. 8. Fluxes of small and big modules at different Re
(3.5% NaCl solution as feed, Q_f =3 L・min^{-1}, Q_p =0.4 L・min^{-1}, T_p =298K)



(a) C and R_i vs. fiber length L



(b) The bulk and membrane wall temperature distributions along fiber length



(c) Thermal boundary layer build-ups
along the fiber length

Fig. 9. Effect of fiber length: (3.5 % NaCl solution as feed, Q_f =0.25 L·min^{-1} (Re_f=992), Q_P =0.017 L·min^{-1} (Re_p=387), T_p =298K, T_f =323K): *(a)* C and R_i vs. fiber length L; (b) The bulk and membrane wall temperature distributions along fiber length; (c) Thermal boundary layer build-ups along the fiber length

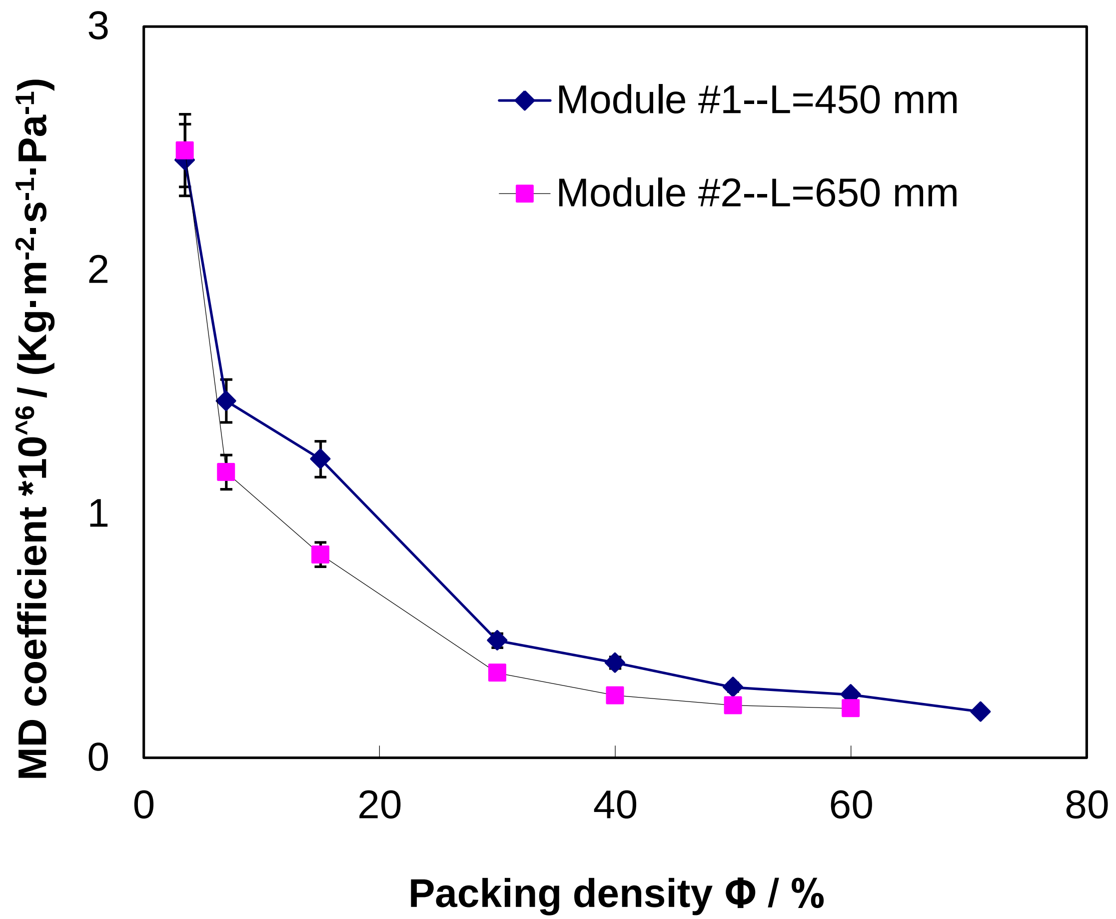


Fig. 10. Relationship between the MD coefficient and module packing density Φ
(3.5 % NaCl solution as feed Q_f =2.5 L・min^{-1}, Q_p =0.4 L・min^{-1}, T_p =298K, T_f =323K)

Table 1 Module specifications for all performance tests

Module No	Housing diameter, d_s	Membrane type	No of fibers, n	Effective fiber length L, mm	Packing density Φ, %	Membrane area A, m^2	Remark
#1	9.5 mm	Original /modified	20	225	50	0.022	Flux tests, circulating velocity and module size comparison
#2	19 mm	Original	80	360	50	0.135	Module size comparison
#3	9.5 mm	Original	1	150-1020	--	--	Single fiber tests
#4	19 mm	Original	--	450/650	3.5-71	--	Packing density tests

Table 2 Comparison of three types of hollow fiber membranes

Membrane type	Dimension	Contact angle (°)	Porosity ε (%)	LEPw (Bar)	Tensile modulus E_t ,MPa	Strain at break δ_b, %
Original PVDF	OD:1.47mm δ:275μm	88	85	1.38	44.60	98.60
Plasma Modified	OD:1.47mm δ:275μm	105	83	3.86	41.05	102.08
Chemically modified	OD:1.47mm δ:275μm	115	80	3.64	45.06	121.94