

Enhanced hollow fiber membrane performance via semi-dynamic layer-by-layer polyelectrolyte inner surface deposition for nanofiltration and forward osmosis applications

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Table 1. Characteristics of PES hollow fiber substrate

Dimension			Porosity	MWCO		Mean	Standard	Pure water	Tensile	Stress	Strain at
OD (μm)	ID (μm)	Thickness (μm)	ε (%)	Outer/inner	surface	pore size	deviation	permeability	modulus	at break	at break
				(kDa)		D* (nm)	σ	(LMH/bar)	(MPa)	(MPa)	%
1480	1080	200	84	39	56	10.9	1.04	350	70.4	3.64	66

Table 2. Polyelectrolyte structure and functional groups

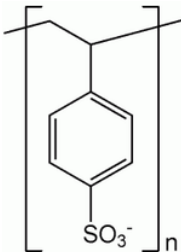
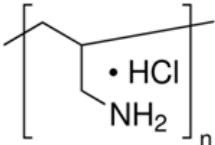
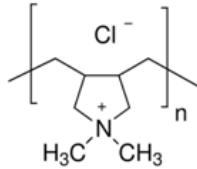
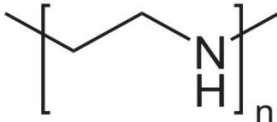
Name	Molecular Structure	Functional Groups
<p>Poly(styrene sulfonate)</p> <p>PSS</p>		<p>SO_3^-</p>
<p>Poly(allylamine hydrochloride)</p> <p>PAH</p>		<p>NH_3^+</p>
<p>Poly(diallyl-dimethylammonium chloride)</p> <p>PDADMAC</p>		<p>NR_4^+</p>
<p>Poly(ethyleneimine)</p> <p>PEI</p>		<p>NH_3^+</p> <p>NRH^{2+}</p> <p>NR_2H^+</p>

Table 3. Neutral solutes rejection performance

Solute	Molecular weight (Da)	Stokes radius (nm)	LBL-2O	LBL-2I
			Solute rejection (%) ⁺	Solute rejection (%) ⁺
Glucose	180	0.36	38.2	69.8
Sucrose	342	0.46	67.2	98.1
Raffinose	504	0.54	74.4	98.3

⁺Tested at 1 bar using 200 ppm neutral solute solutions

Table 4. Comparison of various NF membranes

Membranes	Salt water permeability (LMH/bar)	Salt rejection (%)	MgCl ₂ concentration (ppm)	Operation pressure (bar)	Reference
LBL-2I	9.8	98.2	1000	2	Present work
	8.2	97.4	4000	4.8	Present work
LBL-6O	12	94	1000	2	[16]
UTC-20	9.7	98	1500	10	[28]
NF-270	4	53	4000	4.8	[10]
LBL flat sheet	4	93	4000	4.8	[10]
PDMAEMA/Psf	1	98	1000	8	[29]
PEI/TMC IP	9.75	80	1000	4	[30]
PDMCHEAs/Psf	3.2	94.3	1000	6	[31]

Table 5. Separation performance of mixed salt solutions

Feed solution TDS (ppm)	Ion composition (ppm)			Membrane ^a	SWP ^b (LMH/bar)	Ionic rejection (%)		
	Mg ²⁺	Ca ²⁺	Na ⁺			Mg ²⁺	Ca ²⁺	Na ⁺
3000	142	266	562	od-LBL	11	91	87	11
				id-LBL	8.1	99.5	99	13.7
5000	218	420	894	od-LBL	7.2	72.5	68.8	-7.1
				id-LBL (2 bar)	4.8	96.2	92.1	7.6
				id-LBL (4.8 bar)	7.4	99.6	97	16.4

^a Deposited with (PSS with 0.5 M NaCl/PAH with 2.5 M NaCl) x 2

^b Tested at 2 bar without special indication

Table 6. Comparison of various LBL FO membranes

Sample	Water flux (L/m ² .h)	Salt flux/water flux(g/L)	Orientation	Reference
LBL-2I	73	0.06	AL-facing-DS	Present work
LBL-6O	40.5	0.2	AL-facing-DS	[23]
6#LBL FO	22 ^a	0.3 ^a	AL-facing-DS	[33]
(PAA-PSS/PAH) ₃	28	0.07	AL-facing-DS	[34]
xLbL3	60 ^a	0.1 ^a	AL-facing-DS	[35]
(PAH/PSS) _{3XX}	21	0.06	AL-facing-DS	[36]
LBL-2I	21.5	0.03	AL-facing-FW	Present work
LBL-6O	18.4	0.11	AL-facing-FW	[23]
6#LBL FO	16 ^a	0.57 ^a	AL-facing-FW	[33]
xLbL3	30 ^a	0.3 ^a	AL-facing-FW	[35]
(PAH/PSS) _{3XX}	14.5	0.08	AL-facing-FW	[36]

Feed solution: DI water; draw solution:0.5M MgCl₂ solution

^a Estimated from published figures



Fig. 1. Schematic drawing of layer-by-layer deposition on hollow fiber inner surface.

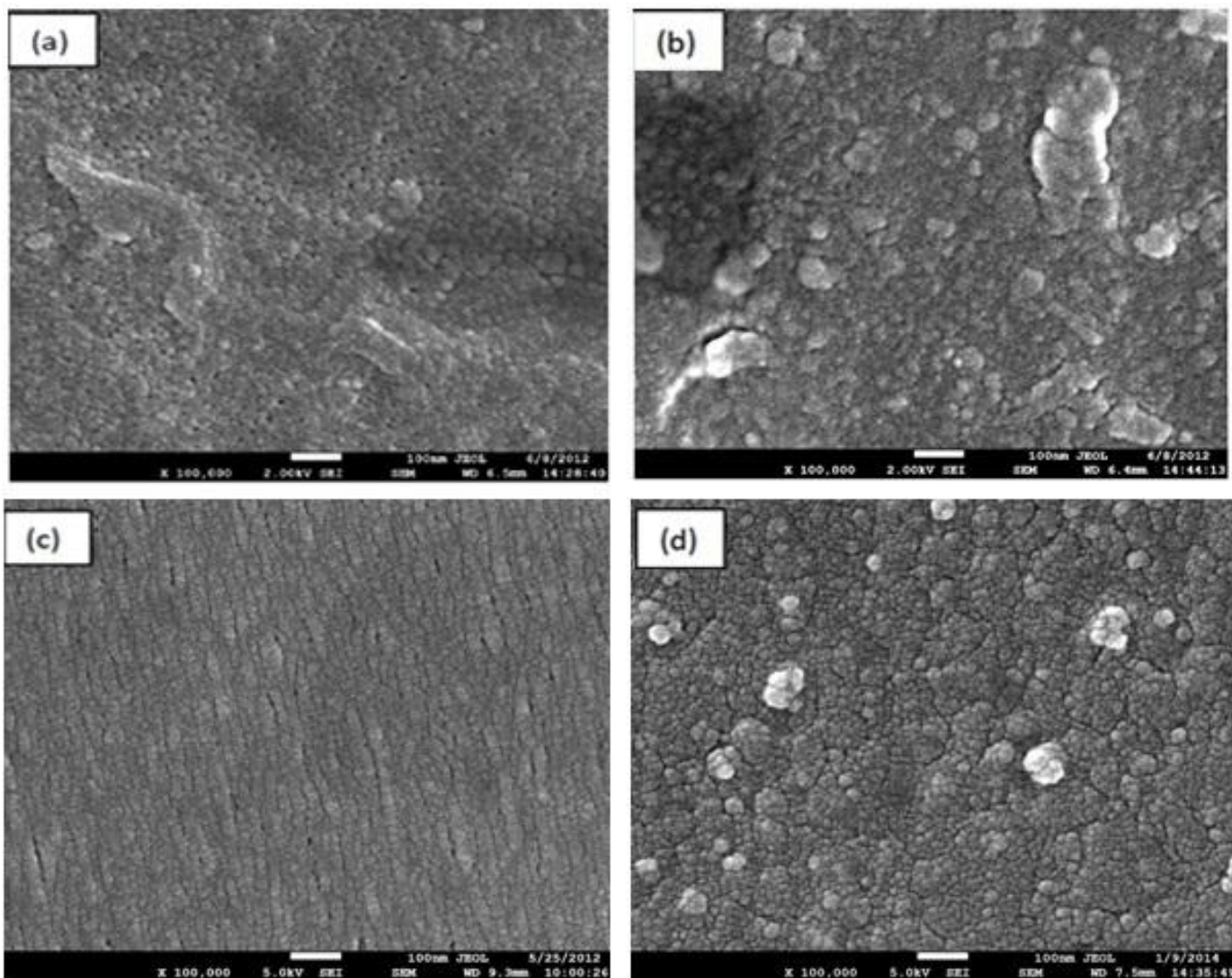


Fig.2. FESEM images of
(a) substrate outer surface; (b) od-LBL membrane outer surface; (c) substrate inner surface;
(d) id-LBL membrane inner surface at magnification of 100k.
(Deposited with (PSS with 0.5 M NaCl/PAH with 2.5 M NaCl) x 2)

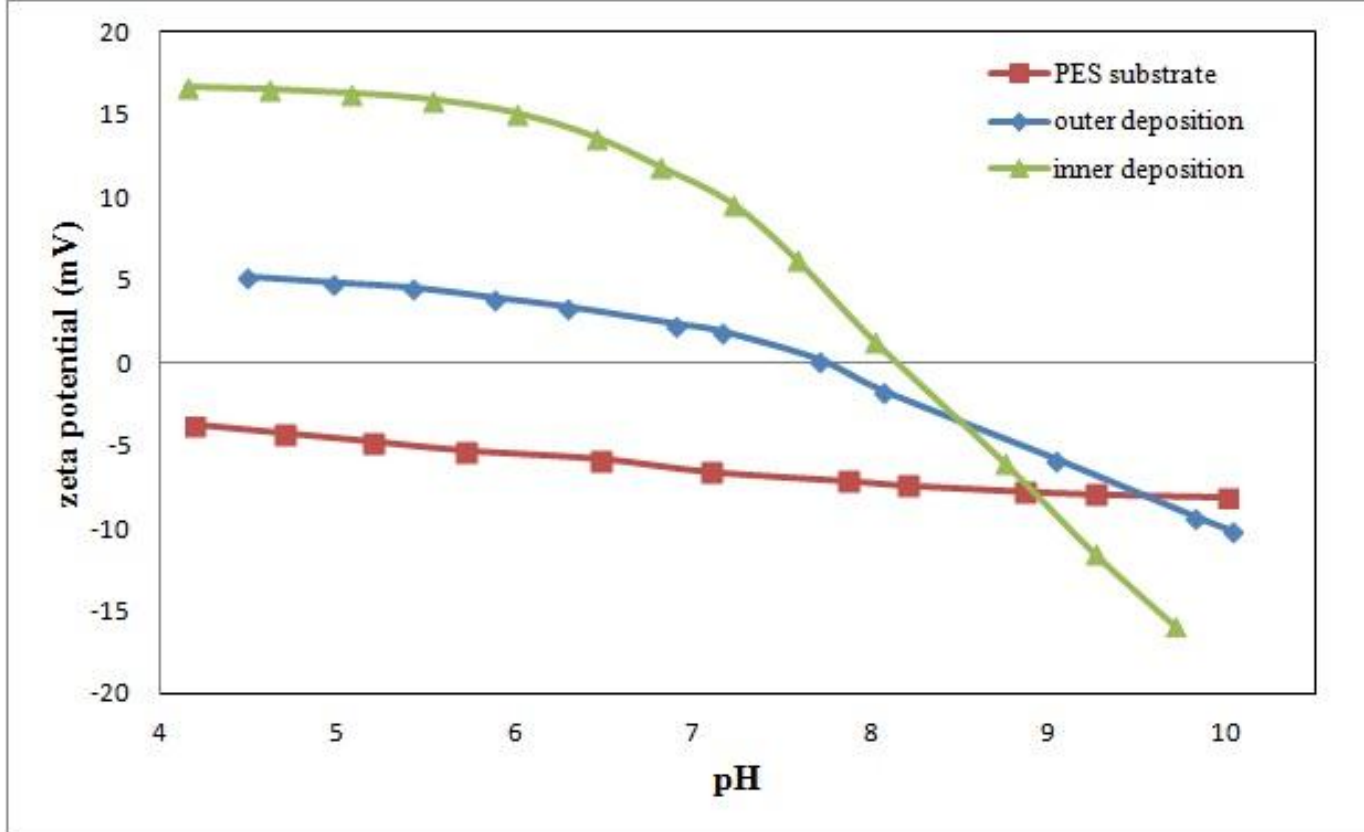


Fig. 3. Zeta potential of PES substrate and LBL membranes (Deposited with (PSS with 0.5 M NaCl/PAH with 2.5 M NaCl) x 2).

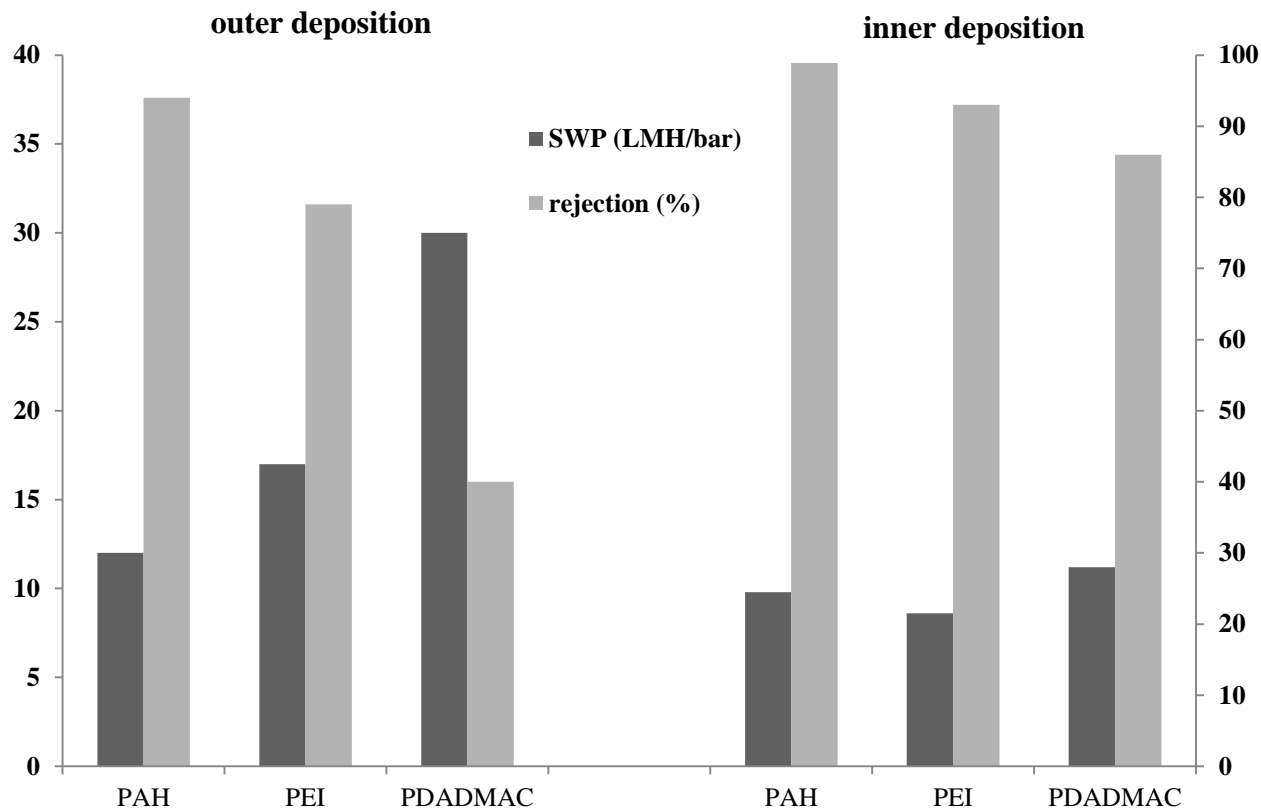


Fig. 4. Nanofiltration performance of LBL membranes using different polycations. (Deposited with (PSS with 0.5 M NaCl/Poly-cations with 2.5 M NaCl) x 2; tested at 2 bar using 1000 ppm $MgCl_2$ solution)

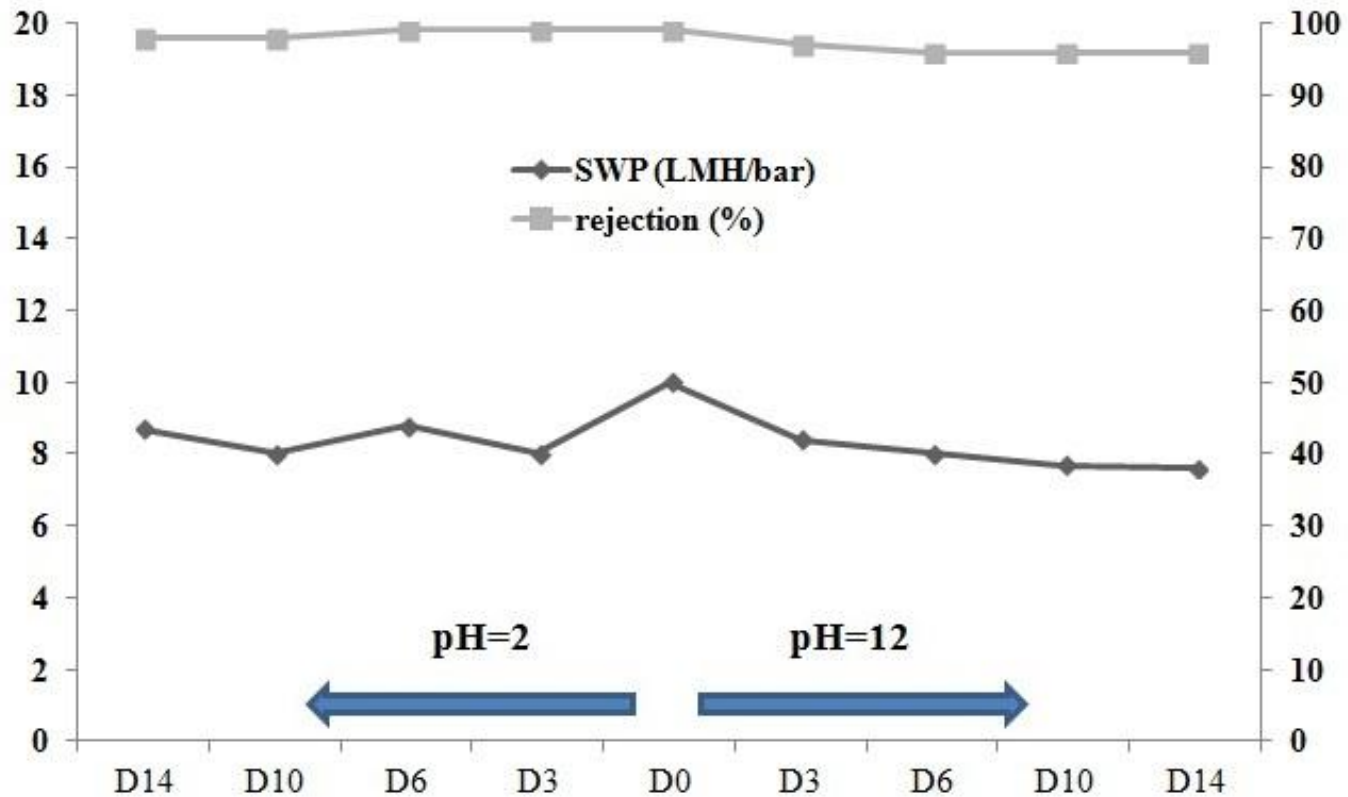


Fig. 5. 14-day acid/alkaline stability tests of inner deposited LBL membranes (Deposited with (PSS with 0.5 M NaCl/PAH with 2.5 M NaCl) x 2).

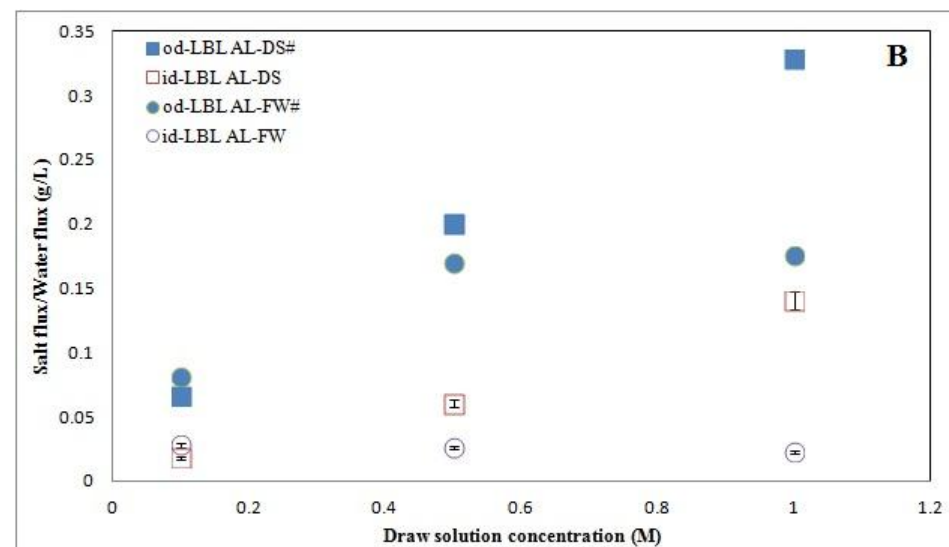
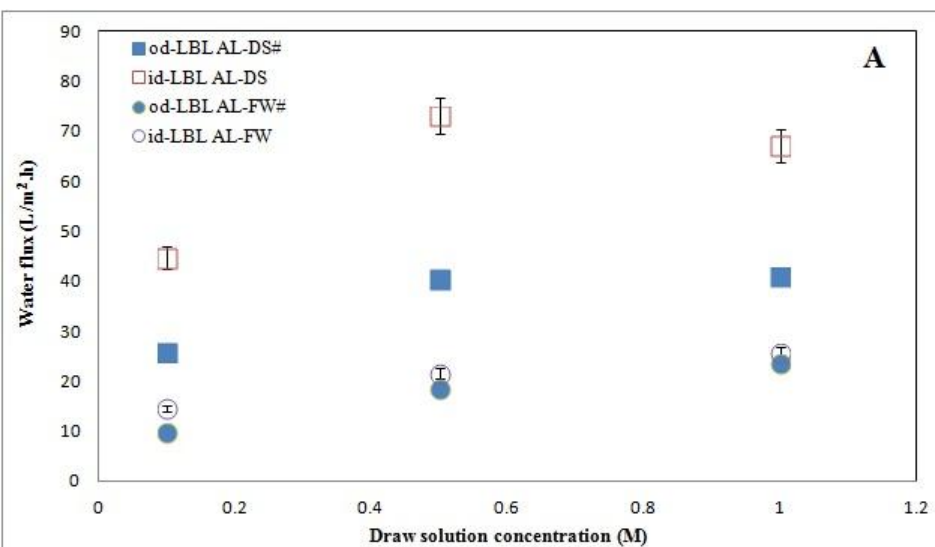


Fig. 6. FO performance of LBL membranes using up to 1 M MgCl_2 draw solutions
 (A) Water flux; (B) Salt flux.
 (od-LBL membranes deposited with $(\text{PSS}/\text{PAH})^*6$ [23]; id-LBL membranes deposited with $(\text{PSS}/\text{PAH}) \times 2$)