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Tetrabutylphosphonium 5-phenyltetrazolate solution as highly effective and energy-efficient thermo-regenerable draw solutes in forward osmosis

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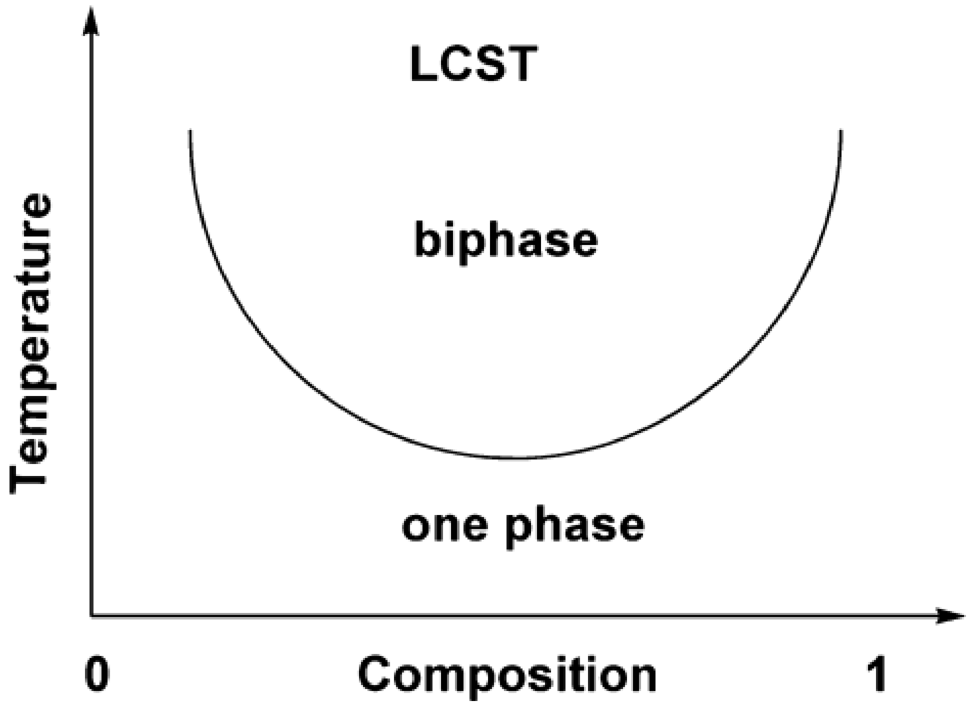
1. Background introduction

Keyword: Ionic Liquids, LCST, Forward Osmosis

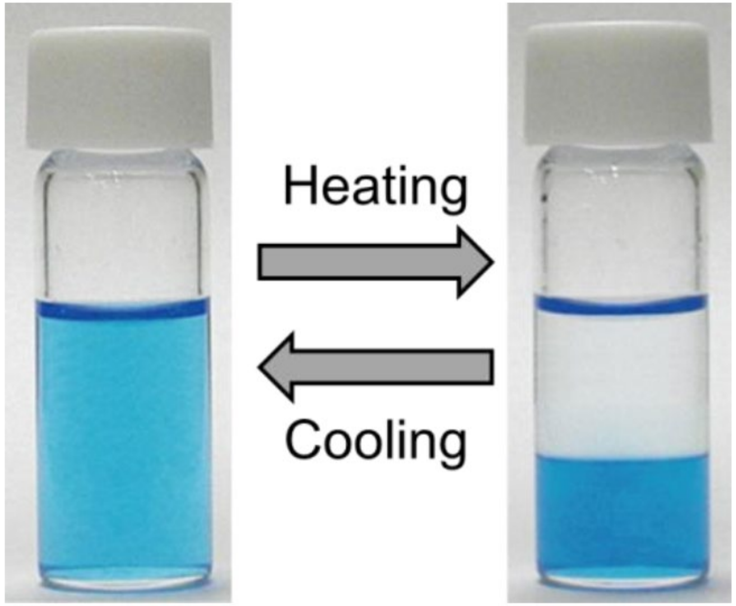
Abbreviations being used:

LCST: Lower critical solution temperature
IL: Ionic liquid
FO: Forward osmosis
PRO: Pressure retarded osmosis
RO: Reverse osmosis
DS: Draw solution
FS: Feed solution
NF: Nanofiltration
ICP: Internal concentration polarization
ECP: External concentration polarization

Lower Critical Solution Temperature



LCST phase diagram



LCST phase transferring[1]

1. S. Saita, Fine Control of LCST-type Phase Transition of Ionic Liquid/Water Mixtures.

LCST behavior in forward osmosis phase separation

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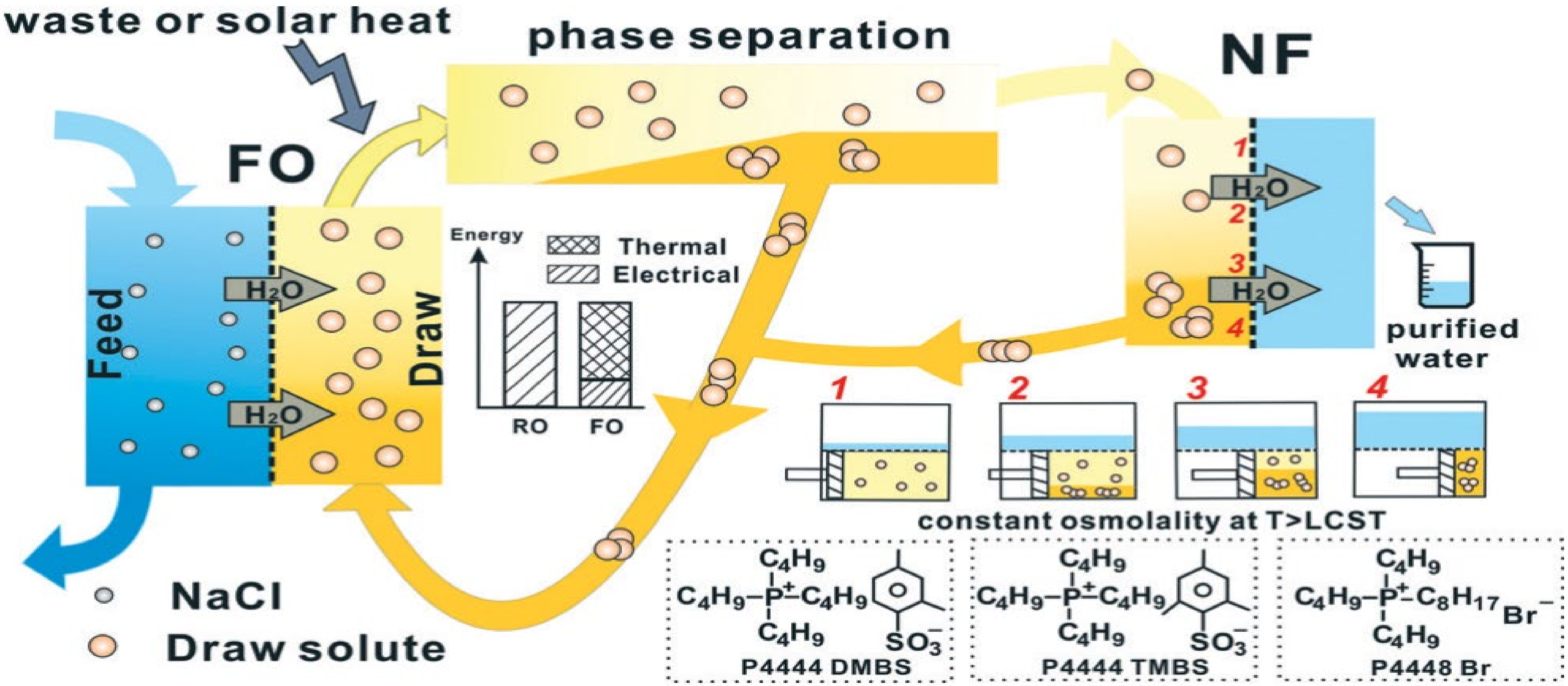

FO and further purification of water

1. Y. Cai, W. Shen, J. Wei, T.H. Chong, R. Wang, W.B. Krantz, A.G. Fane, X. Hu, Energy-efficient desalination by forward osmosis using responsive ionic liquid draw solutes, Environ. Sci.: Water Res. Technol. 1 (2015) 341–347

2. Materials and Methodology

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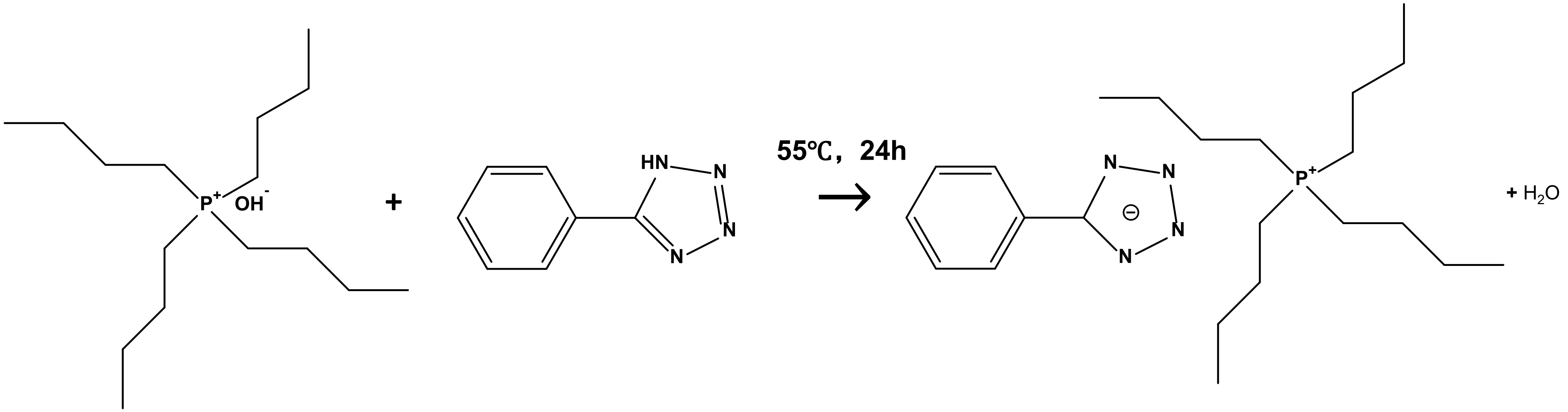
Preparation of Thermo-sensitive Ionic liquids



Lab-scale Forward Osmosis test system

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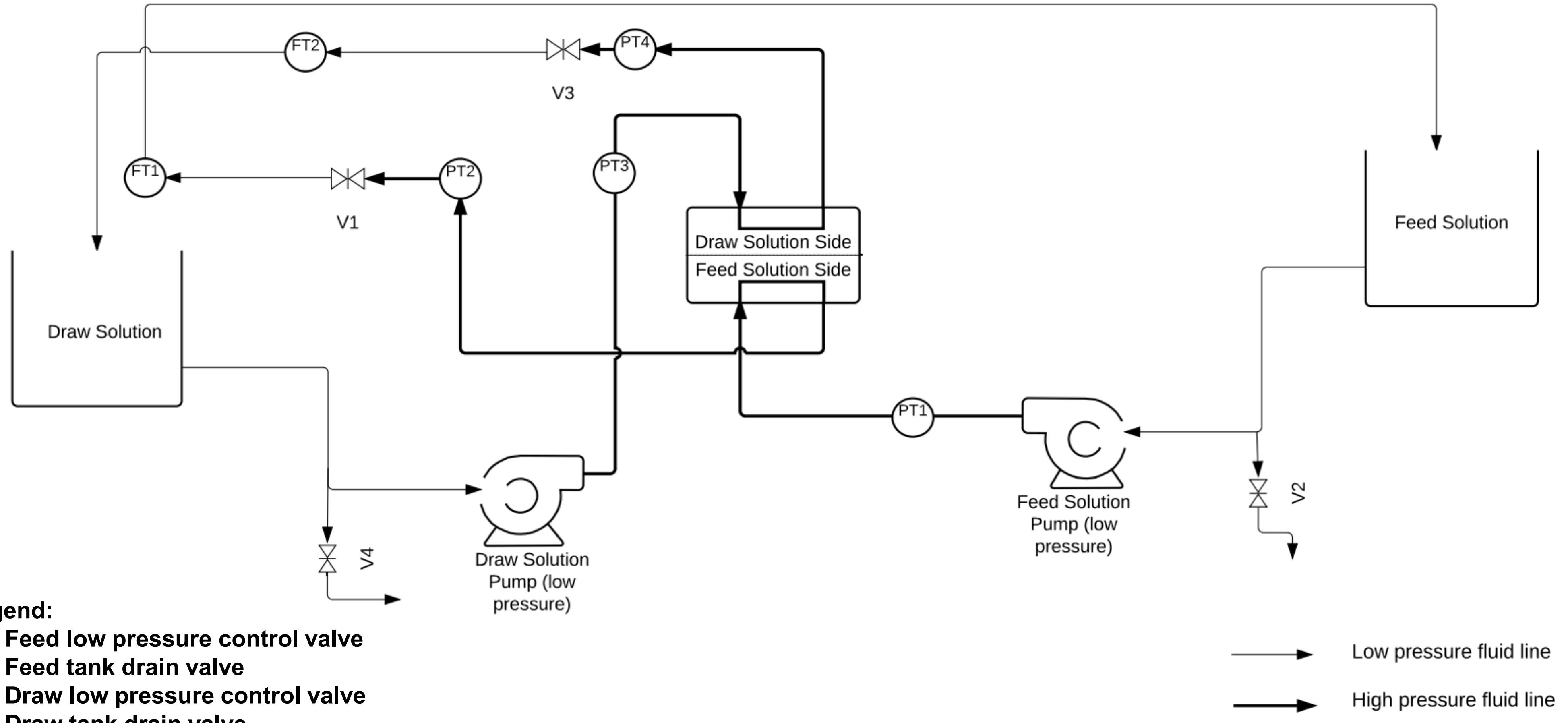
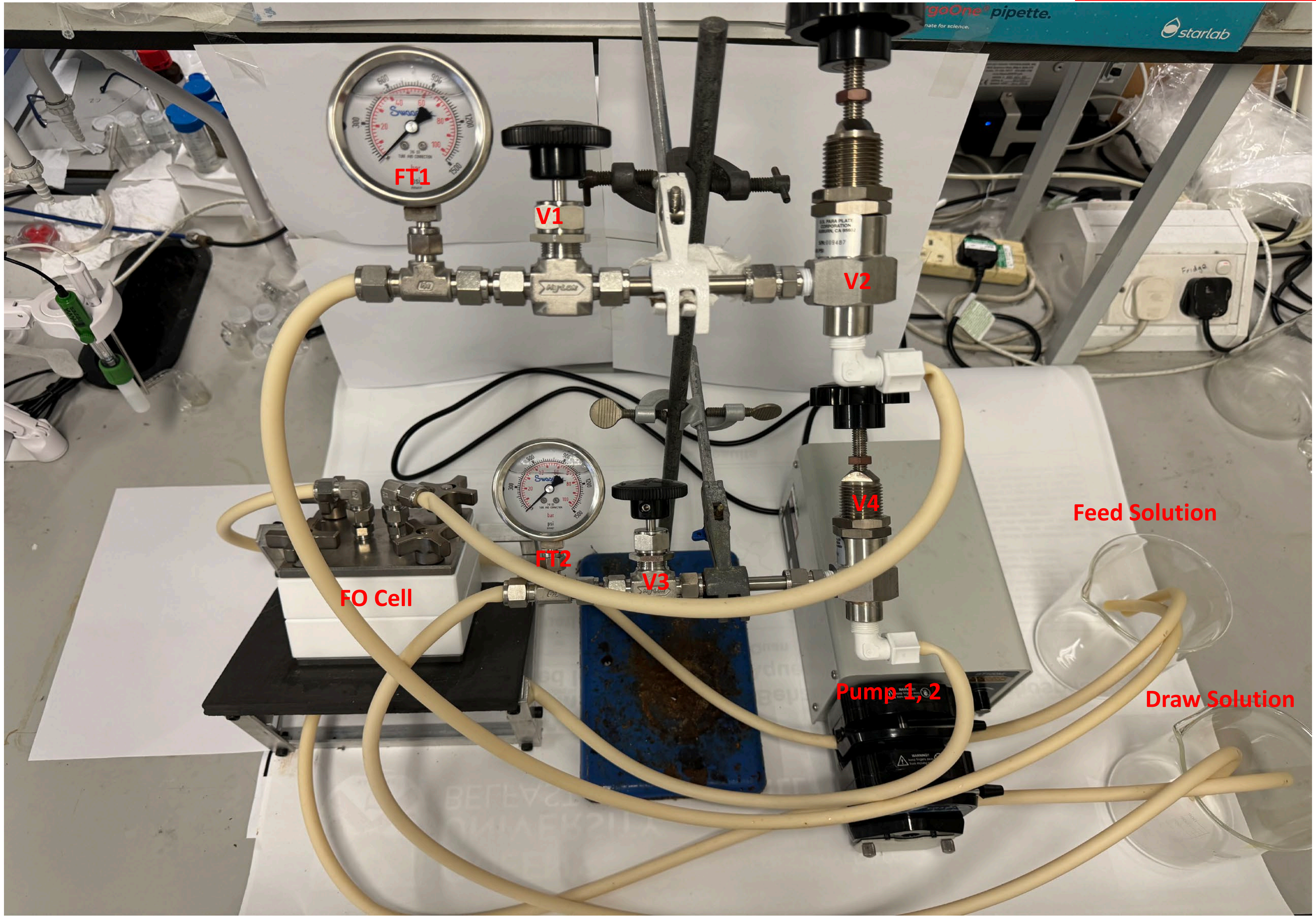


Legend:
V1: Feed low pressure control valve
V2: Feed tank drain valve
V3: Draw low pressure control valve
V4: Draw tank drain valve
PT1: Feed inlet pressure gauge1
PT2: Feed outlet pressure gauge
PT3: Draw inlet pressure gauge1
PT4: Draw outlet pressure gauge
FT1: Feed flow meter
FT2: Draw flow meter



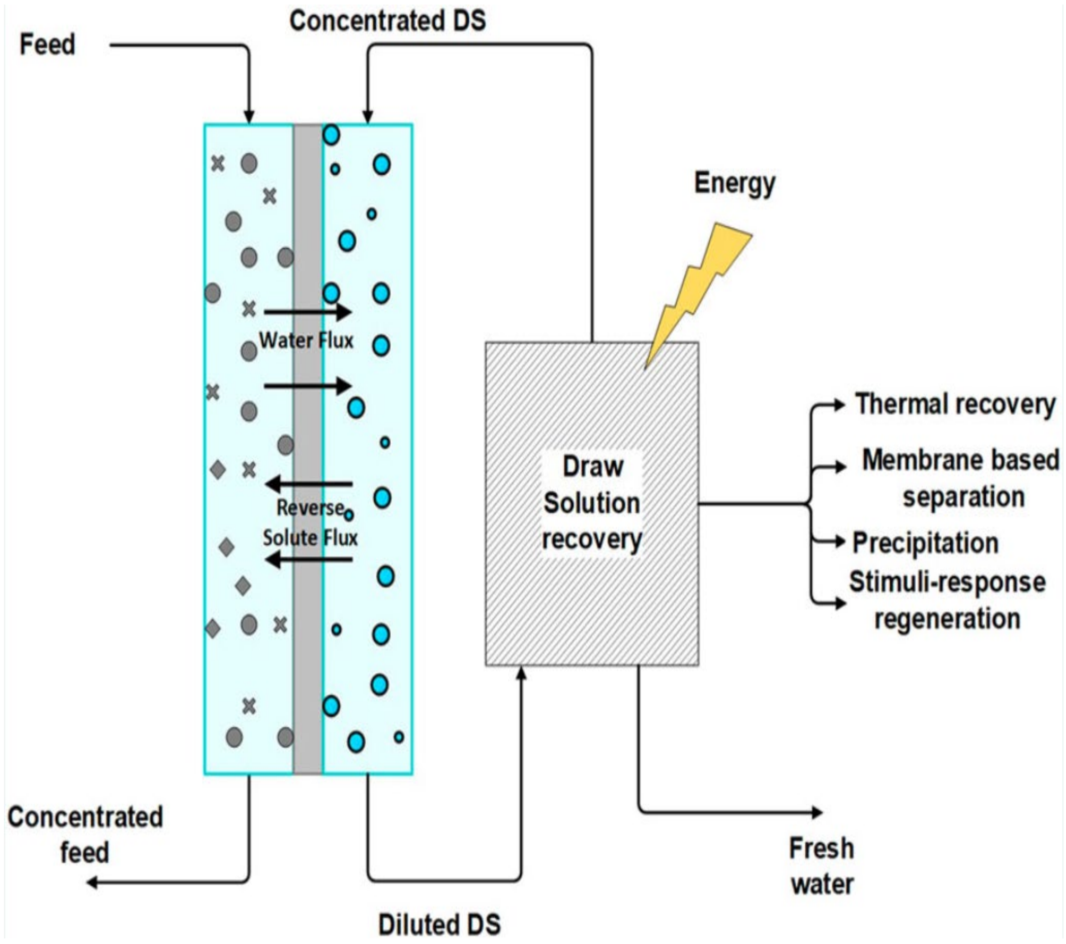
Photograph of the assembled and operational FO test system

FO Essential Parameters

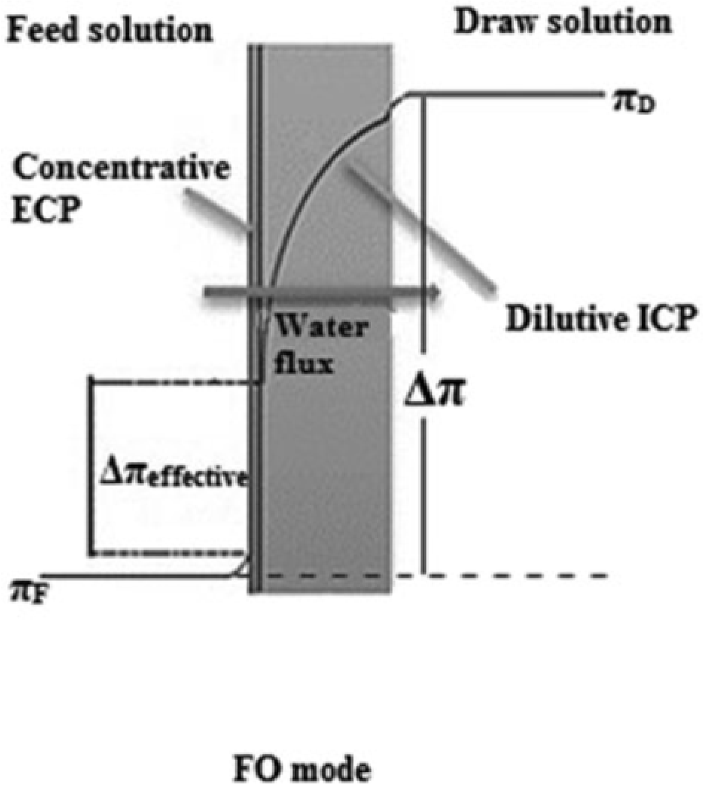
1. Pure water flux J_v :
The volume of water passing through the forward osmosis membrane from feed solution to draw solution per unit area per unit time which is higher is better

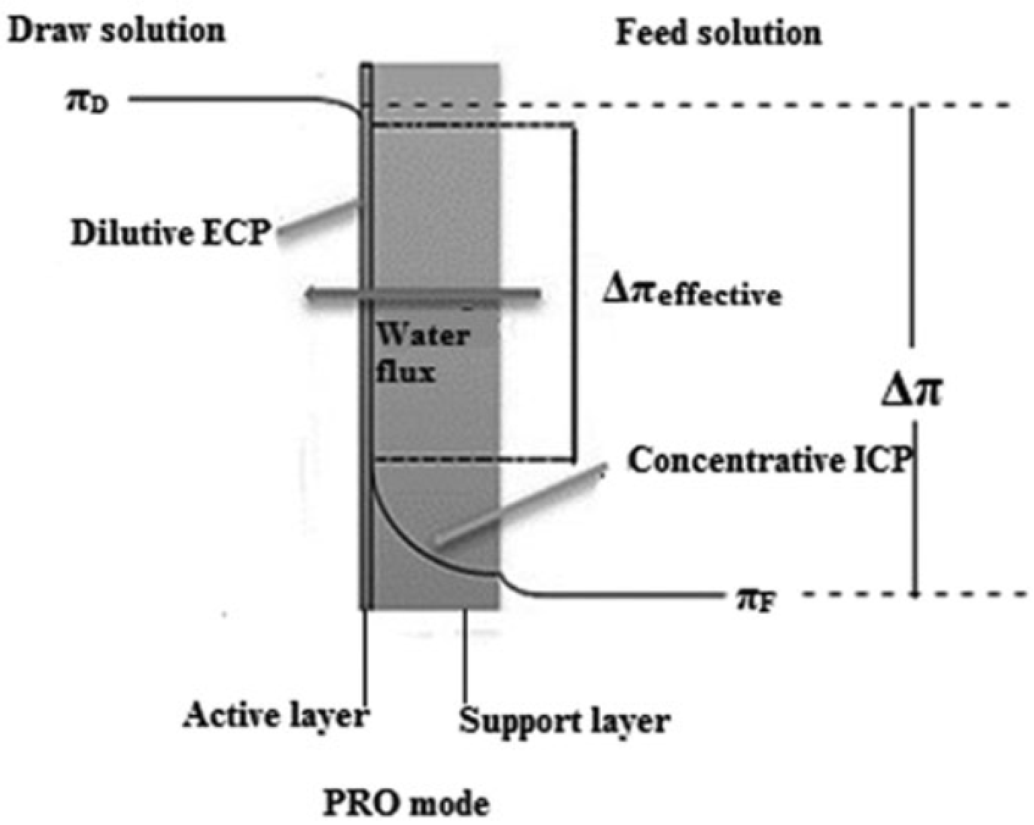
2. Reverse solute flux J_s :
The moles of solute per unit area per unit time that pass through the forward osmosis membrane from draw solution to feed solution which is lower is better

3. J_s/J_v :
Intuitively reflects the overall performance of the membrane which is lower is better.



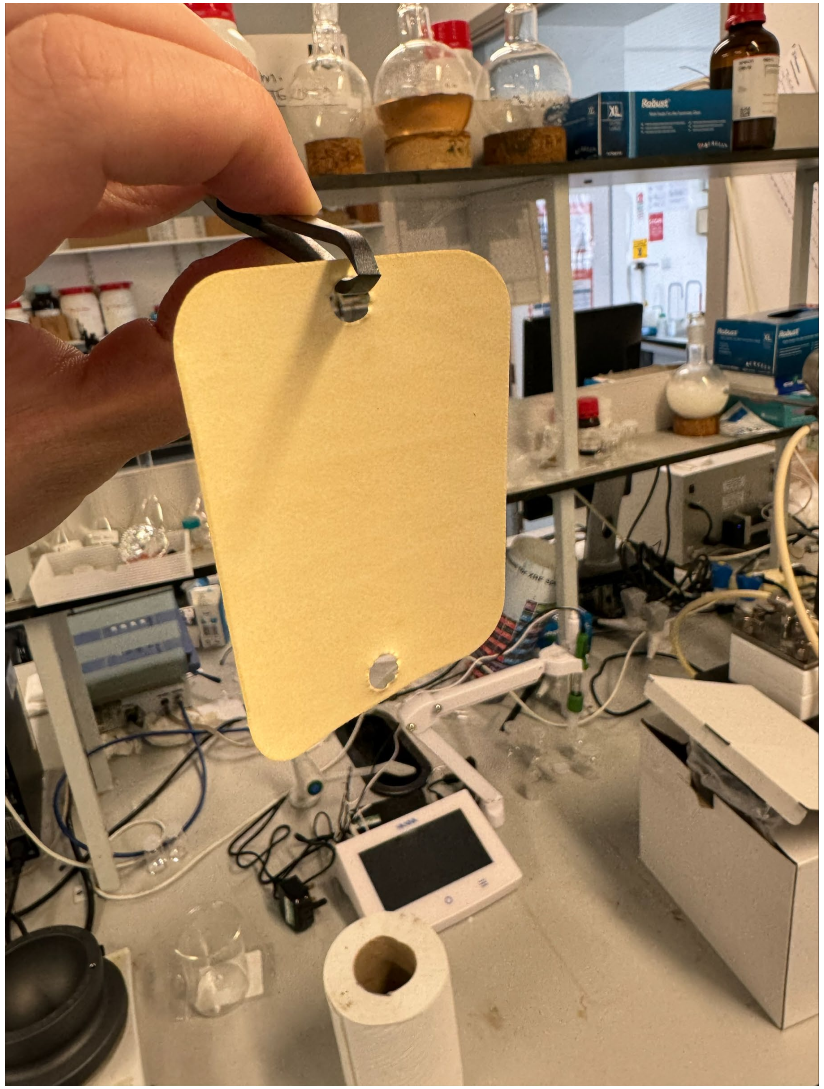
FO mode and PRO mode



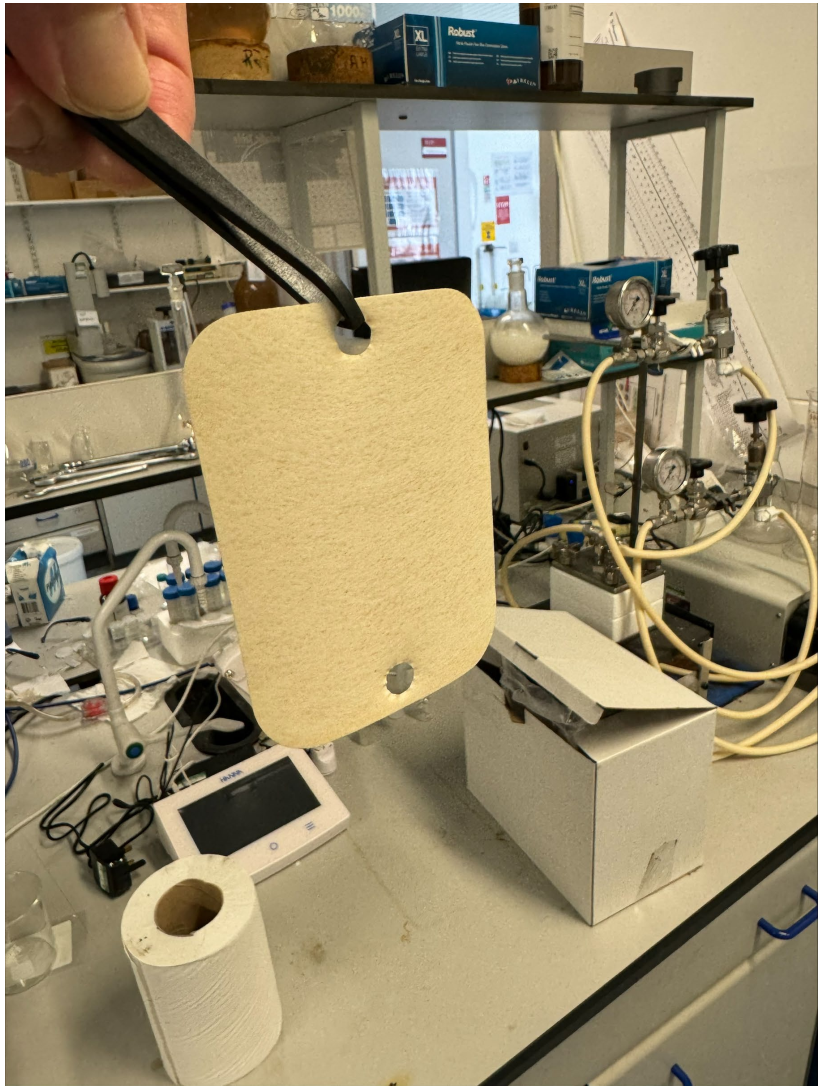


Active Layer Face to Feed Solution

Active Layer Face to Draw Solution



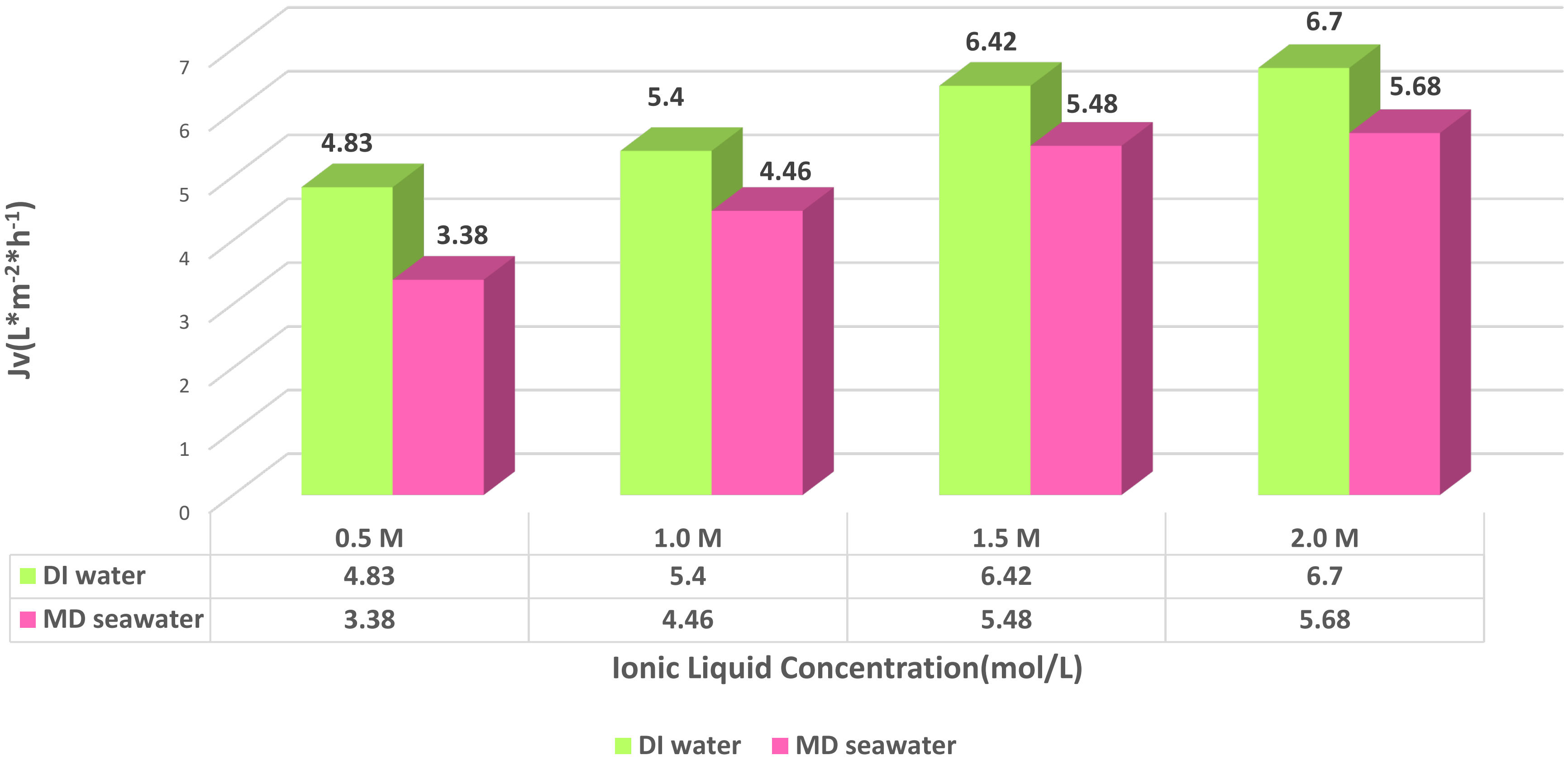
Active layer



Support layer

3. Results and Discussion

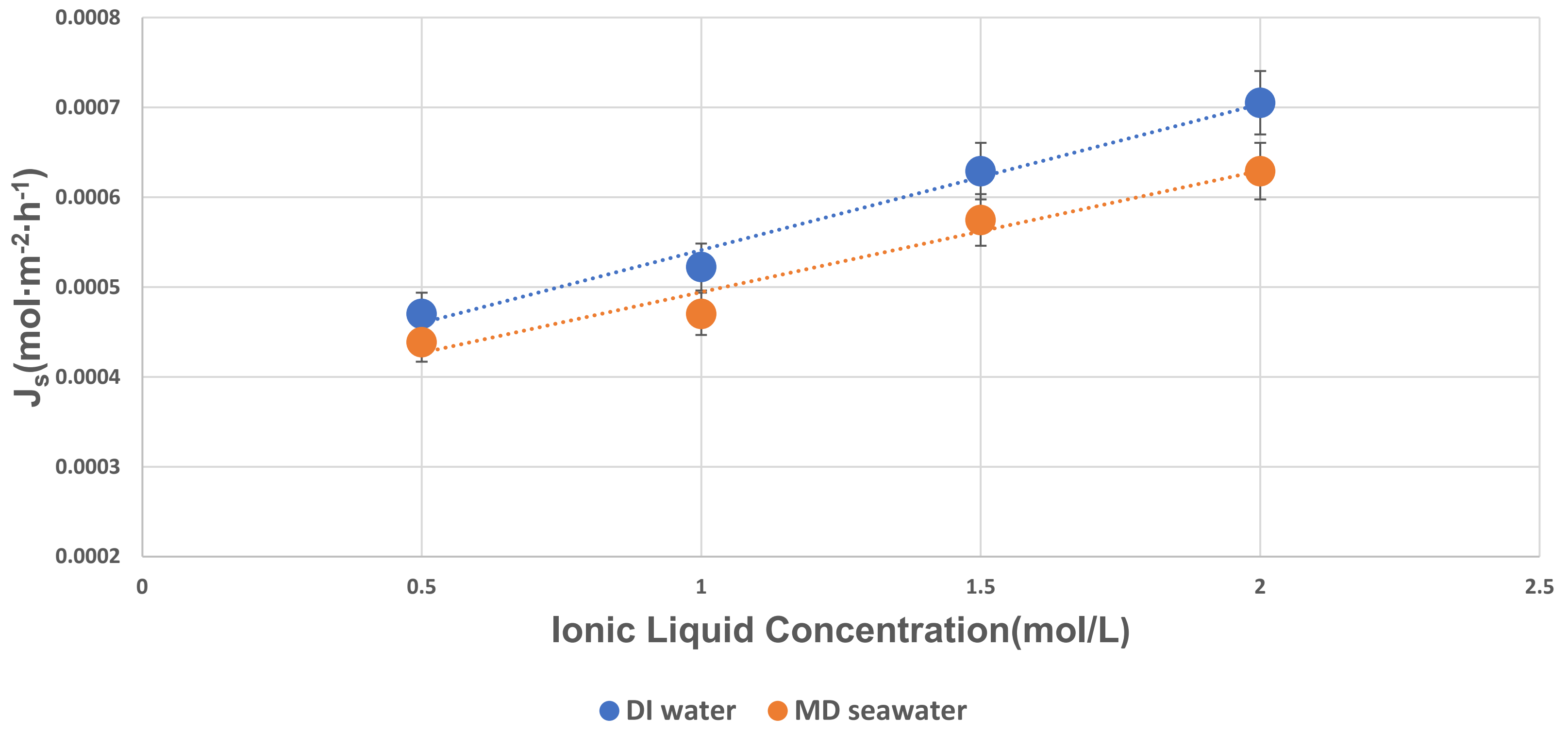
Water Flux of $[P_{4444}][Ph\text{-}tet]$ under FO mode



	0.5 M	1.0 M	1.5 M	2.0 M
DI water	4.83	5.4	6.42	6.7
MD seawater	3.38	4.46	5.48	5.68

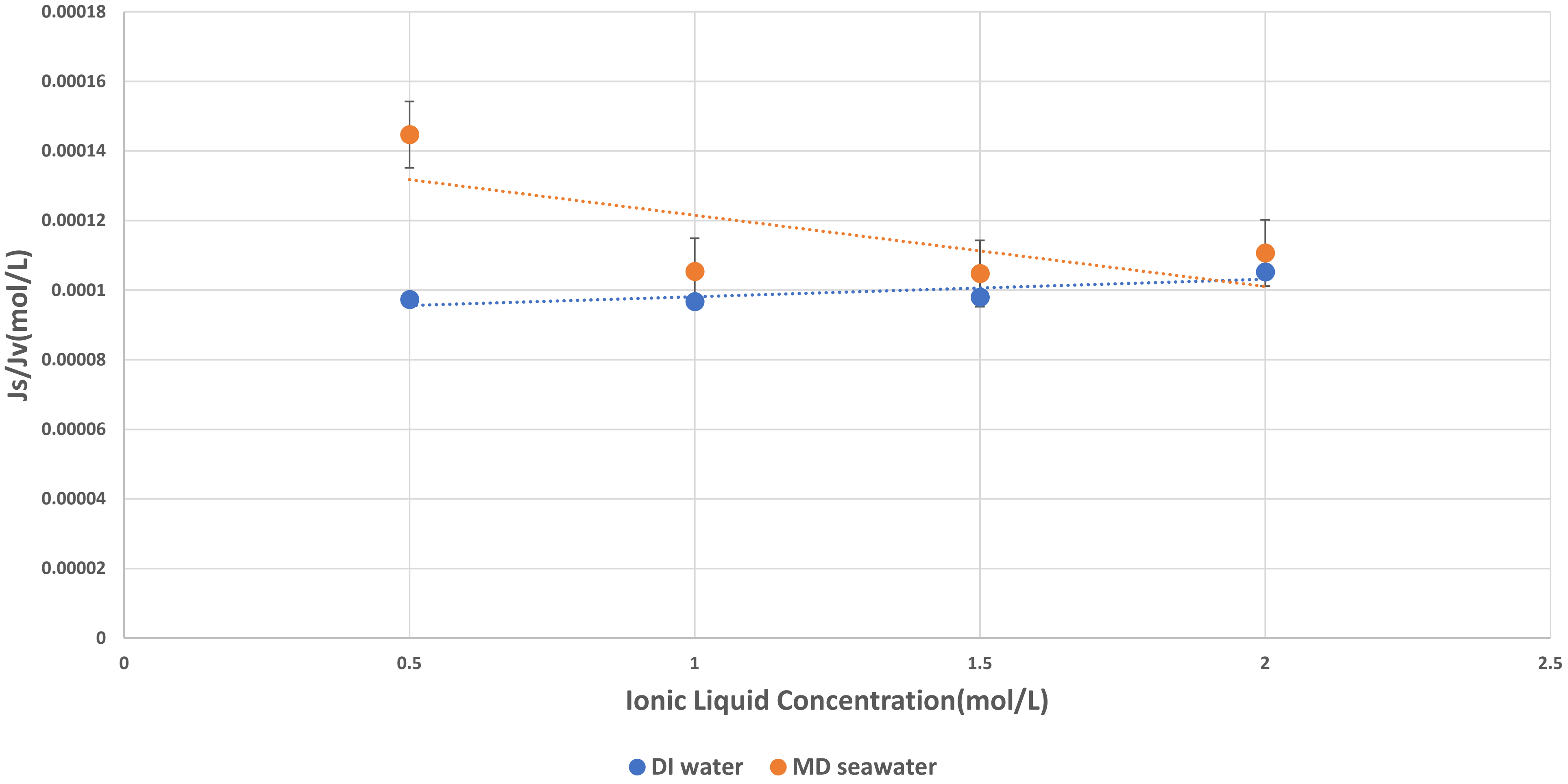
1. **Increasing trend because of the increasing chemical gradient.**
2. **Water flux decreased in MD seawater because ECP happened in feed solution sides.**

Reverse Solute Flux of [P4444][Ph-tet] under FO mode



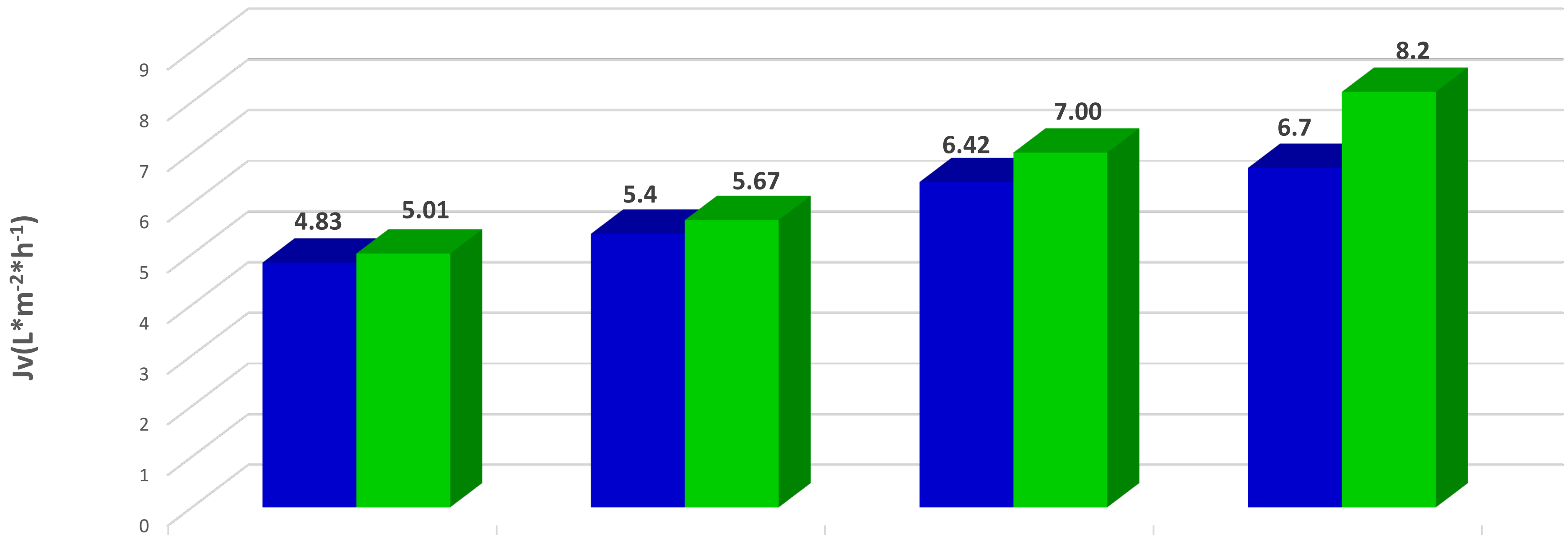
1. Increasing reverse solute flux from increasing chemical gradient.
2. MD Seawater has a little less reverse solute flux because of the concentrative ECP in feed solution side.

FO performance of [P4444][Ph-tet] in DI water and MD seawater



1. It shows higher efficient in higher concentration in MD seawater and shows higher efficient in lower concentration.

Water Flux Comparisn between FO and PRO mode with DI water



	0.5 M	1.0 M	1.5 M	2.0 M
FO mode	4.83	5.4	6.42	6.7
PRO mode	5.01	5.67	7	8.2

Ionic Liquid Concentration(mol/L)

FO mode PRO mode

1. **FO mode has lower water flux because IL will be embedded into support layer making membrane fouling.**
2. **It is hard for large-size molecular ionic liquid across the active layer in PRO mode.**

4. Conclusion

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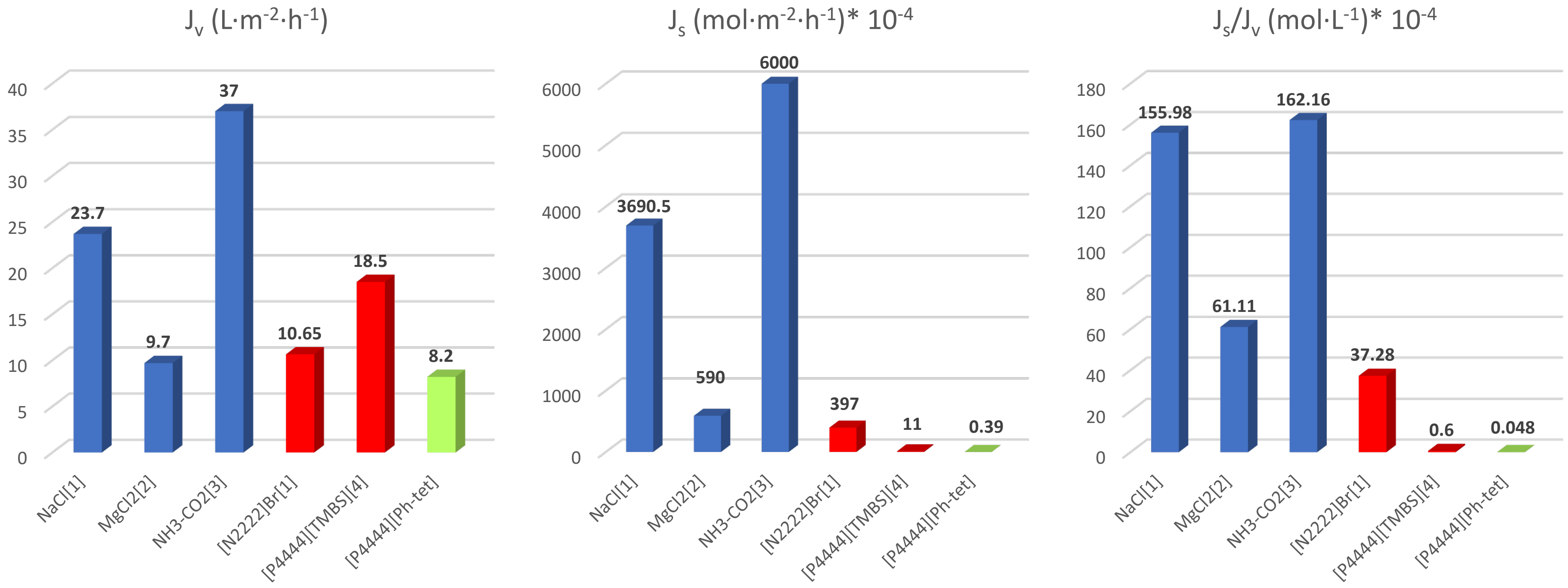
Table. FO performance comparison with literatures

	DS(M)	FS	Membrane	J_v ($L\cdot m^{-2}\cdot h^{-1}$)	J_s ($mol\cdot m^{-2}\cdot h^{-1}$)* 10^{-4}	J_s/J_v ($mol\cdot L^{-1}$)* 10^{-4}
NaCl[1]	2.0	DI water	CTA	23.70	3690.5	155.98
$MgCl_2$[2]	0.5	DI water	CTA	9.70	590.0	61.11
NH_3-CO_2[3]	1.0	DI water	TFC	37.00	6000.0	162.16
[N_{2222}]Br[1]	0.5	DI water	CTA	10.65	397.0	37.28
[P_{4444}][TMBS][4]	1.75	DI water	TFC	18.50	11.0	0.60
[P_{4444}][Ph-tet]	2.0	DI water	TFC	8.20	0.39	0.048

1. H.G. Zeweldi,etc The potential of monocationic imidazolium-, phosphonium-, and ammonium-based hydrophilic ionic liquids as draw solutes for forward osmosis, Desalination 444 (2018) 94–106.
2. A. Achilli, T.Y. Cath, A.E. Childress, Selection of inorganic-based draw solutions for forward osmosis applications, J. Membr. Sci. 364 (2010) 233–241.
3. C. Boo, Y.F. Khalil, M. Elimelech, Performance evaluation of trimethylamine–carbon dioxide thermolytic draw solution for engineered osmosis, J. Membr. Sci. 473 (2015) 302–309.
4. Y. Cai, W. Shen, J. Wei, T.H. Chong, R. Wang, W.B. Krantz, A.G. Fane, X. Hu, Energy-efficient desalination by forward osmosis using responsive ionic liquid draw solutes, Environ. Sci.: Water Res. Technol. 1 (2015) 341–347



J_v,J_s,J_v/J_s comparison between traditional inorganic draw solute and IL draw solute

1. Zeweldi, H. G. et al. Desalination 444, 94-106, doi:10.1016/j.desal.2018.07.017 (2018).

2. Achilli, A., Cath, T. Y. & Childress, Journal of Membrane Science 364, 233-241, doi:10.1016/j.memsci.2010.08.010 (2010).

3. Boo, C., Khalil, Y. F. & Elimelech, M. Journal of Membrane Science 473, 302-309, doi:10.1016/j.memsci.2014.09.026 (2015).

4. Cai, Y. et al. Environmental Science: Water Research & Technology 1, 341-347, doi:10.1039/c4ew00073k (2015).

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