Supplementary Information

Membrane Distillation and High Salinity: Analysis and Implications

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Table S1: Additional experimental details of all the bench-scale studies reported in Table 1 of the manuscript. N/A is Not Available.

	Flow Channel Properties							Membrane Properties					
	Spacer	**Membrane Area (cm^2)**	**Flow area (cm^2)**	**Velocity (m/s)**	**Flow direction**	**Air gap (mm)**	**Feed Water Composition**	**Pore Size (μm)**	**Porosity (%)**	**Thickness (μm)**	**Support layer**	**Module Type (Membrane)**	**Ref**
1	N/A	N/A	N/A	N/A	Counter-Current	8	NaCl	0.2	N/A	175	Yes (N/A)	Flat sheet (Sterlitech)	(1)
2	N/A	N/A	N/A	N/A	Counter-Current	8	NaCl	0.45	N/A	175	Yes (N/A)	Flat sheet (Sterlitech)	(2)
3	N/A	N/A	N/A	N/A	Counter-Current	8	NaCl	0.45	N/A	175	Yes (N/A)	Flat sheet (Sterlitech)	(3)
4	PP[1]	332.5	2.85	0.029	Co-current	3	Seawater	0.3	85	76	N/A	Plate and frame membrane module (Aquastill)	(4)
5	PP[1]	332.5	2.85	0.029	Co-current	3	Seawater	0.3	85	76	N/A	Plate and frame membrane module (Aquastill)	(4)
6	None	22.9	3.96	0.13	Counter-Current	3	NaCl	0.45	79.7	154	Yes (N/A)	Flat sheet (Tisch Scientific)	(5)
7	N/A	N/A	N/A	0.3	Co-current[2]	DCMD	NaCl	0.55-0.22	75	N/A	N/A	Capillary membranes d_{out}/d_{in}=2.6/1.8 mm	(6)
8	New module design to support membrane	12	N/A	1.4	Counter-Current	DCMD (69 kPa)	NaCl	0.45	70	175	PP (5-10 μm)	Flat sheet (Osmonics)	(7)
9	None	600	N/A	0.5	Counter-Current	DCMD	NaCl	0.22	83	110	Scrim	Flat sheet module (GE Osmonics)	(8)
10	None	35	0.284	0.56	Co-current	DCMD	NaCl	0.2	80	60	None	Flat sheet module (Gelman instrument)	(9), (10)
11	None	34.65	0.252	0.59	Counter-Current	DCMD	NaCl	0.2	80	178	PP	Flat sheet module (Gelman instrument)	(11)
12	None	14.4	0.48	0.3	Counter-Current	DCMD	NaCl	0.2	90.8	39	None	Flat sheet module (Changqi)	(12)

13	Tricot woven mesh spacers	138.7	0.575	0.43	Co-current	DCMD	NaCl	0.18	80.1	67	None	Flat sheet module (GE Osmonics)	(13)
14	N/A	108	1.2	0.13	Counter-Current	DCMD	NaCl	0.53	83	188	None	Flat sheet module (Membrana)	(14)
15	N/A	9.1	N/A	N/A	Counter-Current	VMD (4000 PA)	NaCl	0.2	75	163	None	Flat sheet module (Membrana)	(15)
16	N/A	800	N/A	N/A	Outside/In	VMD (1000 PA)	NaCl	0.2	N/A	N/A	N/A	Hollow fibre (Microza modules from Asahi Chemical)	(16)

PP- Polypropylene

[1]Spacers have a thickness 2.0 mm, mesh size 4.0 mm, voidage 0.78 and hydrodynamic angle 60°

[2]Module M1 is used. This module has nine membranes of length 0.52 m arranged in parallel bundles of braided capillaries, each braid containing three membranes.

Table S2: Additional experimental details of all the pilot-scale studies reported in Table 2 of the manuscript. N/A is Not Available.

	Flow Channel Properties								**Membrane Properties**					
	Spacer	**Membrane Area (m^2)**	**Flow area (m^2)**	**Velocity (m/s)**	**Flow direction**	**Air gap (mm)**	**Condenser Material**	**Feed Water Composition**	**Pore Size (μm)**	**Porosity (%)**	**Thickness (μm)**	**Support layer**	**Type**	**Ref**
1	N/A	6.4	N/A	N/A	N/A	VMD 7000Pa	N/A	NaCl	0.2	N/A	N/A	PP	Multi-effect (4 effects)	(17)
2	Yes (2mm thickness)	7.2	0.0048	0.02	Counter-Current	1	Al (1mm)	NaCl	0.3	85	76	None	Spiral wound (6 envelopes, Aquastill)	(18)
3	Yes (2mm thickness)	7.2	0.0048	0.048	Counter-Current	1	Al (1mm)	NaCl	0.3	85	76	None	Spiral wound 6 evaporator, 6 condenser and 12 distillate channels (Aquastill)	(19)
4	HDPE	8.34	N/A	N/A	Counter-Current	2	ETFE (1MM)	NaCl	0.2	0.8	280	Pp	Spiral wound (6 envelopes, Aquastill)	(20)
5	Yes (N/A)	7.2	N/A	0.06	Counter-Current	0.8	Al (1mm)	NaCl	0.3	76	99	N/A	Spiral wound (6 envelopes, Aquastill)	(21)
6	PP	7.2	N/A	0.08	Counter-Current	0.76	PET coated Al (0.08)	NaCl	0.32	76	76	None	Spiral wound (6 envelopes)	(22)
7	PP	7.2	N/A	0.08	Counter-Current	0.76	PET coated Al (0.08)	NaCl	0.32	76	76	None	Spiral wound (6 envelopes)	(22)
8	PP	25.9	N/A	0.04	Counter-Current	0.76	PET coated Al (0.08)	NaCl	0.32	76	76	None	Spiral wound (6 envelopes)	(22)
9	PP	25.9	N/A	0.04	Counter-Current	0.76	PET coated Al (0.08)	NaCl	0.32	76	76	None	Spiral wound (6 envelopes)	(22)
10	PET (2mm thickness)	7.2	N/A	N/A	Counter-Current	0.8	PET film	NaCl	0.32	76	92	None	Spiral wound (6 envelopes)	(23)
11	PET (2mm thickness)	7.2	N/A	N/A	Counter-Current	DCMD	PET film	NaCl	0.32	76	92	None	Spiral wound (6 envelopes)	(23)
12	Yes (N/A)	7.2	N/A	0.06	Counter-Current	DCMD	N/A	NaCl	0.3	76	99	N/A	Spiral wound (6 envelopes, Aquastill)	(21)

References

1. Alkhudhiri A, Darwish N, Hilal N. Treatment of saline solutions using Air Gap Membrane Distillation: Experimental study. *Desalination*. 2013, **323**, 2-7.
2. Alkhudhiri A, Darwish N, Hilal N. Treatment of high salinity solutions: Application of air gap membrane distillation. *Desalination*, 2012, **287**, 55-60
3. Alkhudhiri A, Hilal N. Air gap membrane distillation: A detailed study of high saline solution. *Desalination*, 2017, **403**, 179-186.
4. Duong HC, Duke M, Gray S, Cooper P, Nghiem LD. Membrane scaling and prevention techniques during seawater desalination by air gap membrane distillation. *Desalination*. 2016, **397,** 92-100.
5. Khalifa A, Lawal D, Antar M, Khayet M. Experimental and theoretical investigation on water desalination using air gap membrane distillation. *Desalination*, 2015, **376**, 94-108
6. Gryta M. Concentration of NaCl solution by membrane distillation integrated with crystallization. *Sep Sci Technol*. 2002, **37**(15), 3535-58.
7. Cath TY, Adams VD, Childress AE. Experimental study of desalination using direct contact membrane distillation: A new approach to flux enhancement. *Journal of Membrane Science*, 2004, **228**, 5-16.
8. Hwang HJ, He K, Gray S, Zhang J, Moon IS. Direct contact membrane distillation (DCMD): Experimental study on the commercial PTFE membrane and modeling. *Journal of Membrane Science*. 2011, **371**(1-2),90-8.
9. Martínez-Díez L. Comparison of membrane distillation performance using different feeds. *Desalination*. 2004, **168**(1-3),359-65.
10. Martínez-Díez L, Vazquez-Gonzalez MI. Temperature Polarization in Mass Transport Through Hydrophobic Porous Membranes. *AIChE Journal*. 1996, **42**(7),1844--52.
11. Martínez-Díez L, Florido-Díaz FJ. Desalination of brines by membrane distillation. *Desalination*, 2001, **137**(1-3), 267-73.
12. Li J, Guan Y, Cheng F, Liu Y. Treatment of high salinity brines by direct contact membrane distillation: Effect of membrane characteristics and salinity. *Chemosphere*, 2015, **140**,143-9.
13. Gustafson RD, Murphy JR, Achilli A. A stepwise model of direct contact membrane distillation for application to large-scale systems: Experimental results and model predictions. *Desalination*, 2016, **378**,14-27.

14. Eykens L, De Sitter K, Dotremont C, Pinoy L, Van der Bruggen B. Characterization and performance evaluation of commercially available hydrophobic membranes for direct contact membrane distillation. *Desalination*. 2016, **392**, 63-73.

15. Safavi M, Mohammadi T. High-salinity water desalination using VMD. *Chemical Engineering Journal*. 2009, **149**(1-3),191-5.

16. Wirth D, Cabassud C. Water desalination using membrane distillation : Comparison between inside / out and outside / in permeation. *Desalination*, 2002, **147**,139-45.

17. Minier-Matar J, Hussain A, Janson A, Benyahia F, Adham S. Field evaluation of membrane distillation technologies for desalination of highly saline brines. *Desalination*. 2014, **351**, 101-8.

18. Duong HC, Cooper P, Nelemans B, Cath TY, Nghiem LD. Evaluating energy consumption of air gap membrane distillation for seawater desalination at pilot scale level. *Separation and Purification Technology*, 2016, **166**, 55-62.

19. Bindels M, Brand N, Nelemans B. Modeling of semibatch air gap membrane distillation. *Desalination*, 2018, **430**, 98-106.

20. Schwantes R, Bauer L, Chavan K, Dücker D, Felsmann C, Pfafferott J. Air gap membrane distillation for hypersaline brine concentration: Operational analysis of a full-scale module–New strategies for wetting mitigation. *Desalination*. 2018, **444**,13-25.

21. Eykens L, Hitsov I, De Sitter K, Dotremont C, Pinoy L, Van der Bruggen B. Direct contact and air gap membrane distillation: Differences and similarities between lab and pilot scale. *Desalination*. 2017, **422**, 91-100.

22. Andrés-mañas JA, Ruiz-aguirre A, Acién FG, Zaragoza G. Performance increase of membrane distillation pilot scale modules operating in vacuum-enhanced air-gap configuration. *Desalination*. 2020, **475**,114202.

23. Hitsov I, De Sitter K, Dotremont C, Cauwenberg P, Nopens I. Full-scale validated Air Gap Membrane Distillation (AGMD) model without calibration parameters. *Journal of Membrane Science*. 2017, **533**, 309-320.