

Evaluating the scaling potential in crossflow membrane distillation modules

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Introduction

Membrane distillation (MD) can have a role to play in desalting highly saline brines that have considerable osmotic pressures where RO operation becomes more expensive and problematic. Using MD in this way would allow increasing levels of recovery and help eliminate/reduce the problem of concentrate disposal vexing inland desalination. For this promise to be realized, MD must show itself to be more resistant to scaling than RO and thus not limited by it in the way that RO is. Crossflow membrane distillation modules employing coated hollow fibers developed by Li and Sirkar [1, 2] may show improved resistance to fouling due to improved hydrodynamics and the special coating on these membranes.

Modeling of scaling potential in direct contact membrane distillation (DCMD)

Due to both mass and heat transfer effects the operation of a membrane distillation unit will cause both concentration and temperature polarization. In the case of the inversely soluble salts (calcium sulfate and calcium carbonate) the temperature polarization will tend to reduce the scaling potential at the membrane while concentration polarization will tend to increase the scaling potential on the membrane. In the operation of the cross-flow modules, the brine is fed on the outside of the fibers perpendicular to the fiber axis and the cold distillate is pumped through the lumen of the fibers. Temperature polarization was calculated using the method of Song et al. [3], using the heat transfer correlation of Zukauskas [4] to express the brine side heat transfer in crossflow across the outside fiber:

$$\begin{aligned} Nu_f &= \frac{h_f d_o}{k_o} \\ &= 1.04 Re_o^{0.4} Pr_o^{0.36} \left(\frac{Pr_o}{Pr_w} \right)^{0.25} F_c \end{aligned} \quad (1)$$

For calculating concentration polarization the film model was used and a mass transfer analogue of the Zukauskas equation was used to calculate the concentration polarization.

The overall calculation scheme of the model is shown in Figure 1. An algebraic equation of saturation index as a function of temperature and concentration was developed by regressing reasonable number of saturation indices calculated with a commercial thermodynamic engine (OLI Systems Inc.) for various temperatures and concentrations. Combining this equation with concentration- and temperature-polarization equations permits one to calculate the saturation index at the wall of a membrane fiber where the scaling may exhibit most significant effects on the performance of a MD process.

Typical results for anhydrite and gypsum are shown in Figure 2. As can be seen the region of greatest saturation index is at the fiber layer next to the brine entrance of the module and at the end of the fiber where the distillate enters the module since flux is greatest at this point.

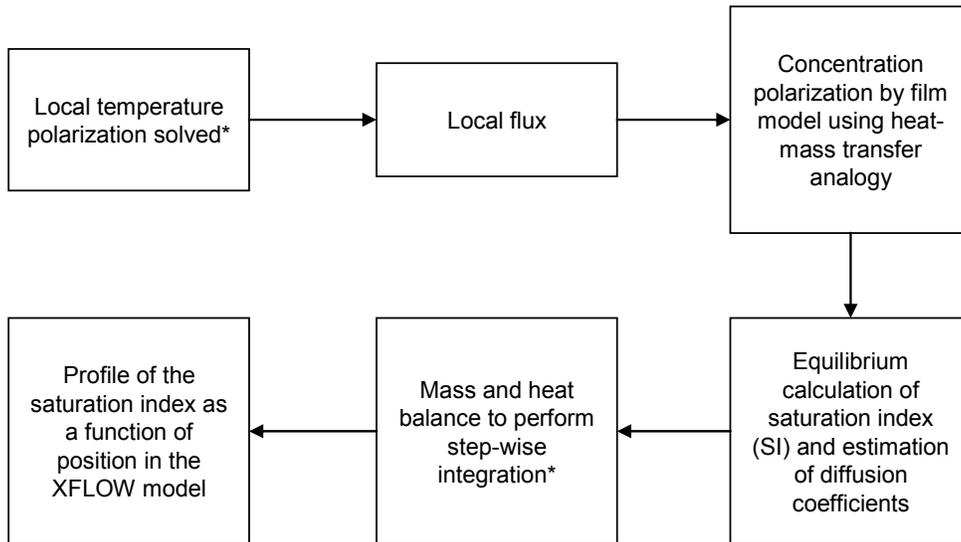


Figure 1. Scheme for calculating saturation indices at different positions in DCMD module.

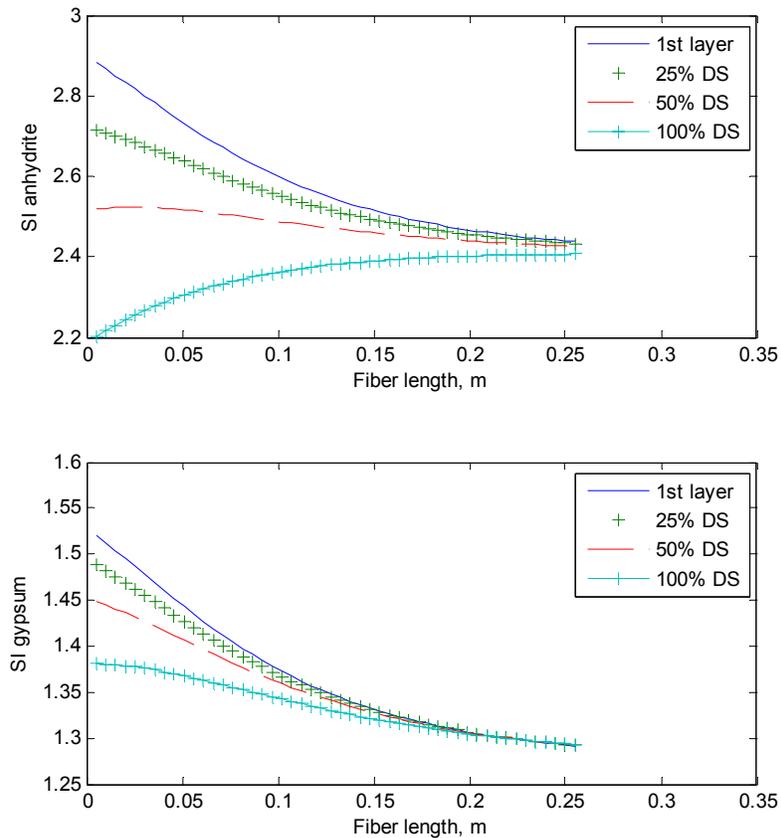


Figure 2. Plot of saturation index for polymorphs of calcium sulfate with 85 °C brine inlet temperature. Module used in simulation has 16 fiber layers composed of 68 fibers with 68 fibers / layer; brine entrance channel window was 25 x 8.6 cm and flow rate was 25 L/min.

Experiments with calcium sulfate and calcium carbonate

Extensive DCMD experiments were run with calcium sulfate and a few experiments were run with calcium carbonate. The modules used had between 168 -250 cm² internal lumen surface area. The distillate inlet temperature was 20 °C and the brine was run at temperatures varying between 60 and 80 °C.

Time of induction was determined by following bulk calcium concentration. As shown in Table 1 for calcium sulfate, even when there was significant supersaturation and in the bulk solution and at the membrane and significant precipitation in the bulk solution, there was no significant drop in the permeate production rate. The few experiments conducted with calcium carbonate show a similar trend. The crossflow hydrodynamics and fiber coating are both thought to contribute to the resistance of the modules to flux decline in the presence of precipitate.

Table 1: Summary of DCMD results with module of 250 cm² and calcium sulfate solution.

DCMD# T/ S _{gyp}	Start [Ca] mol/L	End [Ca]%	Start		End		Induction time min
			mv g/min	Nv kg/m ² -h	mv g/min	Nv kg/m ² -h	
60/ 1.11	0.021	95.5%	3.6	12.86	3.6	12.86	424
60/ 1.93	0.035	92.0%	3.9	13.93	3.9	13.93	80
60/ 1.11	0.021	93.0%	3.6	12.86	3.6	12.86	401-439
70/ 1.17	0.021	96.3%	4.3	15.36	4.3	15.36	233
70/ 1.5	0.0265	73.0%	4.7	16.79	4.55	16.25	40

References

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- 4) Zukauskas, A, Heat Transfer from tubes in Crossflow. *Advances in Heat Transfer*, 8, (1972) 93.