

Numerical Simulation of Concentration Polarization to Estimate Gypsum and Calcium Carbonate Scaling on Membrane Surfaces

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Abstract

Introduction:

One of the main concerns of membrane plant designers and operators is to avoid the membrane fouling produced by salt precipitation (scaling). Scaling is produced when a salt solubility product is exceeded as a consequence of the concentration process [1]. Gypsum and calcium carbonate scaling are typical problems. The scaling potential of calcium carbonate is given by the Langelier Saturation Index (LSI), and for gypsum the percentage of saturation is used. The scaling parameters are evaluated in the final element of the membrane system as the higher concentrations are found at this point (Figure 1). The standard procedure calculates scaling from the expected bulk composition of the concentrate. However, the concentration on the membrane surface can be significantly higher than the bulk concentration because of concentration polarization [2]. Therefore, there is a risk of scaling underestimation.

In this work, a numerical model was performed to estimate the effect of concentration polarization on the scaling parameters of reverse osmosis system using spiral-wound modules with membrane spacers.

Use of COMSOL Multiphysics®:

Like other authors [3-5], the domain was the space inter-membranes filled by an ionic solution and excluding the transversal section of the spacers (Figure 1). A physics-controlled meshed was used.

The Laminar Flow or the Turbulent Flow interfaces were used to model the hydrodynamics of the membrane system. The Nernst-Planck Equations interface was used to model the ionic transport in water. The boundary conditions at the membrane surfaces were obtained from the solution-diffusion model suitable for reverse osmosis membranes: The boundary condition for the Flow interfaces was the volumetric flow through the membrane that is a function of pressure, temperature and ion concentration; the boundary condition for the Nernst-Planck Equations interface was the solute transport through the membrane.

To assure convergence, the solving procedure was structured in a series of steps: first, calculation of the hydrodynamics independently from concentration using periodic boundary conditions; second, calculation of the ionic transport; and finally, calculation of both modes together.

Results:

Two situations were independently studied: gypsum scaling and calcium carbonate scaling. The ionic systems included the ions forming the precipitant salt together with sodium and chloride. In Figure 2, we can see that the regions with $LSI > 0$ (high scaling potential for calcium carbonate) are placed next to the spacers where a stagnant flow is combined with a flux that moves ions towards the membrane. Figure 3 shows more clearly the situation on the membrane surface. Figure 4 shows a similar case for gypsum scaling (saturation $> 100\%$) at the same positions. Parametric studies evaluated the influence of velocity and composition on the scaling parameters.

Conclusion:

The results of this study demonstrated the convenience of modeling the polarization phenomenon to estimate the scaling potential. As an example, some situations in which scaling was not expected according to bulk composition, but having a localized scaling due to polarization were shown. The developed model can be applied to obtain the suitable chemical and hydrodynamics conditions to avoid scaling.

Reference

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- [3] Minkyu Park, Joon Ha Kim, Numerical analysis of spacer impacts on forward osmosis membrane process using concentration polarization index, *Journal of Membrane Science* 427, 10–20 (2013)
- [4] A.L. Ahmad et al., Integrated CFD simulation of concentration polarization in narrow membrane channel, *Computers and Chemical Engineering*, 29, 2087–2095 (2005)
- [5] S. Wardeh, H.P. Morvan, CFD simulations of flow and concentration polarization in spacer-filled channels for application to water desalination, *Chemical Engineering Research and Design*, 86, 1107-1116 (2008)

Figures used in the abstract

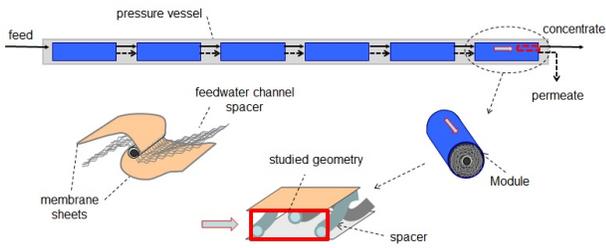


Figure 1: Schematic representation of the module in-series system, and position of the studied domain.

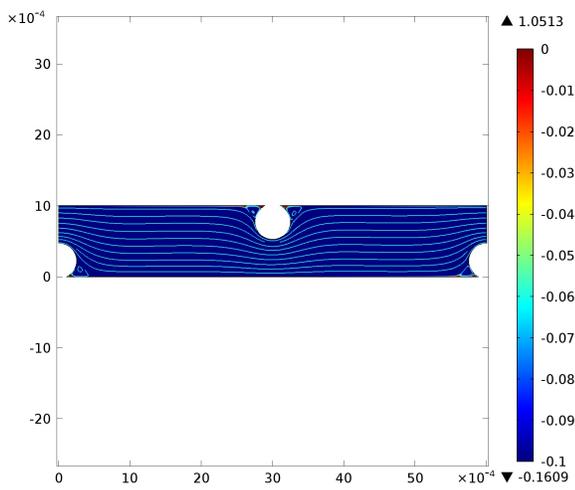


Figure 2: Flow streamlines and LSI mapping.

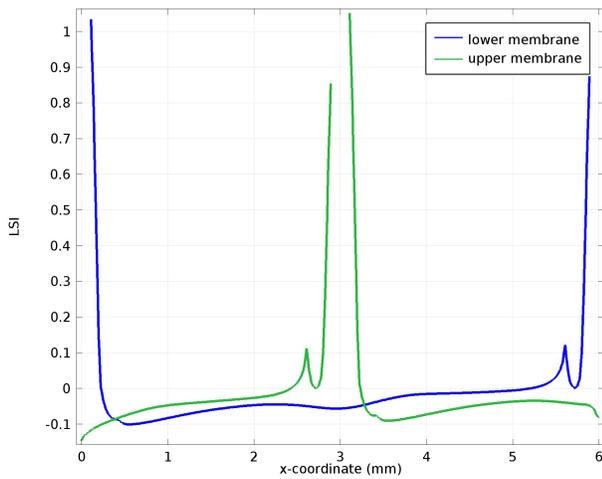


Figure 3: LSI values in the solution in contact with membrane.

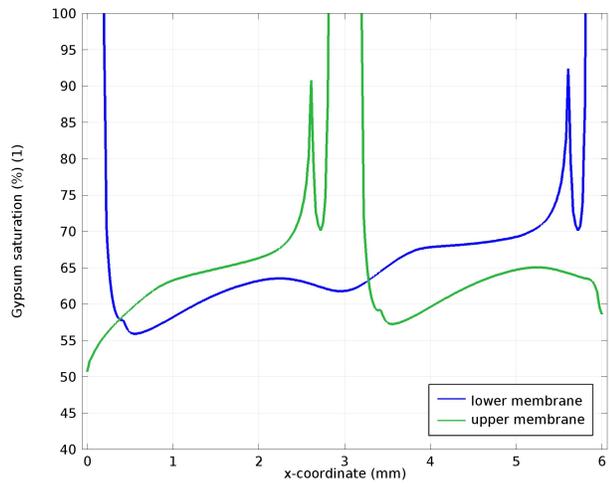


Figure 4: Gypsum saturation index in the solution in contact with membrane.