30e A Predictive Numerical Model for Unsteady State Scale Formation in a Spiral-Wound Membrane Module with Channel Spacers

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Mineral salt scaling is a major impediment to high recovery operation of membrane desalination processes. When the concentrations of mineral salt ions near and at the membrane surface exceeds saturation, mineral salts may crystallize and scale the membrane surface, thereby leading to permeate flux decline and ultimately to shortening of the membrane operational lifetime. Although various salts have been associated with membrane scaling, calcium sulfate dehydrate (gypsum), barium sulfate and calcium carbonate are most commonly encountered in inland water desalination [1]. While calcium carbonate scale can be minimized by acid dosing of the RO feed (typically at pH 6.5), calcium sulfate and barium sulfate solubility is insensitive to pH. As part of a larger effort to mitigate mineral scaling, there is a considerable practical interest in fundamental studies of the mechanism of mineral scale formation along membrane surface and the coupling with concentration polarization (CP).

In order to elucidate the development of mineral scale formation, previous modeling efforts have focused on gypsum and calcium carbonate as model systems, with the goal of developing fundamental models of the kinetics of membrane surface blockage by coupling concentration polarization (CP) predictions with information on the rate of surface crystallization [2- 4]. Previous models, however, have relied on the use of an “average” CP based on the simple film model. Therefore, such models are incapable of predicting the axial scale development along the membrane. Other models have introduced a simplifying local equilibrium assumption with respect to mineral salt crystal formation, thereby resulting in a model that is incapable of predicting the time evolution of mineral scale formation. A number of studies have also made the erroneous assumption that the scale layer can be modeled as a porous cake layer, an assumption that has been proven experimentally to be inappropriate. As a result, previous models are inadequate for quantitative predictions of the dynamics of surface mineral scale formation in cross flow membrane operation.

In the present work, a numerical model was developed to simulate the temporal and axial development of mineral scale and the associated membrane surface blockage. The model is based on coupling of a comprehensive finite element concentration polarization (CP) model with a kinetic surface crystallization (KSC) model. In this CP/KSC model the impact of mineral scale on flux decline is considered to be due to pore blockage, as has been verified by independent experimental studies with gypsum scaling as a model system. The CP model consists of the fully coupled complete governing equations of momentum and mass transfer that describe the hydrodynamics and solute transport in a membrane channel with spacer filaments. The KSC model is based on a surface crystal growth model with the kinetic parameters obtained from experimental data of real-time single-crystal growth kinetics. Although the current approach is applicable, in principle, to any mineral salt, gypsum was selected as a model scalant as it forms tenacious scale due, in part, to its lack of sensitivity to mitigation via pH control.

Simulation results of gypsum scale formation revealed that surface scale coverage in the axial direction was strongly dependent on the CP profile. It was revealed that certain spacer geometries and geometrical imperfections in the membrane channel can induce recirculation regions (or stagnation zones) which can have a significant influence on the level of concentration polarization. In these regions back diffusion is reduced, thereby resulting in high local levels of concentration polarization. Simulation results show an early accumulation of scale formation near the spacers. In spiral-wound RO modules, this crystallization near the filaments may provide initial “hot spots” for the initiation of scaling and subsequent progression across the membrane surface. The average flux decline and membrane surface coverage due to gypsum scaling were calculated and compared to experimental results of gypsum scaling from a laboratory plateand-frame test cell. The modeling approach developed in the present study provides a practical tool for optimizing operating condition so as to minimize scale formation. The model should prove useful in assessing the adequacy of membrane module design for applications in which high concentration of mineral salt ions in the RO feed could result in membrane scaling. References 1. Shih, W-Y, A. Rahardianto, R-W. Lee and Y. Cohen "Morphometric Characterization of Calcium Sulfate Dihydrate (Gypsum) Scale on Reverse Osmosis Membranes," J. Membrane Science., in press. 2. Borden, J., J. Gilron, et al. (1987). "Analysis of Ro Flux Decline Due to Membrane-Surface Blockage." Desalination 66: 257-269. 3. Brusilovsky, M., J. Borden, et al. (1992). "Flux Decline Due to Gypsum Precipitation on Ro Membranes." Desalination 86(2): 187-222. 4. Gilron, J. and D. Hasson (1987). "Calcium-Sulfate Fouling of Reverse-Osmosis Membranes - Flux Decline Mechanism." Chemical Engineering Science 42(10): 2351-2360.