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

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Aim

To estimate the potential of salt precipitation (*scaling*) in spiral-wound membrane modules as a consequence of the concentration polarization of ionic species.

Scaling indices: LSI for calcium carbonate and gypsum saturation.

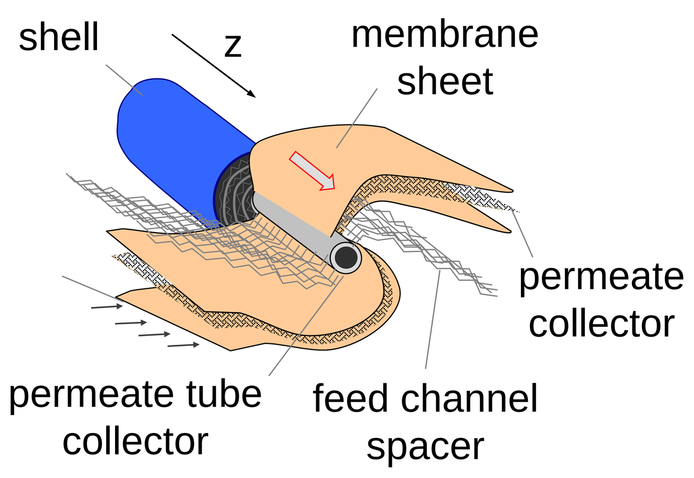

Fig. 1. Structure of spiral- wound module

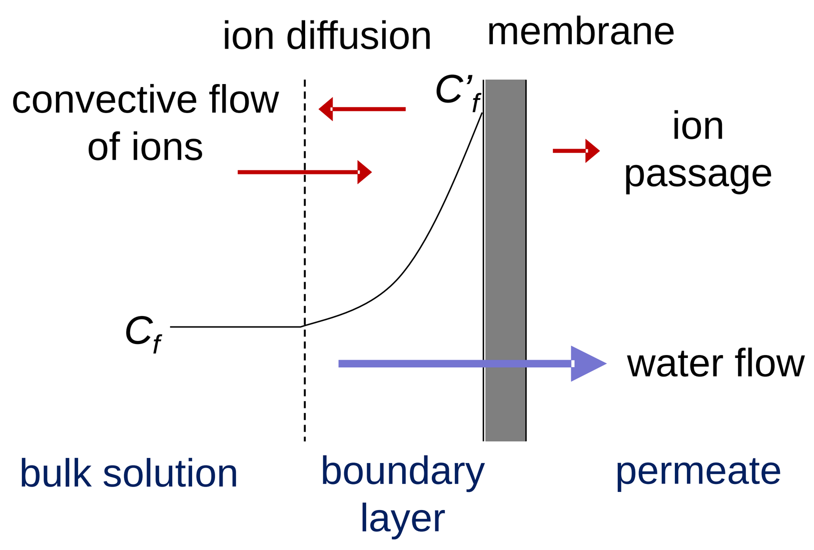

Fig. 2. Concentration polarization

Cases studied

- Reverse osmosis membrane of permeability: A_w = 2,1 cm^3·m^{-2}·s^{-1}
- Ionic systems for $CaCO_3$ scaling (I) and gypsum scaling (II):
  - I) $[Na^+] = [Cl^-]$ = 20 mol/m^3 $[Ca^{2+}]=[HCO_3^-]+[CO_3^{2-}]$=3 mol/m^3
  - II) $[Na^+] = [Cl^-]$ = 20 mol/m^3 $[Ca_2^+]=[SO_4^{2-}]$=6 mol/m^3
- Operating conditions: *pH* = 6.7, *T* = 25 ºC, *P* = 5 bar

Model

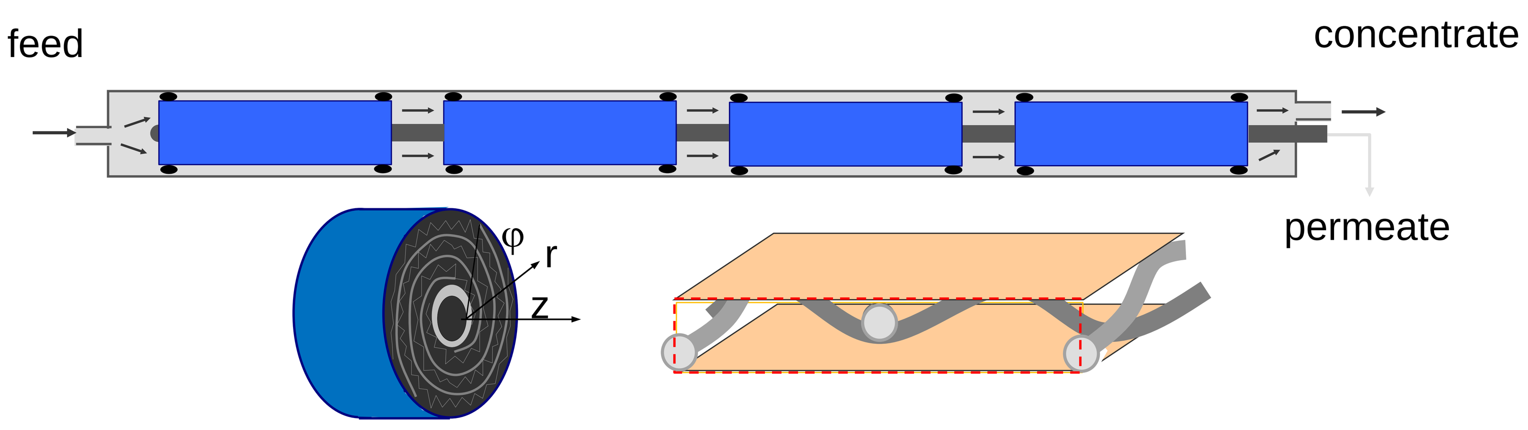

Figure 3. Domain selection

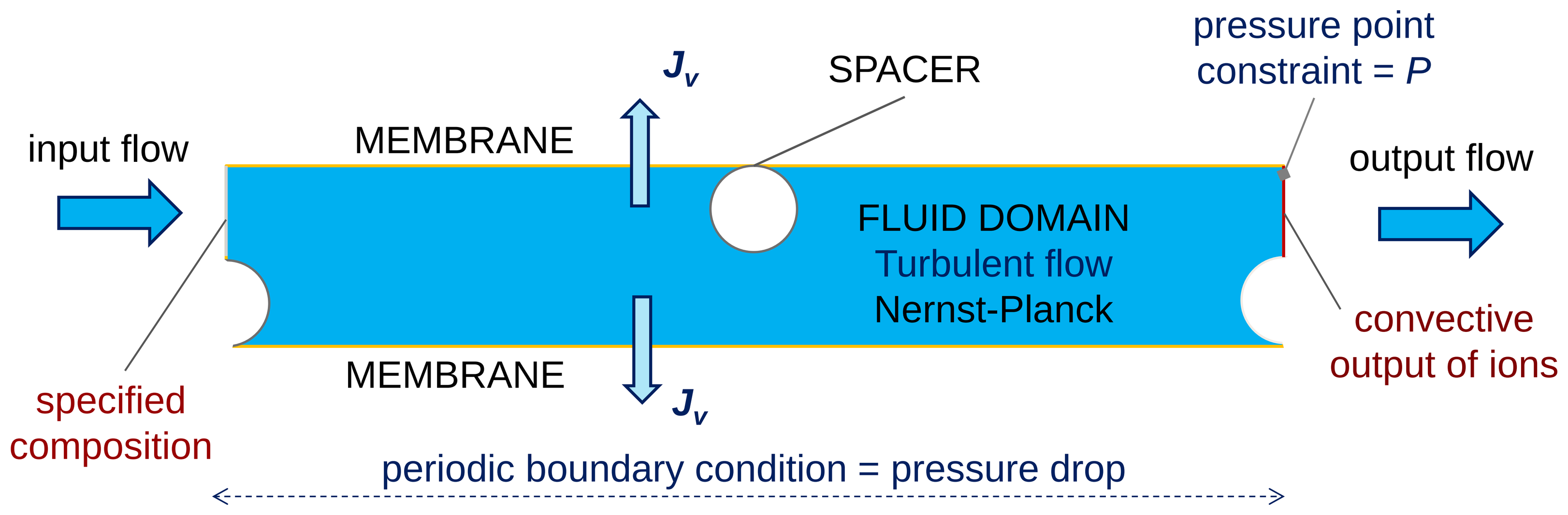

Fig. 4. Boundary specification

- **Flow**
  - → Different cross-flow velocity attained by varying pressure drop
  - → Volumetric flux calculated from phenomenological model:

$$J_v = A_w \cdot (\Delta P - \Delta \Pi)$$

- **Ionic transport**
  - → Nernst-Planck mode
  - → High rejection → ‘No flux’ condition applied to membranes

Solving procedure

- **Meshing**
  - → Fluid domain: ‘finer’ free-triangular mesh → cell Reynolds <3
  - → Membranes and spacers walls: boundary layer mesh
- **Solver steps**
  1. Solution of hydrodynamics
  2. Solution of ionic transport for given hydrodynamics
  3. Application of segregated solver to the coupled model

Conclusions

→ The higher concentration in the membrane wall caused by concentration polarization compared to that of the bulk implies a risk of scaling underestimation if the calculation is based on bulk conditions

→ The developed model can be useful to set suitable chemical and operating conditions in the concentrate to minimize the risk of scaling

Results

→ The low cross-flow velocity in the areas near the base of the spacer causes the greatest values of LSI (scaling occurs for LSI >0)

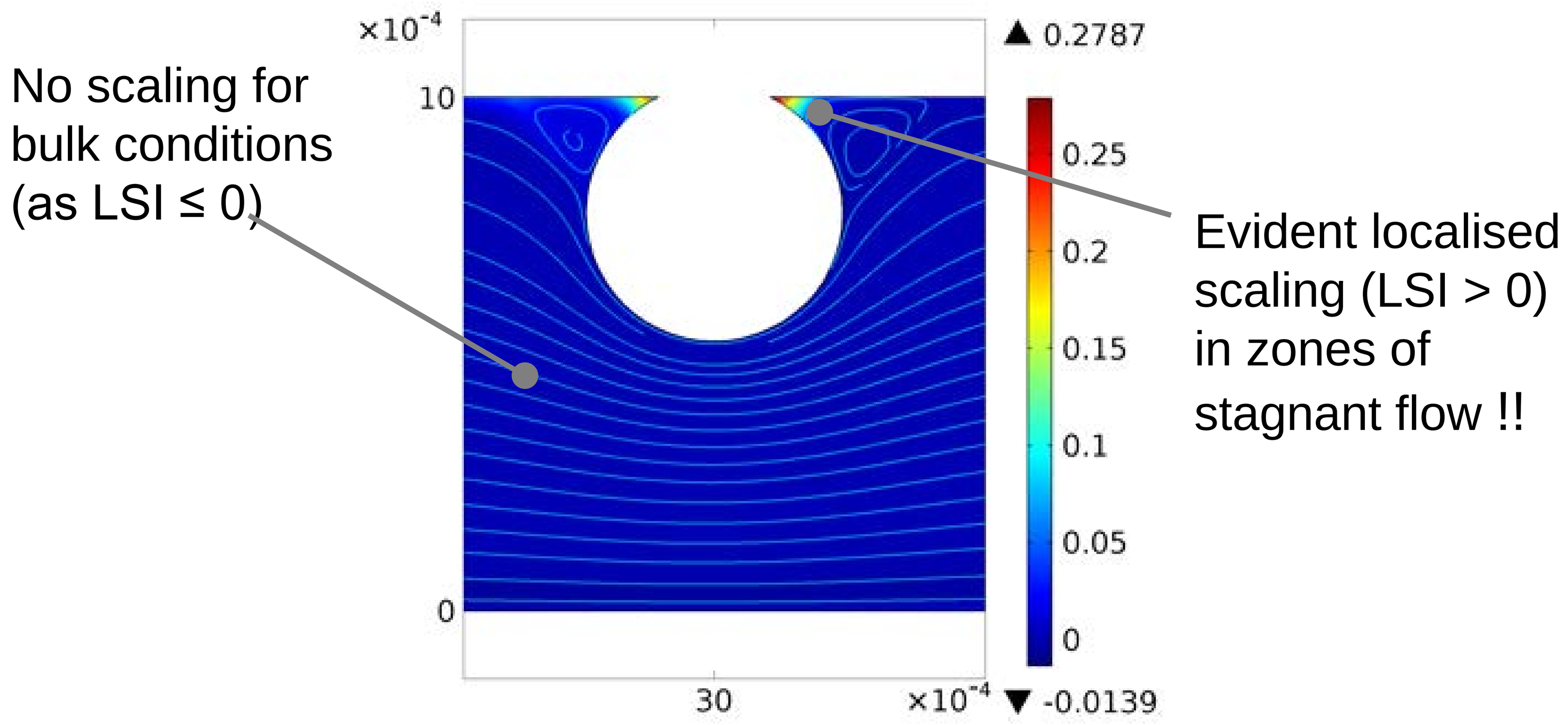

Figure 5. Flow streamlines and mapping of the Langelier Saturation Index (LSI) at cross-flow velocity of 0.5 m/s

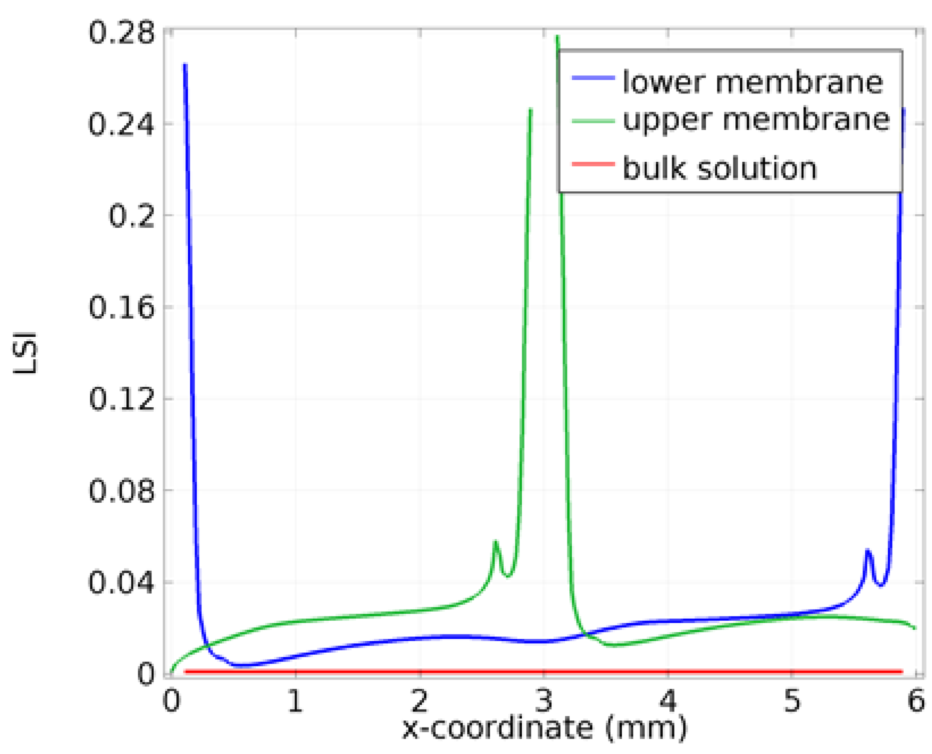

Figure 6. Flow streamlines and LSI mapping at cross-flow velocity of 0.5 m/s

→ Fig. 6 shows LSI > 0 on the whole membrane area, predicting calcium carbonate scaling in the long term

→ For gypsum similar results were obtained (not shown)

→ Acidification or proper change of operating conditions can correct the scaling.

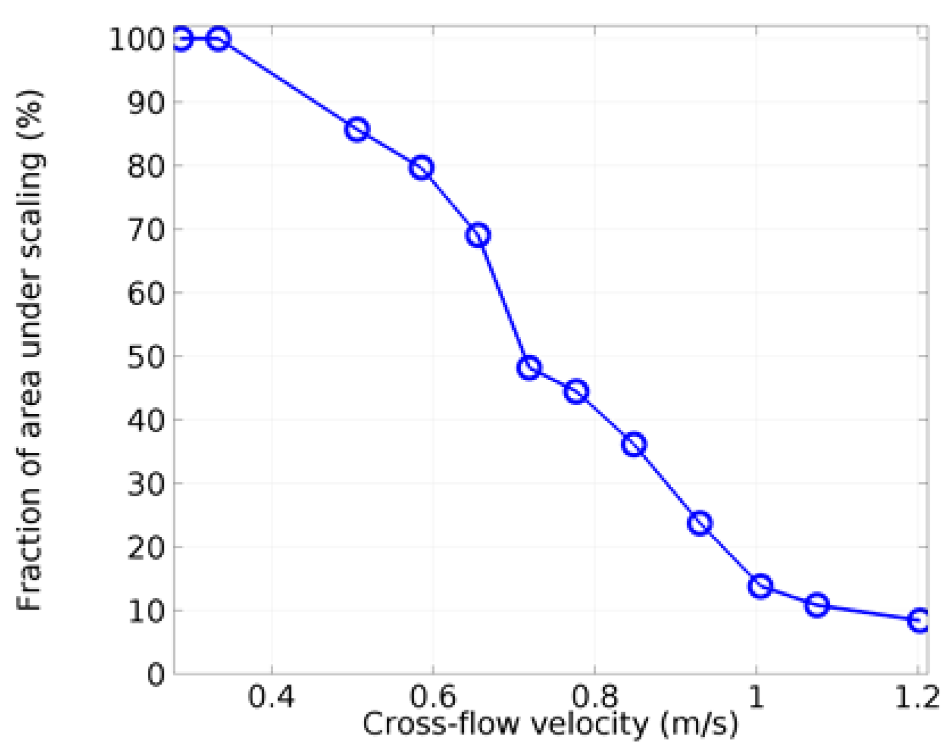

Figure 7. Fraction of membrane area under scaling condition of LSI>0 at different cross-flow velocities

→ Fig. 7 shows how the membrane area under scaling is reduced as a consequence of the increase in cross-flow velocity.

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