Filtration of several uncharged solutes on reverse osmosis membrane: theory modification based on slip boundary
Farsi, Ali; Boffa, Vittorio; Christensen, Morten Lykkegaard

Publication date:
2012

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

? Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
? You may not further distribute the material or use it for any profit-making activity or commercial gain
? You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us at vbn@aub.aau.dk providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from vbn.aau.dk on: december 17, 2018
Filtration of several uncharged solutes on reverse osmosis membrane: Theory modification based on slip boundary

Ali Farsi*, Katja König, Vittorio Boffa, Morten Lykkegaard Christensen
Department of Biotechnology, Chemistry and Environmental Engineering, Aalborg University, 9000 Aalborg, Denmark

Introduction
- Nanofiltration is a promising membrane technique with a large number of applications in treatment of process water, drinking water and wastewater.
- More specifically, nanofiltration can be used to remove small organic molecules. Models for nanofiltration are usually based on non-slip condition which can be modified to slip condition as a rational assumption.
- In this paper, the effects of slip length on the rejection of uncharged solutes such as glycerol and glucose along the effective membrane thickness have been investigated. The Bowen nanofiltration transport model based on Hagen–Poiseuille equation for solvent velocity (no slip condition) has been modified by several slip conditions and a new model allowing calculation of uncharged solute rejection on the basis of a binary membrane parameter (slip length and pore radius) was developed.

Model development

1. The fundamental transport equation to be used for uncharged solutes

\[ j_i = K_i c_i - \frac{D_i}{R T} \frac{dc_i}{dx} \] (1)

\[ \mu = R T \ln a + \frac{V_i}{P} + \text{Constant} \] (2)

\[ f_s = K_s c_s - \frac{D}{R T} \frac{dc_s}{dx} \] (3) & \[ j_s = c_p u \] (4)

2. The average velocity equation in a rectangular nanopore with considering slip length (b)

\[ u = \frac{h^2}{12 \eta} \left( 1 + \frac{6b}{h} \right) \left( \frac{dp}{dx} \right) \] (5)

\[ \left( \frac{dp}{dx} \right) = \frac{12 \eta}{h^2 + 6bh} u \] (6)

3. Develop the Rejection Equation

\[ (3), (4), (6) \rightarrow c_r = K_r c_r - \frac{D}{R T} \frac{dc_r}{dx} + \frac{c_0}{V_r} \frac{12 \eta}{h^2 + 6bh} u \] (7)

If \[ \alpha = \frac{D}{R T} V_r \] & \[ \beta = K_r + \alpha \]

and \[ \epsilon = \left( \frac{1 - \frac{1}{\beta}}{\frac{1}{\beta}} \right) + \frac{1}{\beta} \]

\[ Rej = 1 - \frac{1}{\epsilon} \]

Model procedure

- Introduction
- Transport model
- Reverse osmosis
- Biochemical processes
- Membrane rejection
- Numerical simulation
- Fluid flow processes
- Biochemical effects
- Membrane simulation
- Numerical validation

Model Input

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L )</td>
<td>1 [m h^{-1}]</td>
<td>Solvent velocity</td>
</tr>
<tr>
<td>( b )</td>
<td>0.1–0.005 [nm]</td>
<td>Slip length</td>
</tr>
<tr>
<td>( C_i )</td>
<td>10 [mol m^{-3}]</td>
<td>Bulk feed concentration</td>
</tr>
<tr>
<td>( T )</td>
<td>298.15 [K]</td>
<td>Absolute temperature</td>
</tr>
<tr>
<td>( R )</td>
<td>0.001 [N m^{-1}]</td>
<td>Solvent viscosity within pores</td>
</tr>
<tr>
<td>( Z )</td>
<td>2 [μm]</td>
<td>Width of pore</td>
</tr>
<tr>
<td>( N_p )</td>
<td>1000000</td>
<td>The points number in pore</td>
</tr>
</tbody>
</table>

Solute | \( D_i \) [10^{-3} m²/s] | \( r_s \) [nm] | \( V_r \) [cm³/mol] | Ref |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Glycerol</td>
<td>0.95</td>
<td>0.26</td>
<td>70.8</td>
<td>Kiyosawa (1991)</td>
</tr>
<tr>
<td>Glucose</td>
<td>0.69</td>
<td>0.365</td>
<td>110</td>
<td>Birch (1997)</td>
</tr>
</tbody>
</table>

Results

1. Glycerol

Rej/ΔRej Conc. vs. Pore Length Z for various slip lengths b ((15): b = [0, 1e-10, 5e-11, 1e-11, 5e-12] m)

Conclusion
The obtained results show that by increasing the slip length which has been related to the pore size and membrane materials, the solute rejection can be increased up to approximately 5%. Concerning these results, the solute rejection can be increased by synthesis of a membrane layer with optimum conditions according to slip length.

Acknowledgements
The authors would like to thank Danish National Advanced Technology Foundation for project funding (Project # O99-2011-1).

*Corresponding Author: Address: Department of Biotechnology, Chemistry and Environmental Engineering, Aalborg University, Room: D114, Sohngaardsholmsvej 57, 9000 Aalborg, Denmark
Telephone: +4599403663, Email: alf@bio.aau.dk