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Membrane contactors for intensified physical solvent absorption biogas purification processes: a parametric study.

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Introduction

Context:
Membrane contactors are one of the most promising technology for the intensification of gas-liquid absorption processes with the following advantages [1,2]:
- Large specific area of membrane module
- High expected intensification factors
- Independent choice of gas and liquid flowrates

Adressed questions:
- What is the maximal intensification factor of membrane contactors for physical absorption processes compared to packed columns?
- What are the best flow configurations (i.e. liquid flowing inside or outside the fibers), module design (packing factor), membrane performances (mass transfer coefficient)?
- What is the interplay between intensification and specific energy requirement?
- How do solvent viscosity and gas solubility impact the intensification performances?

Materials and Method

Equations:
- Henry coefficient: \[ H_t = \frac{\mu_{gas}}{\rho} \]
- Absorbed CO₂ molar flow: \[ N_{CO_2} = \frac{Q_0}{v} \frac{X_{CO_2} - X_{CO_2,\text{out}}}{\Delta \mu_{H_2O}} \]
- Transfer coefficient: Graetz equations
- Resistance in series approach
- Differential equations: \[ \frac{d\Delta \mu}{dz} = K_e \frac{\Delta \mu}{\rho \Delta \mu_{H_2O}} - \frac{Q_0}{v} \Delta \mu_{H_2O} \]

Parameters:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>( Q_{in} )</td>
<td>Volume flow of gas at the entrance</td>
<td>0.0139</td>
</tr>
<tr>
<td></td>
<td>( T )</td>
<td>Temperature</td>
<td>298</td>
</tr>
<tr>
<td></td>
<td>( \alpha )</td>
<td>Selectivity</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>( D_{int} )</td>
<td>Internal diameter of the module</td>
<td>0.17</td>
</tr>
<tr>
<td></td>
<td>( r_{int} )</td>
<td>Hollow fiber internal radius</td>
<td>450</td>
</tr>
<tr>
<td></td>
<td>( e )</td>
<td>Membrane thickness</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>( \mu_g )</td>
<td>Gas viscosity</td>
<td>10^(-4)</td>
</tr>
<tr>
<td></td>
<td>( D_{eff} )</td>
<td>Diffusion coefficient in gas phase</td>
<td>1.78x10^-5</td>
</tr>
<tr>
<td></td>
<td>( C_{in} )</td>
<td>inlet CO₂/CH₄ molar ratio</td>
<td>0.4/0.6</td>
</tr>
<tr>
<td></td>
<td>( C_{out} )</td>
<td>Outlet CO₂ molar ratio</td>
<td>&lt; 0.02</td>
</tr>
<tr>
<td>Variable</td>
<td>( q )</td>
<td>Module packing fraction</td>
<td>0.1 – 0.9</td>
</tr>
<tr>
<td>parameters</td>
<td>( u/w )</td>
<td>Intestinal velocity</td>
<td>0.1 – 20</td>
</tr>
<tr>
<td></td>
<td>( k_m )</td>
<td>Membrane effective mass transfer coefficient</td>
<td>10^(-4) – 10^(-5)</td>
</tr>
<tr>
<td></td>
<td>( P )</td>
<td>Pressure</td>
<td>1 – 10</td>
</tr>
</tbody>
</table>

Table 1: Fixed and variable parameters in this work

Main results

Influence of solvent properties
Performance of the solvents decreases as follows:
- methanol > N-methyl-2-pyrrolidinone (NMP) > Propylene carbonate (PC) > selexol > water
- Key factors: low CO₂ solubility in water, high viscosity of selexol.

Influence of membrane properties
Decrease of the \( k_m \) value decreases the transferred molar flow.
- Methanol and NMP are the most efficient solvents and the most affected.
- For water, limitation is made by the liquid side instead of the membrane

Influence of flow configuration (liquid in or liquid out)
- Optimum of the compactness value in liquid-out configuration. Value is dependent of the solvents used.
- Always higher value of compactness is better in liquid-in configuration.
- Strong dependence of the correlation used

Comparison with packed columns: Intensification possibilities
High value of intensification factors
- Intensification factor independent of the inlet pressure

Conclusion and perspectives

This study intended to explore the possibilities of process intensification thanks to membrane contactors for absorption processes based on physical solvents. A systematic parametric study has been performed for CO₂ absorption in five different solvents showing a broad range of solubility and viscosity.

The results obtained here show however that solvent viscosity strongly impacts the interest and feasibility of membrane contactors compared to packed columns. Because the solubility / viscosity interplay plays a key role in the maximal intensification performances, a parametric study on operating temperature would be interesting. It is known that a lower temperature generally increases solubility but also viscosity. The intensification / energy trade-off is thus likely to strongly depend on the solvent temperature. The influence of solvent volatility, which has not been taken into account in this study, should also be considered.

It is expected that this exploratory parametric study will stimulate further researches on intensified processes with physical solvents.

References