Advanced Membrane Reactors: Fuel Decarbonisation in IGCC’s: H₂ versus CO₂ Separation

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Introduction
Reactor modelling studies indicated possible application potential of CO₂-selective Water-Gas-Shift Membrane Reactors (WGS-MR) within Integrated Gasification Combined Cycles (IGCC). Both H₂- and CO₂-selective WGS-MR’s were assessed with respect to implementation downstream of the gas cleaning section upon dry-fed entrained-flow coal gasification. Several variables were manipulated during modeling to obtain both elevated efficiencies and carbon capture ratios. The simulation results will serve to continue or stop the development of CO₂-selective membranes.

Modelling & Results
AspenPlus was applied for the simulations, suited with a dedicated Fortran based membrane model developed by ECN and the exergy analysis tool ‘Exercom’. The membrane permeation was set at 2.0 \( \times 10^{-6} \) mol m\(^{-2}\) s\(^{-1}\) Pa\(^{-1}\) for both cases; this value serves as target for H₂-selective membranes.

Key design variables:
- Steam/CO-ratio: 1.3 – 2.0 (molar basis)
- Membrane Surface: 5,000 – 30,000 m\(^2\)
- Sweep Pressure: 3.0 – 23.0 bara (H₂ WGS-MR)
- Sweep Flow: 13.0 – 56.0 kg/s (CO₂ WGS-MR, 6 bara, 175 ºC)

Conclusions and Recommendations
Coal gasifiers always produce H₂/CO₂-ratios higher than unity, resulting in higher H₂ partial pressures, which are beneficial in membrane permeation. The steam sweep flow applied in CO₂-selective WGS-MR results in higher efficiency penalties than H₂-selective WGS-MR, when similar carbon capture ratios are pursued. Doubling the permeation target for CO₂-selective WGS-MR offers potential for development of CO₂-selective membranes.

Sensitivity Analysis
The subsequent sensitivity analysis demonstrated that doubling the permeation of CO₂-selective WGS-MR, reduces the sweep steam flow by a factor 4 at an efficiency of 40.7%

<table>
<thead>
<tr>
<th>Case</th>
<th>Output (MWₑ)</th>
<th>Efficiency</th>
<th>Carbon Capture</th>
<th>Membrane Area (m²)</th>
<th>Sweep Steam (kg/s)</th>
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</thead>
<tbody>
<tr>
<td>IGCC Base Case</td>
<td>500</td>
<td>47.9</td>
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<tr>
<td>IGCC Selexol (HT- &amp; LT-WGS)</td>
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<td>39.9</td>
<td>91.7</td>
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<td>38.1</td>
<td>85.5</td>
<td>22500</td>
<td>55.6</td>
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