Modularization of Ceramic Hollow Fiber Membrane Technology for Air Separation

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Objective:
Develop membrane stack and module for air separation and oxygen production using ceramic hollow fiber membrane technology

Strategic alignment of project to Fossil Energy objectives

• **Cost of Energy and Carbon Dioxide (CO2) Capture**
  • Using pure oxygen instead of air for combustion of power plant produces CO2, no need to separate nitrogen from downstream;
  • Can reduce the cost and simplify the system for CO2 capture.

• **Power Plant Efficiency Improvements**
  • Pure oxygen instead of air increases efficiency of power plant;
  • Cost-effective, reliable technologies to improve the efficiency of coal-fired power plants.
Fabrication of Membranes
Fabrication of Membranes
Fabrication of Membranes
Gas Diffusion Performance of Substrate

- Open microchannels
- Close microchannel pores
Microstructure of Membrane Device
EDS Analysis of Membrane

Fe

Sr

Zn

La

Co
Oxygen Permeation Performance

a) Oxygen permeation performance as a function of sweep gas flow rate at different temperatures (950°C, 900°C, 850°C, 800°C).

b) Logarithmic plot of oxygen permeation rate ($J_o$) vs. reciprocal temperature ($1000/T$) for various sweep gas flow rates (80 mL·cm⁻²·min⁻¹, 70 mL·cm⁻²·min⁻¹, 60 mL·cm⁻²·min⁻¹, 50 mL·cm⁻²·min⁻¹, 40 mL·cm⁻²·min⁻¹, 30 mL·cm⁻²·min⁻¹, 20 mL·cm⁻²·min⁻¹, 10 mL·cm⁻²·min⁻¹).

c) Activation energy as a function of sweep gas flow rate.

d) Oxygen permeation rate ($J_o$) over time for a specific sweep gas flow rate.
Characterization of Membrane
Oxygen Permeation Performance

(a) Oxygen permeation flux ($J_0$) as a function of sweep gas flow rate at different temperatures.

(b) Logarithm of oxygen permeation flux ($\log(J_0)$) as a function of $1000/T$ (inverse temperature) for different sweep gas flow rates.

(c) Activation energy ($E_a$) as a function of sweep gas flow rate.

(d) Comparison of activation energy for samples with and without LSCF catalytic layer as a function of sweep gas flow rate.
Long-Term Stability of Membrane

- long-term (~400 h) test
- 20 thermal cycles between 900 and 600 °C.
Characterization of membrane after stability test
Membrane with Different Surface Catalyst
## Performance Comparison

<table>
<thead>
<tr>
<th>Reference</th>
<th>Surface catalysts</th>
<th>Dense layer thickness (μm)</th>
<th>Sweep gas</th>
<th>( J_{O_2} ) (mL/cm(^2)/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work</td>
<td>PrBaCo((Fe_{0.6}Zr_{0.2}Y_{0.2})O_{5+\delta})</td>
<td>20</td>
<td>Ar</td>
<td>1.76</td>
</tr>
<tr>
<td>[1]</td>
<td>HCl</td>
<td>40</td>
<td>He</td>
<td>0.6</td>
</tr>
<tr>
<td>[2]</td>
<td>LSCF</td>
<td>40</td>
<td>He</td>
<td>1.5</td>
</tr>
<tr>
<td>[3]</td>
<td>None</td>
<td>88</td>
<td>He</td>
<td>1.4</td>
</tr>
<tr>
<td>[4]</td>
<td>Pt</td>
<td>100</td>
<td>Ar</td>
<td>1.1</td>
</tr>
<tr>
<td>[5]</td>
<td>None</td>
<td>300</td>
<td>He</td>
<td>0.3</td>
</tr>
<tr>
<td>[6]</td>
<td>Ba(<em>{0.5})Sr(</em>{0.5})Co(<em>{0.9})Nb(</em>{0.1})O(_{3-\delta})</td>
<td>530</td>
<td>He</td>
<td>0.7</td>
</tr>
<tr>
<td>[7]</td>
<td>LSCF</td>
<td>710</td>
<td>He</td>
<td>1.0</td>
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<tr>
<td>[8]</td>
<td>((La_{0.5}Sr_{0.5})<em>2COO</em>{4+\delta})</td>
<td>750</td>
<td>He</td>
<td>0.9</td>
</tr>
</tbody>
</table>

- Thin film separation layers do improve oxygen permeation flux
Accelerated Long-term Stability

- long-term (~ 550 h) test
- 46 thermal cycles between 850 and 600 °C.
Characterization after Long-term Stability Test
Membrane Stack Test

- Proof of concept;
Membrane Stack Test

- Performance after long-term stability test;
- New membrane stack is being fabricated;
- Further stack test will be conducted;
- Accelerated long term stability test is still running.
Multiphysics Modeling of Membrane
Multiphysics Modeling of Membrane
Acknowledgments

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