Electrochemical Compression

Yunho Hwang, Reinhard Radermacher

Center for Environmental Energy Engineering
Department of Mechanical Engineering
University of Maryland
College Park, MD 20742-3035
**Mechanical Compressors**

**Advantage:**
- Cost effective
- Highly efficient
- Highly reliable

**Disadvantage:**
- Noise and vibration
- Need for lubrication oil
- Hard for cooling

**Dynamic**
- Centrifugal
- Axial

**Positive Displacement**
- Reciprocating
- Rolling Piston
- Scroll
- Screw

2-Turn Rectangular Scroll Compressor
Eletrochemical Compression

- Electrochemical compression (EC) is a way to compress gas through electrochemical reactions instead of moving mechanical parts.
- The compressor configuration is proposed based on the ion exchange membrane used in fuel cells.
- Works with natural, low-GWP and zero-ODP refrigerants including hydrogen, water, carbon dioxide, and ammonia.
- Potential for efficient, oil less, noiseless, and vibration-free compression for use in air conditioning, refrigeration and power generation.
CO₂ EC Working Principle

- Under external electric field, CO₂ reacts with O₂ and H₂O on cathode to form HCO₃⁻/CO₃²⁻
- Highly selective catalyst effectively absorb both CO₂ and O₂
- Anion exchange membrane (AEM) transfers HCO₃⁻/CO₃²⁻
- CO₂ and O₂ reform at anode with higher pressure
- O₂ can be separated by either storage electrode, or through phase separation

Pt based catalyst facilitates reaction with H₂O, CO₂ and O₂
suction side: \( O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \)
\( 4OH^- + 4CO_2 \rightarrow 4HCO_3^- \)

CaRuO₃ based catalyst facilitates reaction with CO₂ and O₂
suction side: \( 2CO_2 + O_2 + 4e^- \rightarrow 2CO_3^{2-} \)
**CO₂ EC Prototype**

- Stainless steel prevents corrosion caused by oxygen
- Reduced cost by switching from graphite to stainless steel
- Mechanically more durable
CO$_2$ EC Test Facility

Low pressure inlet:
- CATHODE: $2\text{CO}_2 + \text{O}_2 + 4e^- \rightarrow 2\text{CO}_3^{2-}$
- AEM
- ANODE: $2\text{CO}_3^{2-} \rightarrow 2\text{CO}_2 + \text{O}_2 + 4e^-$

High pressure outlet:
- CO$_2$ + O$_2$, Low pressure
- CO$_2$ + O$_2$, High pressure

Diagram:
- O$_2$ flow
- CO$_2$ flow
- Mixer
- Electrochemical compressor
- Humidifier
- DC Power
- Heat
- Low pressure inlet
- High pressure outlet
## CO₂ EC Discharge Side Gas Composition

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO₂ concentration</td>
<td>O₂ concentration</td>
</tr>
<tr>
<td>Pt MEA 2 mg/cm²</td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.88</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.73</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.88</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.61</td>
<td>0.41</td>
</tr>
<tr>
<td>CaRuO₃ MEA 2 mg/cm²</td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.88</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.86</td>
<td>0.44</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.89</td>
<td>0.4</td>
</tr>
<tr>
<td></td>
<td>1.2</td>
<td>50</td>
<td>50</td>
<td>0.88</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Pt catalyst EC discharge side: $4HCO_3^- \rightarrow 4CO_2 + 4OH^-$  
$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$

CaRuO₃ catalyst EC discharge side: $2CO_3^{2-} \rightarrow 2CO_2 + O_2 + 4e^-$
CO₂ EC Compression Ratio

- EC is operated under high voltage
- Highest compression ratio is 5.6, at suction condition of 101 kPa (1 atm)
Advantages and Challenges

**Advantages**
- EC generally appears to be more efficient at high pressure ratios
- High pressure ratios have been reported
- EC is likely better at rejecting heat than mechanical compressor

**Challenges**
- Necessity for precious metals in MEA catalyst layers
- Difficult to separate carrier gas from working fluid
- Very large membrane area requirements for high flow rates
Conclusions

• Electrochemical compression is emerging from H₂ compression.
• EC compression mechanisms for CO₂ and NH₃ were proposed and experimentally verified.
• Achieved compression ratios of 3 to 5.6
• More material and experimental researches needed to determine EC performance map and reliability
• Challenges of EC in vapor compression cycle need more researches
Acknowledgement

I gratefully acknowledge the support of the Center for Environmental Energy Engineering (CEEE) at the University of Maryland.