Development of Novel Process Intensification Device, Acoustic Driven Packing Material

Award Number
DE-FE0026825

University Coalition for Fossil Energy Research

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05Oct22

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http://www.caer.uky.edu/powergen/home.shtml
What is Packing Material?

- Packing material provides additional surface area for reactions, such as, mass transfer to occur.
- Most packing materials are composed of dense corrugated sheets of metal.
- Research and development into advanced packing materials seek to increase available surface area, improve liquid/gas distribution, and reduce capital costs while minimizing pressure drop.

Market Opportunities

Available Fields of Use

- CO₂ Capture
- General Acid Gas Scrubbing
- Stripping
- Distillation
- General Separations
Mechanism

- A propagating surface wave in a liquid film will increase the film’s surface area and localized gas-liquid mixing increasing absorption rate.

- **Acoustic Streaming:** Flow in a fluid driven by the absorption of high amplitude acoustic oscillations.
- **Micro Turbulence:** A form of turbulence that varies over distances on the micrometer scale.
- **Acoustic amplitude:** Observed to be positively correlated with an increase in solvent absorption rate.
A 30% mass transfer enhancement can reduce absorber costs by up to 26%

Current UKy-CAER Cost Estimate (60 ft Absorber): **$84.6 Million**

With Acoustic Packing (42 ft Absorber): **$62.1 Million**
The Path Forward

- **Proof of Concept**
- **Proof of Application**
- **First Working Prototype**
- **Bench Scale Testing (Current)**
- **Pilot Scale Testing**
- **Full Commercial Deployment**
# Research Goals

<table>
<thead>
<tr>
<th>Research Goal</th>
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<tbody>
<tr>
<td>Solve resonance issue with the use of an advanced acoustic generator provided by MPI Ultrasonic.</td>
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<tr>
<td>Design and construct a column that can accommodate and optimize the acoustic driven packing material</td>
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<tr>
<td>Test the performance of the column on UK CAER’s 30 L/min CO₂ capture bench unit at known optimal conditions.</td>
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<tr>
<td><strong>Testing with MEA</strong></td>
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<tr>
<td>Quantify Performance Enhancement with ADPM</td>
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<td>Investigate energy consumption and scalability.</td>
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<td><strong>Effectiveness of fine solids additive</strong></td>
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<td>A second solvents tested</td>
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</table>
UK CAER’s 30 L/min CO2 Capture Bench Unit

→ 3” diameter absorber column with attach stripping unit
→ Latest NI controls management system
→ Pressurized stripping unit
→ Bottled CO₂ and house nitrogen

Multiple acoustic amplitudes will be used for each test

Test with 30 wt% MEA
Test with 30 wt% MEA + fine solids
Test with Uky-CAER Solvent
Test with Uky-CAER Solvent + fine solids
Hybrid Design
Acoustic Simulation: Hybrid Design

freq(1)=19912 Hz

Surface: Total displacement (mm)
Final: New Design

By applying acoustics to the outer column tube air coupling can transfer that energy into the packing material

freq(1)=20140 Hz

Surface: Total displacement (μm)
Design Changes

Main Components: “Spring” Flange, Tube, and Teflon spacers

Acoustic Components: Aluminum clamp, Titanium waveguide, transducer & driver, laptop.
Packing Material with Teflon Spacers

These spacers will pull solvent off the walls and back into the packing material.
“Spring” Flange: Acoustic Decoupling

These deep cuts into flange acoustically decouple the column from the rest of the process. Isolating the acoustic energy to the acoustic column.

Packing Shelf

This will keep the packing material inside the column.
## MEA Testing (no cooling)

<table>
<thead>
<tr>
<th>Run &amp; Information</th>
<th>Stripping Temp (°C), and Pressure (kPa)</th>
<th>Solvent Flow (ml/min) and Inlet CO2%</th>
<th>Solvent and Gas Inlet Temp (°C)</th>
<th>Lean and Rich Alkalinity (mol/kg)</th>
<th>% Capture</th>
<th>Lean C/N and Carbon Loading (mol/kg)</th>
<th>Rich C/N and Carbon Loading (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Condition: 1</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>109.7/130</td>
<td>300/14.31</td>
<td>42/30</td>
<td>5.50/5.402</td>
<td>46.4/1.41</td>
<td>0.26/2.35</td>
<td>0.43/2.35</td>
</tr>
<tr>
<td>Acoustic</td>
<td>109.7/127</td>
<td>295/14.34</td>
<td>42/30</td>
<td>5.68/5.50</td>
<td>49.4/1.45</td>
<td>0.26/2.45</td>
<td>0.45/2.49</td>
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<tr>
<td><strong>Condition: 2</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>110.5/129</td>
<td>286/14.31</td>
<td>25/20</td>
<td>5.24/4.91</td>
<td>57.0/0.98</td>
<td>0.19/0.44</td>
<td>0.44/2.16</td>
</tr>
<tr>
<td>Acoustic</td>
<td>110.5/132</td>
<td>303/14.41</td>
<td>26/21</td>
<td>5.36/5.01</td>
<td>63.3/1.00</td>
<td>0.19/1.00</td>
<td>0.45/2.26</td>
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<tr>
<td><strong>Condition: 3</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>106.1/128</td>
<td>513/14.30</td>
<td>42/29</td>
<td>5.05/4.85</td>
<td>45.3/1.73</td>
<td>0.34/1.65</td>
<td>0.46/2.22</td>
</tr>
<tr>
<td>Acoustic</td>
<td>106.4/128</td>
<td>495/14.27</td>
<td>42/29</td>
<td>4.92/4.79</td>
<td>47.2/1.65</td>
<td>0.34/1.65</td>
<td>0.46/2.22</td>
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<tr>
<td><strong>Condition: 4</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>110.9/135</td>
<td>498/14.28</td>
<td>31/29</td>
<td>4.84/4.71</td>
<td>66.5/1.21</td>
<td>0.25/1.96</td>
<td>0.42/1.96</td>
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<tr>
<td>Acoustic</td>
<td>110.0/134</td>
<td>495/14.29</td>
<td>30/29</td>
<td>4.90/4.66</td>
<td>69.9/1.15</td>
<td>0.24/1.15</td>
<td>0.44/2.05</td>
</tr>
</tbody>
</table>

### Capture Improvement with ADPM

- **Condition 1**: 6-7%
- **Condition 2**: 11%
- **Condition 3**: 4-5%
- **Condition 4**: 5-6%

**ADPM Power**: 800W set point consumed about 600-620W
Temperature Bulge

**Condition 1**
- Blue line: Acoustic
- Orange line: Baseline

**Condition 2**
- Blue line: Acoustic
- Orange line: Baseline

**Condition 3**
- Blue line: Acoustic
- Orange line: Baseline

**Condition 4**
- Blue line: Acoustic
- Orange line: Baseline

Temperature (°C) vs. TC Position

Solvent Inlet
Gas Outlet
Sump Temp
Gas Outlet
Sump Temp
Temperature Bulge
Absorber Cooling
Absorber Cooling: How Effective?

**Condition 2**
- Acoustic (With Cooling)
- Baseline
- Acoustic (Without Cooling)

**Condition 4**
- Acoustic (With Cooling)
- Baseline
- Acoustic (Without Cooling)
## MEA Testing with Absorber Cooling

<table>
<thead>
<tr>
<th>Run &amp; Information</th>
<th>Hot Oil Temp (°C), and Pressure (kPa)</th>
<th>Solvent Flow (ml/min) and Inlet CO2%</th>
<th>Solvent and Gas Inlet Temp (°C)</th>
<th>Lean and Rich Alkalinity (mol/kg)</th>
<th>% Capture Gas/Liquid ± error %</th>
<th>Lean C/N and Carbon Loading (mol/kg)</th>
<th>Rich C/N and Carbon Loading (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition: 5 Baseline L/G: 1.70</td>
<td>144 136</td>
<td>302 14.31</td>
<td>26.25 21.29</td>
<td>5.05 4.81</td>
<td>50.7 4.44</td>
<td>0.221 1.12</td>
<td>0.448 2.16</td>
</tr>
<tr>
<td>Condition: 5 Acoustic L/G: 1.63</td>
<td>144 132</td>
<td>291 14.26</td>
<td>25.29 21.50</td>
<td>5.11 4.88</td>
<td>53.1 10.91</td>
<td>0.223 1.14</td>
<td>0.451 2.20</td>
</tr>
<tr>
<td>Condition: 2 Baseline L/G: 1.70</td>
<td>150 130</td>
<td>300 14.33</td>
<td>25.52 21.75</td>
<td>5.31 5.05</td>
<td>55.7 0.45</td>
<td>0.189 1.00</td>
<td>0.435 2.20</td>
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<tr>
<td>Condition: 2 Acoustic L/G: 1.71</td>
<td>150 124</td>
<td>301 14.33</td>
<td>25.72 21.94</td>
<td>5.41 5.15</td>
<td>58.5 10.32</td>
<td>0.211 1.14</td>
<td>0.440 2.27</td>
</tr>
<tr>
<td>Condition: 4 Baseline L/G: 2.86</td>
<td>150 138</td>
<td>505 14.31</td>
<td>31.34 21.77</td>
<td>5.07 4.91</td>
<td>61.9 4.09</td>
<td>0.279 1.42</td>
<td>0.441 2.17</td>
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<tr>
<td>Condition: 4 Acoustic L/G: 2.79</td>
<td>150 129</td>
<td>492 14.31</td>
<td>30.46 21.83</td>
<td>5.19 5.00</td>
<td>65.9 8.59</td>
<td>0.257 1.34</td>
<td>0.425 2.13</td>
</tr>
</tbody>
</table>

### Capture Improvement with ADPM

- **Condition 2**: 5%
- **Condition 4**: 6-7%
- **Condition 5**: 4-5%

ADPM Power: 800W set point consumed about 600-620W
### MEA Testing with Absorber Cooling (6’ packing)

<table>
<thead>
<tr>
<th>Run&amp;Information</th>
<th>Hot Oil Temp (°C), and Pressure (kPa)</th>
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<th>Gas Velocity (m/s)</th>
<th>Lean and Rich Alkalinity (mol/kg)</th>
<th>% Capture Gas/Liquid ±error %</th>
<th>Lean C/N and Carbon Loading (mol/kg)</th>
<th>Rich C/N and Carbon Loading (mol/kg)</th>
<th>Cyclic Capacity (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition: 2 Baseline L/G: 1.70</td>
<td>150 130</td>
<td>300 14.33</td>
<td>25.5</td>
<td>21.8</td>
<td>0.44</td>
<td>5.31</td>
<td>5.05</td>
<td>55.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Condition: 2 Acoustic L/G: 1.71</td>
<td>150 124</td>
<td>301 14.33</td>
<td>25.7</td>
<td>21.9</td>
<td>0.44</td>
<td>5.41</td>
<td>5.15</td>
<td>58.5</td>
<td>10.3</td>
</tr>
</tbody>
</table>

### MEA Testing with Absorber Cooling (3’ packing)

<table>
<thead>
<tr>
<th>Run&amp;Information</th>
<th>Hot Oil Temp (°C), and Pressure (kPa)</th>
<th>Solvent Flow (ml/min) and Inlet CO2%</th>
<th>Solvent and Gas Inlet Temp (°C)</th>
<th>Gas Velocity (m/s)</th>
<th>Lean and Rich Alkalinity (mol/kg)</th>
<th>% Capture Gas/Liquid ±error %</th>
<th>Lean C/N and Carbon Loading (mol/kg)</th>
<th>Rich C/N and Carbon Loading (mol/kg)</th>
<th>Cyclic Capacity (mol/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Condition: 2 Baseline L/G: 1.61</td>
<td>150 115</td>
<td>285 14.33</td>
<td>25.1</td>
<td>22.7</td>
<td>0.44</td>
<td>5.13</td>
<td>5.32</td>
<td>37.7</td>
<td>4.4 (gas higher)</td>
</tr>
<tr>
<td>Condition: 2 Acoustic L/G: 1.71</td>
<td>150 117</td>
<td>301 14.33</td>
<td>25.27</td>
<td>22.6</td>
<td>0.44</td>
<td>5.16</td>
<td>5.37</td>
<td>45.1</td>
<td>11.8 (gas higher)</td>
</tr>
</tbody>
</table>

Capture Improvement with ADPM, 3’ packing, condition 2: **19.63%**
Acoustic Enhancement (3’ column)

- 6’ packing column total CO₂ capture due to acoustics: 1.229 mol/hr
- 3’ packing column total CO₂ capture due to acoustics: 3.326 mol/hr

- This is a **2.7x** increase in CO₂ capture from the acoustics, why?
  - 1. Reducing column height also reduces flu gas residence time, by 50%.
  - 2. micro- and macro-scale flashing/mixing matters.

- Regeneration Energy reduction for condition 2 on 3’ packing column with acoustics is 18.7% lower over the baseline (without taking into account the energy for acoustics).

- Ideally, we would like to achieve 5-6 ft/s but the unit is currently operating at capacity; 1.45 ft/s.

The ADPM can be used to improve the removal capacity of existing scrubbing units
Model Estimation

Capture Improvement with ADPM, 3’ column, condition 1: 19.63% → 28% reduction in column height

Brf-85
IA Factor = 0.6799
Energy Costs

Acoustic Energy \( \text{kJ/(mol CO}_2\) vs. Technology Evolution

- Proof of Concept
- 2\" Bench
- First Prototype
- 3\" Bench
- 4\" Bench Prediction

Energy Costs decrease with technology evolution.
Scaling Up

✓ This design can be directly applied to the larger 4” bench that we have on site at CAER with minimal modifications.

To scale this technology to the pilot scale it needs to modular.

- A small resonating tube can be equipped with a acoustic transducer and affixed to the outside of an exiting column.
- Air coupling will be used to transfer the acoustic energy into the packing material and solvent.
Acknowledgement

Thank You

DOE, NETL
Dustin Brown
Benjamin Omell

UK CAER
Kunlei Liu
Roger Perrone
Lisa Richburg

UCFER and Penn State Team
Bruce Miller

and
MPI Ultrasonics