Small-Scale Engineered High Flexibility Gasifier

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Annual Project review Meeting

Crosscutting Research, Rare Earth Elements, Gasification Systems and Transformative Power Generation

Virtual
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Project Team

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Project Goals

• Develop a fuel flexible and modular/shop fabricated oxygen-blown small-scale coal gasifier to produce medium BTU syngas with a low tar content

• Demonstrate gasifier performance to meet target at bench-scale (10-50 lb/h)

• Optimization of bench scale gasifier to a pilot scale module; techno-economic evaluation (TEA) for syngas conversion to liquids (fuels, chemicals)
<table>
<thead>
<tr>
<th>Project Tasks</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational modeling to optimize gasifier design</td>
<td>Done-2019 presentation</td>
</tr>
<tr>
<td>Laboratory testing to obtain model input parameters</td>
<td>Done-2020 presentation</td>
</tr>
<tr>
<td>Design and construct gasification rig</td>
<td>Underway</td>
</tr>
<tr>
<td>Commission &amp; test &amp; HAZOP review of gasification rig</td>
<td>Underway</td>
</tr>
<tr>
<td>Demonstrate performance</td>
<td>This presentation</td>
</tr>
<tr>
<td>Optimization of 1-5MW energy conversion system</td>
<td>This presentation</td>
</tr>
</tbody>
</table>
Bituminous Coal Selected for Modeling and Testing

**Ultimate analysis**

<table>
<thead>
<tr>
<th>Element</th>
<th>Wt.,%</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>84.7</td>
</tr>
<tr>
<td>H</td>
<td>4.8</td>
</tr>
<tr>
<td>N</td>
<td>1.0</td>
</tr>
<tr>
<td>O</td>
<td>3.7</td>
</tr>
<tr>
<td>S</td>
<td>0.8</td>
</tr>
<tr>
<td>Ash</td>
<td>5.0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>

**Proximate analysis**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>12.0</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>26.2</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>57.4</td>
</tr>
<tr>
<td>Ash</td>
<td>4.4</td>
</tr>
</tbody>
</table>
Process flow diagram of small-scale gasification skid

Modular structure of gasification process allows feedstock flexibility (coal, biomass, natural gas)

- **Hopper with volumetric feeder**
  - COAL (particles < 6 mm)
  - Electric heating elements

- **PYROLYZER**
  - O2(optional)

- **Ejector**
  - Control Flow Valve
  - Removed due to an absence of budget

- **Electric boiler with pump**
  - Water tank

- **Control Flow Valve**
  - Ambient Air

- **Cyclone**
  - Coarse particles (≥5µm)

- **Non-catalytic convertor**
  - O2(excess)
  - H2

- **Ambient Air**
  - NG- nat. gas from the grid

- **Thermal Oxidizer with exhaust (induced draft) fan**

- **Gas analysis suite**
  - Sensible Heat (lost)
  - Fine filter

- **Syngas cooler**
  - Sensible Heat (lost)

- **Check valve**
  - CH4

- **Exhaust gas to stack**

**Flow diagram details:**
- **Pyrolysis gas**
- **SYNGAS (recycle)**
- **SYNGAS**
- **SYNGAS**
- **SYNGAS**
- **Syngas cooler**
- **Thermal oxidizer**
- **Exhaust gas to stack**

**Additional notes:**
- Modular structure of gasification process allows feedstock flexibility (coal, biomass, natural gas).
- Process allows for the gasification of a variety of feedstocks, including coal, biomass, and natural gas.
- The gasification process involves pyrolysis, where solid biomass is heated in the absence of oxygen to produce a gas mixture.
- The gas is then cleaned through a series of filters and heat exchangers to remove particulate matter and cool the gas.
- The cleaned gas is then used for various applications, such as power generation or further treatment.
Current P&ID diagram of gasification skid
Lab-View Screen to run gasification skid
Current picture of gasification skid

Coal hopper & volumetric feeder

Electric pyrolyzer

Non-catalytic converter

Feeder

Pyrolyzer

Converter

Fine filter

Steam generator

Thermal oxidizer
Testing of electric pyrolyzer (at 15 lb/hr of coal; 35 lb/hr of superheated steam at 120-130°C)

Heaters Power Consumption (100% is 3kW)
Total Power Consumption is 13kW
Testing of electric pyrolyzer (at 15 lb/hr of coal; 35 lb/hr of steam; residence time about 6 min.)

Temperatures of pyrolyzer wall in the middle of each heater length

Temperature of the gas at the pyrolyzer outlet is 523°C
Efficiency of pyrolysis

Raw coal

<table>
<thead>
<tr>
<th>Moisture, %wt.</th>
<th>Volatiles, %wt.</th>
<th>Fixed Carbon, %wt.</th>
<th>Ash, %wt.</th>
<th>Fixed carbon, mg</th>
<th>Ash, mg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.0</td>
<td>26.2</td>
<td>57.4</td>
<td>4.4</td>
<td>11.0</td>
<td>0.84</td>
</tr>
</tbody>
</table>

Without moisture

<table>
<thead>
<tr>
<th>Moisture, %wt.</th>
<th>Volatiles, %wt.</th>
<th>Fixed Carbon, %wt.</th>
<th>Ash, %wt.</th>
<th>Fixed Carbon/Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>29.8</td>
<td>65.2</td>
<td>5.0</td>
<td>13.1</td>
</tr>
</tbody>
</table>

Char coal

<table>
<thead>
<tr>
<th>Fixed Carbon, %wt.</th>
<th>Ash, wt%</th>
<th>Fixed carbon, mg</th>
<th>Ash, mg.</th>
<th>FC/ASH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven dried</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>71.5</td>
<td>15.6</td>
<td>15.6</td>
<td>3.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Air dried</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>75.3</td>
<td>16.13</td>
<td>13.1</td>
<td>2.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td>4.65</td>
</tr>
</tbody>
</table>
Performance indicators of coal pyrolysis (steam:coal $\approx$2:1)

Coal Mass reduction: \[
\frac{19.15 - (3.9 + 0.84)}{19.15} = 75\%
\]

\[
\approx 73\% \text{ of total carbon reduction (calculated)}
\]

LHV with raw coal: 26.1MJ/kg * 7kg/hr = 182.7MJ/hr

LHV in char = 6.7 MJ/kg-input * 7 kg/hr=46.9 MJ/hr

Electricity is not converted into heating value of pyrolysis gas

LHV in pyrolysis gas = 182.7-46.9 = 135.8 MJ/hr

74% of heating value was recovered in Pyrolysis gas

Electricity is converted into heating value of pyrolysis gas

Accounting for 64% of C is converted C+H2O→CO+H2

LHV in pyrolysis gas = 182.7-46.9+28.0 = 163.8 MJ/hr

90% of heating value was recovered in Pyrolysis gas

Electricity_pyrolyzer : 13kW *3600s = 46.8 MJ/hr

Electricity boiler : 10 kW *3600s = 36 MJ/hr

Thermal efficiency of Pyrolysis $\approx$50%
Non-catalytic convertor

Oxygen is taken in an excess to stoichiometric amount to burn H2 to allow partial oxidation of hydrocarbons.
Testing of the pilot-scale non-catalytic converter

<table>
<thead>
<tr>
<th>H₂, L/min</th>
<th>O₂, L/min</th>
<th>CH₄, L/min</th>
<th>Steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15</td>
<td>20</td>
<td>-----</td>
</tr>
</tbody>
</table>

Non-stoichiometric oxy-hydrogen burner

\[ \text{H}_2 + 0.5 \text{O}_2 \rightarrow \text{H}_2\text{O} \text{ (10 L/min O}_2\text{ left)} \]

Stoichiometric ratio between CH₄ and O₂

\[ \text{CH}_4 + 0.5 \text{O}_2 \rightarrow \text{CO} + 2\text{H}_2 \]
## Test results

<table>
<thead>
<tr>
<th>Units</th>
<th>H2</th>
<th>O2</th>
<th>N2</th>
<th>CH4</th>
<th>CO</th>
<th>CO2</th>
<th>C2H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>%, Vol.</td>
<td>56.7</td>
<td>0</td>
<td>2.8</td>
<td>11.9</td>
<td>30</td>
<td>5.03</td>
<td>1.05</td>
</tr>
<tr>
<td>L/min</td>
<td>23.1</td>
<td>0</td>
<td>1.14</td>
<td>4.85</td>
<td>12.2</td>
<td>2.05</td>
<td>0.43</td>
</tr>
</tbody>
</table>

**Methane Conversion** = \( \frac{20-4.85}{20} \approx 75\% \)

**Efficiency of 75% of methane conversion into syngas (CO+H2)**

**Methane-to-syngas efficiency** = \( \frac{23.1+12.2}{(20*3)*0.75} \approx 80\% \)
A commercial success depends on a syngas utilization technology

Syngas \((H_2+CO) = 2\) moles

- \(H_2/CO=1\)
- Heating value = 524 kJ (LHV per 2 mol syngas)
- Power (47% efficiency) with carbon capture
- Electricity = 0.068 kWh (246 kJ)
- Electricity: 0.62 cents at 9 cents/kWh

- \(H_2/CO\approx2\)
- Fischer-Tropsch gasoline \((C_8H_{18})\)
- \(8CO+17H_2\rightarrow C_8H_{18}+8H_2O\)
- 9.1 g \(C_8H_{18}\) (per 2 mol syngas)
- Gasoline: 0.68 cents at 0.75 $ per kg (1$/l)

- \(H_2/CO=1\)
- Formic acid
- \(CO+H_2O\rightarrow HCOOH\)
- 46 g \(HCOOH\) (per 2 mol syngas)
- Formic acid: 3.2 cents at 0.70 $/kg [23] for 98% formic acid

O2: 0.1-0.2 cents

A significant relative decrease if O2 is used instead of air

Conclusions and Future Work

• Pyrolyzer was tested at 15 lb/hr of coal; steam:coal=2:1 ratio;
• Pyrolysis of bituminous coal with steam allows conversion of about 73% of carbon into pyrolysis gas
• A proprietary pilot-scale non-catalytic reactor was tested with methane with encouraging results
• The full experiment with conversion of pyrolysis gases into syngas is underway (after HAZOP analysis)
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Thanks for Listening! Questions?