Wet Torrefaction of Lignocellulosic Biomass

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Gasification of biomass

- Low mass density
  - Complex, expensive logistics
    - Seasonal availability
    - Widely distributed
    - Low fuel density

- Unique challenges:
  - Generation of tars during gasification
    - Related to high Oxygen content
  - Poor storage stability
  - Expensive to mill
  - Diverse handling characteristics
Goals

- Develop a process
  - To homogenize diverse biomass feedstocks
  - To increase the energy density of biomass
  - To produce solid with increased Carbon content

- Characterize solid fuel
- Mass & Energy Balances
- Reaction kinetics
Wet torrefaction: Hydrothermal carbonization

- Hot compressed water (200 – 280 °C)
- Short contact time (< 10 min)
- Increased fuel values

Diagram:
- Biomass + Water → 200 – 260 °C
- Gases → Organic acids → Aqueous sugars → Solid fuel
Torrefaction: Two approaches

- **Dry torrefaction**
  - 250 – 300 °C (inert environment)
  - 30 min- 90 min. residence time
  - Modest fuel densification
  - Very friable product

- **Wet torrefaction (carbonization, pretreatment)**
  - 200 – 260 °C
  - 5-10 minute residence time
  - Modest fuel densification
  - Significant oxygen elimination
  - Pressure is up to 50 atm (water vapor pressure)
  - Very friable product
Experimental method

- High-pressure 100-mL Parr reactor
- $200 \, ^\circ \text{C} \leq T \leq 260 \, ^\circ \text{C}$
- Pressure is monitored, not controlled
- Batch experiments
- 5 minutes residence time
- 5:1 water:biomass (w:w)
- Various feedstocks
Results

- Product is soft, friable solid
- Odor of “charcoal”
Yields

- Mass yield = mass dry product fraction of bone dry biomass feedstock
- Energy Densification = Ratio of HHV of product to HHV of raw biomass
- Energy yield = Fuel value of solid product as a fraction of fuel value of raw biomass
Mass yield

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Energy yield

Energy Yield (%)

0 10 20 30 40 50 60 70 80 90 100

Rice hull Corn stover Switch grass Poplar Loblolly pine

- 200 °C
- 230 °C
- 260 °C

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Fuel densification

HHV densification

Rice hull
Corn stover
Switch grass
Poplar
Loblolly pine

200 °C
230 °C
260 °C

Wet torrefaction of lignocellulosic biomass
van Krevelen diagram

“Coalification” of woody biomass?
Proximate analysis

Loblolly pine

<table>
<thead>
<tr>
<th></th>
<th>Raw</th>
<th>200 °C</th>
<th>230 °C</th>
<th>260 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed carbon (%)</td>
<td>50%</td>
<td>60%</td>
<td>70%</td>
<td>80%</td>
</tr>
<tr>
<td>Volatiles (%)</td>
<td>200 °C</td>
<td>230 °C</td>
<td>260 °C</td>
<td></td>
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</tbody>
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Fiber analysis

Loblolly pine

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Hydrophobic solid fuel?

- Use the equilibrium moisture as a proxy for hydrophobicity
- Measured at 30 °C in enclosed chamber with humidity controlled by saturated aqueous salt solution
- Solid takes up moisture for 7 – 14 days, depending on final EMC
Equilibrium moisture content

EMC measurements at $T = 30 \degree C$

Pretreatment reduces equilibrium moisture content.
EMC

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Reactor Additives

- **Acetic acid**
  - Acid catalyzes degradation of cellulose
  - Acetic acid is produced in hydrothermal carbonization: yield 3-5%

- **LiCl**
  - Salt solutions reduce vapor pressure of hot water
  - Use as a tool to reduce reactor pressure
Effect of Acetic Acid, LiCl on Fuel Densification

Loblolly pine

Hydrothermal treatment at 230 °C

HHV of raw loblolly is 4510 cal/g

HHV (cal/g)

Acetic Acid Added per g Loblolly Pine (g/ g Pine)
Future work

- Further characterization
  - Pelletization
  - Gasification (GTI)
- Measurements of reaction kinetics
- Optimize reactor conditions for different feedstocks
- Demonstration of continuous hydrothermal carbonization (DRI, GTI)
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Thank you for your attention

- Questions?

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