Pyrolysis of Agricultural and Forestry Residues into Bio-oil

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Outline

• Motivation
• Approach
• Experimental Set Up
• Experimental Results
• Conclusions
Motivation -1

- Global Warming.
- Depleting Conventional Fossil Fuel Reserves.
- Demand for renewable energy.

Demand for proper disposal of agricultural and forestry residues.

Utilization of Agricultural and Forestry Residues as Energy Resources
Motivation -2

Wine Grape
- Wine
- Grape Skins and Seeds
  - 12.2 million tonnes worldwide

Corn
- Bio ethanol
- Dried Distiller’s Grains
  - 3.5 million tonnes in North America

Sugarcane
- Sugarcane Juice
- Sugarcane Bagasse
  - 500 million tonnes worldwide

Forest Resources
- Pulp and Paper
- Forestry Residue
  - 280 million tonnes worldwide
One Possible Solution

• Conversion of Agricultural and Forestry Residues into Bio-Oil via Fast Pyrolysis.
Outline

• Motivation
• Approach

• Experimental Set Up
• Experimental Results
• Conclusion
Experimental Set Up

Pilot Plant Reactor

Fluidized bed:
- 7.8 cm diameter
- 0.5 m high.

Equipped with removable freeboard sections.
- Residence Time Range:
  1 to 30 seconds.

Intense heat transfer & mixing

Operating Temperature Range:
Up to 700 °C.
Experimental Set Up

ICFAR Pilot Plant

- GC gas bag
- Gas Filter
- Quenching N2
- Carrier N2
- Pre-heater
- Fluidization N2
- Condensers train
- Demister pad
- Pneumatic Feeder
- Chilled Water
Experimental Set Up

ICFAR Pilot Plant

- GC gas bag
- Gas Filter
- Experimental Set Up
- Biomass Slug
- Compensating line
- Carrier N2
- Pneumatic Valve
- To the reactor
- Fluidization N2
- Pneumatic Feeder
- Pulse Ar (at 3.5 atm)
- Solenoid valve
- Timer
- Condensers train
- Demister pad
- Pre-heater
- Chilled Water
Experimental Set Up

ICFAR Pilot Plant

- Vapors Inlet
- Gas Outlet
- GC gas bag
- Carrier N2
- Fluidization N2
- Pre-heater
- Chilled Water
- Condensers train
Outline

• Motivation
• Approach
• Experimental Set Up

• Experimental Results
  ➢ Product Yields (Mass Balance)
  ➢ Thermal Sustainability (Heat Balance)
  ➢ Liquid Bio-Oil Product

• Conclusion
Experimental Results

Product Yields: Liquid

Liquid Bio-oil Yields of Different Biomass Resources
Residence Time: 5 seconds

<table>
<thead>
<tr>
<th>Biomass Resource</th>
<th>Liquid Bio-oil Yield, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDGS</td>
<td>55</td>
</tr>
<tr>
<td>Forestry Residue</td>
<td>60</td>
</tr>
<tr>
<td>Grape Residue</td>
<td>45</td>
</tr>
<tr>
<td>Sugarcane Bagasse</td>
<td>35</td>
</tr>
</tbody>
</table>

Pyrolysis Temperature, °C

Graph showing the liquid bio-oil yield percentages for different biomass resources at various pyrolysis temperatures.
Experimental Results

Product Yields: Biochar

Solid Biochar Yields of Different Biomass Resources

Residence Time: 5 seconds

RESULTS: YIELDS

<table>
<thead>
<tr>
<th>Product Yields: Biochar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grape Residue</td>
</tr>
<tr>
<td>Sugarcane Bagasse</td>
</tr>
<tr>
<td>DDGS</td>
</tr>
<tr>
<td>Forestry Residue</td>
</tr>
</tbody>
</table>

**Solid Char Yield, %**

**Pyrolysis Temperature, °C**

- Grape Residue
- Sugarcane Bagasse
- DDGS
- Forestry Residue
Experimental Results

Product Yields: Gases

Gas Yields of Different Biomass Resources
Residence Time: 5 seconds

RESULTS: YIELD

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Sugarcane Bagasse</th>
<th>Forestry Residue</th>
<th>Grape Residue</th>
<th>DDGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>400</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>450</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>500</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>550</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>600</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>30</td>
</tr>
</tbody>
</table>

Gas Yield, %

Pyrolysis Temperature, °C
Experimental Results

Thermal Sustainability (Heat Balance)

Heat Measurements

- Heat of Pyrolysis
- Lower Heating Value (LHV) of the Feedstocks and Liquids Products
- Lower Heating Value (LHV) of the product gases

Heaters Power consumption during the pyrolysis test
- Power consumption before the start of the feed
- Higher Heating Value (HHV)
- Water vapor in the combustion gases

estimated from the product gases composition and the lower calorific value of each gas.

Thermal Sustainability

Heat of Pyrolysis vs. Product Gases LHV
Product Bio-oil LHV
Experimental Results

Thermal Sustainability (Heat Balance)

Pyrolysis at the Temperature for Maximum Liquid Yield, 5s Residence Time

<table>
<thead>
<tr>
<th>Biomass Type</th>
<th>Temperature</th>
<th>Liquid Yield</th>
<th>Solid Yield</th>
<th>Gas Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grape Residue</td>
<td>450°C</td>
<td>42.5%</td>
<td>19.7%</td>
<td>6.96%</td>
</tr>
<tr>
<td>DDGS</td>
<td>450°C</td>
<td>27.8%</td>
<td>65.2%</td>
<td>66.2%</td>
</tr>
<tr>
<td>Sugarcane Bagasse</td>
<td>350°C</td>
<td>38.7%</td>
<td>40.8%</td>
<td>20.5%</td>
</tr>
<tr>
<td>Forestry Residue</td>
<td>500°C</td>
<td>20.2%</td>
<td>50.4%</td>
<td>29.4%</td>
</tr>
</tbody>
</table>

Energy, kJ/g biomass feed

<table>
<thead>
<tr>
<th>Biomass Type</th>
<th>Energy Contained in the product bio-oil</th>
<th>Energy Contained in the product gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grape Residue</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>DDGS</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sugarcane Bagasse</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Forestry Residue</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Forestry Residue Bio-oil
Bio-oil Phase Separation

Forestry Residue Pyrolysis Liquid Biooil
Aqueous Phase & Organic Phase Yields

<table>
<thead>
<tr>
<th>Pyrolysis Temperature/°C</th>
<th>Liquid Yields%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Organic Phase</td>
</tr>
<tr>
<td>400</td>
<td></td>
</tr>
<tr>
<td>450</td>
<td></td>
</tr>
<tr>
<td>500</td>
<td></td>
</tr>
<tr>
<td>550</td>
<td></td>
</tr>
<tr>
<td>600</td>
<td></td>
</tr>
</tbody>
</table>

RESULTS: LIQUID BIO-OIL
• Environmental analysis has been conducted for the distilled aqueous phase (85 C to 115 C):

  Total Ammonia-N, Total BOD, COD, TKN, TOC, Phenols-4AAP, etc.

• Comparison with ”Sanitary and Combined Sewer Discharge by Law, Toronto, Canada” shows that the distilled aqueous phase needs to be treated before disposal to sewer.
Dried Distiller’s Grains Bio-oil
Organic Phase Drying Agents

**Molecular Sieve 4A**
- Increased by 7%

**Sodium Sulfate Anhydrous**
- Increased by 6%

**RESULTS: LIQUID BIO-OIL**

- **Higher Heating Value, kJ/g**
  - Before Treatment
  - After Treatment

- **Moisture Content %**
  - Before Treatment
  - After Treatment

- Decreased by 59%
- Decreased by 66%
Conclusions

For the product yields at 5 s residence time:

Maximum liquid yield at:
- 450 °C for grape residue and DDGS.
- 350 °C for sugarcane bagasse.
- 500 °C for forestry residue.

Thermal Sustainability: It can be achieved by burning all the gas products and part of the bio-oil

Phase separation of Bio-oil:
- The aqueous phase of grape bio-oil needs to be treated before disposal to sewer.
- The heating value of the organic phase of DDGS bio-oil can be enhanced through the use of drying agents.
Acknowledgements

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Our Team: Supervisors

Dr. Cedric Briens

Dr. Franco Berruti
Our Team: Lab Pilot Plant Team

Lorenzo Ferrante
Ran Xu
Mohammad Latifi
Rohan Bedmutha
Questions?

Thank You!
## Grape Residue Bio-oil
### Aqueous Phase Environmental Analysis

<table>
<thead>
<tr>
<th>Calculated Parameters</th>
<th>Units</th>
<th>Distilled Aqueous Phase Grape Bio-oil</th>
<th>Sanitary and combined sewer discharge by Law, Toronto, Ontario</th>
<th>RDL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness (CaCO$_3$)</td>
<td>mg L$^{-1}$</td>
<td>11</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Inorganic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Ammonia-N</td>
<td>mg L$^{-1}$</td>
<td>10000 #</td>
<td>&lt;50</td>
<td>300</td>
</tr>
<tr>
<td>Total BOD</td>
<td>mg L$^{-1}$</td>
<td>3400</td>
<td>&lt;300</td>
<td>2</td>
</tr>
<tr>
<td>Total Chemical Oxygen Demand (COD)</td>
<td>mg L$^{-1}$</td>
<td>21000</td>
<td>&lt;500</td>
<td>800</td>
</tr>
<tr>
<td>Conductivity</td>
<td>Umho/cm</td>
<td>29100</td>
<td></td>
<td>2</td>
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<tr>
<td>Total Kjeldahl Nitrogen (TKN)</td>
<td>mg L$^{-1}$</td>
<td>10000 #</td>
<td>&lt;100</td>
<td>400</td>
</tr>
<tr>
<td>Total Organic Carbon (TOC)</td>
<td>mg L$^{-1}$</td>
<td>7010</td>
<td>&lt;500</td>
<td>5</td>
</tr>
<tr>
<td>pH</td>
<td>pH</td>
<td>9.5</td>
<td>6~10.5</td>
<td></td>
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<tr>
<td>Phenols-4AAP</td>
<td>mg L$^{-1}$</td>
<td>1080</td>
<td>&lt;1.0</td>
<td>250</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>mg L$^{-1}$</td>
<td>ND *</td>
<td>&lt;10</td>
<td>1</td>
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<tr>
<td>Total Suspended Solids</td>
<td>mg L$^{-1}$</td>
<td>36</td>
<td>&lt;350</td>
<td>10</td>
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<tr>
<td>Volatile Suspended Solids</td>
<td>mg L$^{-1}$</td>
<td>36</td>
<td>&lt;350</td>
<td>10</td>
</tr>
<tr>
<td>Alkalinity (Total as CaCO$_3$)</td>
<td>mg L$^{-1}$</td>
<td>32700</td>
<td>&lt;250</td>
<td>10</td>
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<tr>
<td>Nitrite (N)</td>
<td>mg L$^{-1}$</td>
<td>ND</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Nitrate (N)</td>
<td>mg L$^{-1}$</td>
<td>ND</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Nitrate + Nitrite</td>
<td>mg L$^{-1}$</td>
<td>ND</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td><strong>Petroleum Hydrocarbons</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Oil &amp; Grease</td>
<td>mg L$^{-1}$</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**RESULTS:** LIQUID BIO-OIL | 16