TORREFACTION & DENSIFICATION OF BIOMASS

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Outline

1. Introduction
2. Torrefaction kinetics
3. Torrefaction in fixed and fluidized beds
4. Densification and properties of torrefied pellets
5. Conclusion and future work
1. Introduction to torrefaction
Problem definition

- High cost associated with long distance transportation of Canadian wood pellets to overseas markets in Europe and Asia.
- Health and safety concerns over off-gas emissions, self-heating and spontaneous combustion associated with combustible gases and dust.
- Short shelf-life time (< 1 year) due to the degradation and moisture absorption.
- Poor hydrophobicity (sheltered storage) and low heating values prevent them from being used in coal power plants.
Thermal treatment on wettability of fir

## Types of torrefaction reactors

<table>
<thead>
<tr>
<th>Reactor type</th>
<th>Indirect heating</th>
<th>Direct heating</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary drum</td>
<td>✓</td>
<td>✓</td>
<td>• Proven, relatively simple equipment</td>
<td>• Lower heat transfer (especially for indirect)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Low pressure drop</td>
<td>• Temperature control more difficult</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Less plug-flow c/w other reactors</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Large equipment, drum sealing</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• Scale-up limitations?</td>
</tr>
<tr>
<td>Moving bed</td>
<td></td>
<td>✓</td>
<td>• Simple reactor</td>
<td>• Pressure drop limitations (cannot accept excessive fines)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Very good heat transfer</td>
<td>• Potential for bed channeling, scaling challenges?</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>• High bed density</td>
<td>• Temperature control challenges</td>
</tr>
<tr>
<td>Screw</td>
<td></td>
<td>✓</td>
<td>• Oldest system for torrefaction</td>
<td>• Indirect heating, risk of hot spots</td>
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<td></td>
<td></td>
<td></td>
<td>• Plug flow</td>
<td>• Scale-up limitations (parallel reactors)</td>
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<td></td>
<td></td>
<td></td>
<td>• Lower heat transfer</td>
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<td></td>
<td></td>
<td>• Shaft sealing</td>
</tr>
<tr>
<td>Multiple hearth furnace</td>
<td></td>
<td>✓</td>
<td>• Proven equipment design &amp; scalable</td>
<td>• Lower heat transfer c/w other direct systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Close to plug flow</td>
<td>• Volumetric capacity limitations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Good temperature &amp; residence time control possible</td>
<td>• Relatively large reactor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fines acceptable</td>
<td>• Shaft sealing</td>
</tr>
<tr>
<td>Fluid bed</td>
<td></td>
<td>✓</td>
<td>• Excellent heat transfer</td>
<td>• Particle size limitations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Can be readily scaled up</td>
<td>• Possible additional gas equipment to match fluidization requirements</td>
</tr>
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<td></td>
<td>• Potential for attrition (fines formation)</td>
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<td></td>
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<td>• May be difficult to achieve plug flow</td>
</tr>
</tbody>
</table>
UBC heat-recuperative fluid bed torrefaction process

Dryer → Grinder → Torrefier → Conditioner → Pelletizer → Cooler

Fuel → Combustor/Incinerator

Air → Dryer

Water
Research Objectives

- To investigate the kinetics of torrefaction of BC’s softwood (Spruce, Pine and Fir) and bark in a Thermogravimetric (TGA) unit on the effect of temperature, residence time, particle size and oxygen content in the carrier gas on the torrefaction kinetics, in order to develop a simple torrefaction kinetic model to assist in the design and scaleup of large scale torrefaction reactors;

- To study the torrefaction performance in a fixed bed reactor and a fluidized bed reactor;

- To study the pelletization of torrefied particles and to characterize the properties of torrefied pellets.
2. Torrefaction kinetics
Test equipment

- **SHIMADZU TGA-50, TG analyzer**;
- **Sample size, 5-20 mg**
- **N₂ carrying gas at 50 ml/min.**
- **Heating rate from 1 to 50 K/min.**
Test Materials

- **Wood Components**: Pure cellulosics (Long, Medium), Birchwood xylan, Oat xylan, 5k Mwt lignin, and 10k Mwt lignin;
- **Wood fibers**: Pine, Fir, and SPF;
- **Wood Bark**: Mountain Pine Bark;
- Palm residues
Torrefaction of different wood species
Torrefaction of different particle sizes

Different Size
Pine Sawdust (250°C)

- □ <250μm
- ○ 250-500μm
- △ 500μm-1.0mm

Relative weight (t)

Time (s)
Torrefaction at different gas O$_2$ content

![Graph showing the effect of different oxygen and nitrogen contents on the residual weight fraction over time. The graph illustrates the decrease in residual weight fraction with time for various oxygen and nitrogen concentrations. The data points are marked with different symbols, each representing a specific oxygen and nitrogen composition.]

- O$_2$: 0%; N$_2$: 100%
- O$_2$: 3%; N$_2$: 97%
- O$_2$: 6%; N$_2$: 94%
- O$_2$: 10%; N$_2$: 90%
- O$_2$: 21%; N$_2$: 79%

The graph shows the residual weight fraction on the y-axis and time in seconds on the x-axis.
3. Torrefaction tests in a fixed tubular reactor and a fluidized bed reactor
Fixed bed torrefaction unit
Three-way valve

Rotameter

Tar collector

dehumidifier

Vent

Sampling bag
High heating values of torrefied biomass
## Comparison with TGA and kinetics model

<table>
<thead>
<tr>
<th></th>
<th>Spruce</th>
<th>Pine</th>
<th>Fir</th>
<th>SPF</th>
<th>Pine bark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature, K</td>
<td>553</td>
<td>553</td>
<td>553</td>
<td>553</td>
<td>553</td>
</tr>
<tr>
<td>Residence time, min</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>23</td>
</tr>
<tr>
<td>Weight loss from fixed bed, %</td>
<td>24.4</td>
<td>28.6</td>
<td>27.2</td>
<td>31.2</td>
<td>30.3</td>
</tr>
<tr>
<td>Weight loss from TGA, %</td>
<td>29.2</td>
<td>30.6</td>
<td>28.8</td>
<td>29.1</td>
<td>29.7</td>
</tr>
</tbody>
</table>
4. Densification and properties of torrefied pellets
Pelletization equipment
Pellets made from untreated and torrefied wood particles
Specific energy required to form pellets

![Bar chart showing energy per unit density for different treatments. The treatments range from 250-15-6 to 300-30-6, with average and control (untreated) also included. The energy values range from 10000 to 40000 mJ/g/cm³.]}
Hydrophobicity equipment

- Chamber to maintain constant temperature and humidity
- Temperature: 30°C
- Humidity: 90%
- Duration: Variable
- 2 - 3 pellets in a petri dish
- Weigh at time intervals
Results on hydrophobicity

Pellets from small particles 0.8 mm

Pellets from large particles 6.2 mm

Humid chamber at 30°C  90% RH
Saturated moisture uptake for torrefied pellets

![Graph showing saturation moisture uptake for different particle sizes.](image-url)
Deformation after water intake

SPF pellets.

(a) control pellet;
(b) 13.3% mass loss (240 °C, 60 minutes);
(c) 33.8% mass loss (270 °C, 60 minutes);
(d) 50.7% mass loss (300 °C, 60 minutes);
(e) 60.6% mass loss (340 °C, 60 minutes).
Conclusions

- Torrefaction of BC softwood within the typical reaction temperature range and relatively short residence times can be well described by a one step two-components 1\textsuperscript{st} order decomposition kinetic model.
- It takes more energy to form pellets from torrefied than from untreated wood particles, because torrefied particles do not bind well.
- The hydrophobicity of torrefied pellets increased with increasing the severity of torrefaction.
- Pellets made from oxidative torrefaction showed similar properties as regular torrefied pellets.
Future work

To optimize the torrefaction conditions based on torrefaction reactor performance, the pelletibility of torrefied sawdust and the quality of torrefied pellets;

To build a pilot scale heat-recuperative fluidized bed torrefaction reactor;

To develop a continuous torrefaction process for continuous production of torrefied pellets, integrating the use of volatiles and condensable;

To study torrefaction in pilot scale torrefaction reactors and continuous pelletization.
Future work (Continued)

- To optimize grinding and pelletizing torrefied biomass on a continuous pellet mill.
- To develop mass and energy data for each of the unit operations for torrefied and untreated pelletization processes.
- To conduct cost benefit analysis of integrating torrefaction process in commercial pellet operations.
- To investigate logistics of storage and transport of torrefied pellets to final application.
- To evaluate torrefied pellets for pyrolysis and gasification processes.
- To evaluate storage properties of torrefied pellets and their impact on environment.
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- Mr. Hui Li, visiting PhD student
- Dr. Congwei Wang, Postdoctoral fellow
- Dr. Xinhua Liu, Postdoctoral fellow
- Bahman Ghiasi, Research assistant
Related publications


Thank you!