Intrinsic Reactivity Investigations of Biomass and Coal Chars, and their Blends

Naoko Ellis and Mohammad Masnadi
Chemical and Biological Engineering
Clean Energy Research Centre
University of British Columbia
Canada

David J. Harris and Daniel G. Roberts
CSIRO Energy Technology
Kenmore, QLD
Australia

Content

• Canadian perspective
• Motivation
  • Co-gasification
    • Australian coal and Canadian biomass
• Experimental
  • Char generation and characterization
  • Fixed bed char reactivity study
• Future work
• Gasification research at UBC
• Invitation to Vancouver
Canada’s Energy System

Canadian Coal

- Production: 65–75 Mt annually
- >40% exported
- Consumed 58 million tonnes of coal in 2006
  - Most used to generate electricity
    - 74 % in Alberta, 63 % in Saskatchewan, 60 % in Nova Scotia, and 18 % in Ontario from coal
  - Clean coal technology: CO₂ capture

Canada’s Energy Mix

Motivation

Co-gasification of coal and biomass

• Coal:
  • High energy density
  • Conventional technology
  • Supply network

• Biomass:
  • Renewable
  • Logistics and infrastructure issue
  • Reactive
  • High tar content

• Additionally:
  • Catalytic/synergistic effect on gasification
  • Lower tar content
Coal Conversion in Gasification

- Coal gasification is a multi-stage process
  - Coal pyrolysis
    - Rapid volatile release
    - Determines char yield and morphology
  - Combustion
    - Limited, fast. $O_2$ consumed early in process
    - Exothermic, provides heat for endothermic gasification reactions
  - Char Gasification
    - Slow, rate determining. Endothermic
    - $CO_2$ and $H_2O$ converted to $CO$ and $H_2$.
  - Slag formation and flow
    - Flux may be required to achieve adequate viscosity

Feedstock

<table>
<thead>
<tr>
<th></th>
<th>Coal (CRC272)</th>
<th>BC Pine</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate (% , db)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>air dried moisture</td>
<td>2.3</td>
<td>7.0</td>
</tr>
<tr>
<td>ash</td>
<td>10.1</td>
<td>1.0</td>
</tr>
<tr>
<td>volatile matter</td>
<td>35.0</td>
<td>78.0</td>
</tr>
<tr>
<td>fixed carbon</td>
<td>52.6</td>
<td>14.0</td>
</tr>
<tr>
<td><strong>Ultimate (% daf)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon</td>
<td>82.6</td>
<td>51.7</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>5.36</td>
<td>5.97</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>1.68</td>
<td>0.18</td>
</tr>
<tr>
<td>Sulfur</td>
<td>1.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Oxygen (diff)</td>
<td>9.4</td>
<td>42.2</td>
</tr>
</tbody>
</table>
Char Preparation

- Samples prepared from Australian coal and Canadian pine
- Tube furnace at 900°C
- Sized samples (−1.0 +0.6 mm) of coal, biomass and blends are placed in a tube furnace under slow pyrolysis conditions
- Heating rate of 20°C/min under Nitrogen for 2 hrs holding time
- Resulting char is crushed and sieved to −1.0 +0.6 mm size range
- Char yield based on as received weight ratio

<table>
<thead>
<tr>
<th></th>
<th>Moisture</th>
<th>Volatiles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass</td>
<td>7.2%</td>
<td>71.4%</td>
</tr>
<tr>
<td>Coal</td>
<td>1.8%</td>
<td>33.5%</td>
</tr>
</tbody>
</table>

Char Surface Area

![Graph showing char surface area vs biomass wt. ratio]
Char Surface Area

- **Graph**: Scatter plot showing surface area vs. biomass char wt. ratio with markers for surface area and BET.
- **Remarks**:
  - Surface area $\text{m}^2/\text{g}$
  - BET $\text{m}^2/\text{g}$

Char Reactivity

**CO$_2$ gasification mechanism**

$$C_t + CO_2 \iff C(O) + CO$$

$$C(O) \rightarrow CO + C_t'$$

**Steam gasification mechanism**

$$C_t + H_2O \iff C(O) + H_2$$

$$C(O) \rightarrow CO + C'_t$$

$$C_t + H_2 \rightarrow C(H_2)$$

Hodge, 2009
CO$_2$ Gasification

Specific reaction rate at 900ºC

Surface Area Evolution

- CO$_2$ gasification at 10% Conversion
Char Reactivity

Surface related intrinsic reaction rate

![Graph showing surface related intrinsic reaction rate vs. biomass char wt. ratio.]

Activation Energy

- CO₂ gasification at 10% Conversion

![Graph showing activation energy vs. biomass char wt. ratio.]

Hodge et al., Energy Fuels, 24, 100-107 (2010)
Steam Gasification

- Specific reaction rate at 900ºC

Intrinsic Rates and SA

- Steam gasification reactivity
Future Work

- Ash analysis (low temp analysis)
- Char morphology
- Catalytic effects
  - Secondary Ion Mass Spectrometry
  - Intensity of K⁺
  - Crystalinity

(a) Coal                (b) Fluid coke          (c) Switchgrass

University of British Columbia
BC Carbon Tax – since 2008

First tax of its kind in North America

UBC’s Vancouver campus:
total GHG emissions (2008) 60,400 CO2–e tonnes

Business as usual approach:
An estimated $50 million in carbon tax and carbon offsets over the next 25 year period
Reducing our GHG emissions will reduce the carbon liability to $33 million.

2 MW Demonstration Layout

UBC System Summary
Required fuel: 12,000 BDMT/year (2/3 trucks/day)
Net Power: 1.7MWe
Net Thermal:10 MMBtu/hr (80,000 MMBtu/yr)
(~8% of based steam load and ~4% of peak electricity demand)
CO₂ Reduction: 5,000 tpy
Nexterra System

Campus as a Living Lab concept

UBC Clean Energy Research Centre

- Biomass feedstock and logistics
- Biomass pre-treatment
- Torrefaction and pelletization
- Integrated gasification and looping CO₂ capture
- CO₂ capture sorbent reactivity (pressure and temp swing)
- CO₂ capture sorbent attrition
- Biomass tar cracking unit
- Dual fluidized bed gasifier
Integrated Fluidization Bed Gasification with Looping CO₂ Capture

Overall Goal:
To test the most promising material in the UBC pilot plant: gasification and capture

Sorbents being synthesized, prepared, pelletized, coated and/or tested:
• Calcite
• Limestone
• lithium zirconate
• lithium orthosilicate
• sodium silicate

Acknowledgement

• Natural Sciences and Engineering Research Council of Canada
A special issue of ‘Fuel’ will feature the most worthy papers from iSGA-3

For more information go to: www.isga3.com