Investigation of innovative and conventional pyrolysis of ligneous and herbaceous biomasses for biochar production

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INVESTIGATION OF INNOVATIVE AND CONVENTIONAL PYROLYSIS OF LIGNEOUS AND HERBACEOUS BIOMASSES FOR BIOCHAR PRODUCTION

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PYROLYSIS AS A TERMOCHEMICAL PROCESS

- BIOMASS
- PYROLYSIS
- GAS
- BIO-OIL
- BIO-CHAR
## PYROLYSIS: SLOW OR FAST?

<table>
<thead>
<tr>
<th></th>
<th>SLOW PYROLYSIS</th>
<th>FAST PYROLYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>heating rate</td>
<td>&lt;10 (°C/min)</td>
<td>&gt;100(°C/s)</td>
</tr>
<tr>
<td>Temperature range (°C)</td>
<td>400-800</td>
<td>450-550</td>
</tr>
<tr>
<td>vapor residence time</td>
<td>minutes</td>
<td>&lt;2 s</td>
</tr>
<tr>
<td>solid residence time</td>
<td>hours</td>
<td>seconds</td>
</tr>
<tr>
<td>bio-oil yield (%)</td>
<td>≈ 30</td>
<td>≈ 60-75</td>
</tr>
<tr>
<td>bio-char yield (%)</td>
<td>≈ 30</td>
<td>≈ 15-25</td>
</tr>
<tr>
<td>gas yield (%)</td>
<td>≈ 35</td>
<td>≈ 15</td>
</tr>
<tr>
<td>typical reactor configuration</td>
<td>fixed bed, kilns, auger</td>
<td>fluidized and circulating fluidized bed, ablative, vacuum</td>
</tr>
</tbody>
</table>
APPROACH and AIM OF THE RESEARCH

- FEEDSTOCK
  (herbaceous vs ligneous biomasses)

- REACTOR DESIGN

- PYROLYSIS PROCESS
  (slow vs fast)

production of ACTIVATED BIOCHAR
FEEDSTOCKS

ligneous

a. RUBBERWOOD  
b. EUCALYPTUS

erbaceous

c. PHRAGMITES AUSTRALIS
REACTORS DESIGN: slow vs fast pyrolysis

1. Mechanically Fluidized Reactor (MFR)
2. Bubbling Bed Reactor (BBR)
3. Jiggled Bed Reactor (JBR)
Figure 2.2- Sequence of mixing during a) downward actuator retraction, b) upward actuator extension (Latifi, 2012)
METHODOLOGY: PYROLYSIS

- Rubberwood
- Eucalyptus
- Phragmites

- MFR 550 °C
  - Rubberwood char
  - Eucalyptus char
  - Phragmites char

- BBR 500 °C
  - Rubberwood char
  - Eucalyptus char
  - Phragmites char

- JBR 500 °C
  - Rubberwood char
  - Eucalyptus char
  - Phragmites char
METHODOLOGY: BIOCHAR ACTIVATION

Figure 3 Reactions occurring within a char particle during activation [23]
JBR OPERATING CONDITIONS

Pyrolysis and activation - JBR

- Reactor temperature [°C]
- Time [min]
- 0°C to 900°C
- 0 min to 80 min

- pyrolysis
- activation
- cooling

Gas flow rate [ml/min]

- N₂
- CO₂

Biochar

Activated biochar
RESULTS: BIOMASSES CHARACTERIZATION AND YIELDS

<table>
<thead>
<tr>
<th>Moisture content [%]</th>
<th>Proximate analysis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VOC [%]</td>
<td>Fixed carbon [%]</td>
</tr>
<tr>
<td>Rubberwood</td>
<td>5.9</td>
<td>19.4</td>
</tr>
<tr>
<td>Eucalyptus</td>
<td>9.1</td>
<td>26.2</td>
</tr>
<tr>
<td>Phragmites</td>
<td>9.0</td>
<td>31.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CHAR YIELDS [%]</th>
<th>BBR</th>
<th>MFR</th>
<th>JBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus</td>
<td>22.8</td>
<td>22.4</td>
<td>23.8</td>
</tr>
<tr>
<td>Phragmites</td>
<td>27.9</td>
<td>34.5</td>
<td>26.9</td>
</tr>
<tr>
<td>Rubberwood</td>
<td>20.9</td>
<td>18.4</td>
<td>23.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIVATED CARBON YIELDS [%]</th>
<th>BBR</th>
<th>MFR</th>
<th>JBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus</td>
<td>71.1</td>
<td>72.8</td>
<td>95.5</td>
</tr>
<tr>
<td>Phragmites</td>
<td>68.3</td>
<td>77.3</td>
<td>98.2</td>
</tr>
<tr>
<td>Rubberwood</td>
<td>75.8</td>
<td>84.7</td>
<td>87.2</td>
</tr>
</tbody>
</table>
RESULTS: ELEMENTAL ANALYSIS

Evolution of carbon

Evolution of nitrogen

Evolution of hydrogen

Evolution of oxygen

DRIED BIOMASS  BIO-CHAR  ACTIVATED CARBON

DRIED BIOMASS  BIO-CHAR  ACTIVATED CARBON

BBR  MFR  JBR

Eucalyptus  Phragmites  Rubberwood
## RESULTS: BET ANALYSIS (PHRAGMITES)

<table>
<thead>
<tr>
<th>Char</th>
<th>BET surface area [m²/g]</th>
<th>t-Plot micropore area [m²/g]</th>
<th>t-Plot micropore volume [cm³/g]</th>
<th>Adsorption average pore width [Å]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFR</td>
<td>63,59</td>
<td>57,07</td>
<td>0,03</td>
<td>17,31</td>
</tr>
<tr>
<td>BBR</td>
<td>2,11</td>
<td>1,83</td>
<td>0,00</td>
<td>66,84</td>
</tr>
<tr>
<td>JBR</td>
<td>73,32</td>
<td>75,31</td>
<td>0,03</td>
<td>16,09</td>
</tr>
<tr>
<td>Activated Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MFR</td>
<td>308,59</td>
<td>292,50</td>
<td>0,14</td>
<td>17,52</td>
</tr>
<tr>
<td>BBR</td>
<td>368,83</td>
<td>247,95</td>
<td>0,11</td>
<td>22,48</td>
</tr>
<tr>
<td>JBR</td>
<td>385,24</td>
<td>283,02</td>
<td>0,13</td>
<td>20,82</td>
</tr>
</tbody>
</table>

![Adsorption isotherms graph](image)
RESULTS: SEM IMAGES
CONCLUSIONS

• JBR is an **effective** reactor to **simulate different technologies**, to **optimize process conditions** and to **test activation processes** on different biomasses;

• JBR is a **valid alternative to conventional reactors** for the experimental investigation of biochar production;

• *Phragmites australis* showed an **interesting potential** as biochar and activated carbon feedstock, analogous to conventional ligneous biomasses.

**Further research** is necessary to investigate:

• the **optimization of biochar production and activation** to enhance micropore area;

• the **adsorption capacity** of the produced activated carbons towards organic and inorganic pollutants.