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Green Coal: a New Energy Source from Leaves

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Abstract

Pollution is a major concern with fossil fuels. Present work would like to discuss a “Green Fuel” produced from waste leaves on the ground; hence it could be considered eco-friendly. The objective is to use leaves (biomass) as raw materials and convert them into solid biofuel briquettes/pellets using roasting process, here shown to be more effective than usual carbonization by using simulation techniques. The reactor optimum design is also discussed. The process flow diagram for densification of roasted leaves starts with the choice of leaves depending on their proximate analysis and their calorific value, after being collected, sun dried and submitted to roasting process. Because of poor energy characteristics, the roasting end product is to be crushed and densified with specific additives chosen for binding the roasted biomass and increases its calorific value. To reduce green gas emissions, the process uses solar energy to heat up the reactor and reach desired temperature for optimal working process. Finally, after processing, the roasted leaves are converted into briquettes by densification process. This fuel is energy efficient and techno economically feasible compared to other primary fuels.

Keywords: Briquettes; Torrefaction; Green Fuel

1. Introduction

Human kind is nowadays facing the difficult problem to moderate significantly greenhouse effect consecutive to energy increasing consumption and associated pollutions [1-4]. Severe bounds have been fixed in different international meetings, but their application is made difficult by the difference between the participating countries in their respective development. Aside these global assignments, different solutions have been proposed such as

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proceeding directly with biomass materials [5-8]. However, inherent problems with raw biomass materials compared to fossil fuel resources (low bulk density, high moisture content, hydrophilic nature, and low calorific value [CV]) render raw biomass difficult to use on a large scale. These limitations greatly impact logistics and final energy efficiency. Due to its low energy density compared to fossil fuels, very high volumes of biomass are needed, which compounds problems associated with storage, transportation, and feed handling at cogeneration, thermo-chemical, and biochemical conversion plants. High moisture in raw biomass is one of the primary challenges, as it reduces the efficiency of the process and increases fuel production costs. Other approach is in coal gasification as there are environmental, technical and commercial reasons why coal might be co-gasified with biomass and waste [9]. Conservation of fossil fuel resources and reduced CO₂ emissions are real and tangible environmental benefits. The technical benefits are less certain and the separate gasification of biomass or waste materials may prove to be more practical [10]. Coal offers a high level of fuel supply security and this can be important for commercial reasons. All these approaches are implying a relatively large scale operation technique.

A much simpler possibility is to research if any an alternative way which would reconstitute in accelerated time the natural process which was leading over millennia to existing conventional fossil resources, and without their constitutive defects. This problem has been discussed in the following where a complete production cycle from leaves to charcoal has been analysed. After choosing appropriate leaves as concerns their content in the needed elements, best transformation type has been determined, and reactor structure where such transformation takes place has been designed. It is shown that energy can be entirely provided from a solar station the characteristic features of which are given, making with the reactor an autonomous non-polluting energy production unit. The “short cycle” principle underlying resulting dual unit comprising the transformation reactor and associated solar energy source is extendable to other types of leaves as well, and represents an interesting potential possibility for reducing overall Earth pollution.

2. Overall Process Analysis

Leaves Selection: The evolution on chemical and physical properties of biomass as a solid fuel helps to find which material has the best properties. It has been demonstrated that each kind of leaf reacts in a different way to roasting process. From Table I, the Willow leaves have 21.31% Hemicellulose the thermal degradation of which is relatively violent, 63.69% Cellulose and 15% Lignin which give the material a higher resistance to thermal degradation.

<table>
<thead>
<tr>
<th>Raw material</th>
<th>Willow</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate analysis (wt.%)</strong></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>3.47</td>
</tr>
<tr>
<td>Volatile matter (VM)</td>
<td>80.29</td>
</tr>
<tr>
<td>Fixed carbon (FC)</td>
<td>15.57</td>
</tr>
<tr>
<td>Ash</td>
<td>0.67</td>
</tr>
<tr>
<td><strong>Fiber analysis (wt.%)</strong></td>
<td></td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>21.31</td>
</tr>
<tr>
<td>Cellulose</td>
<td>63.69</td>
</tr>
<tr>
<td>Lignin</td>
<td>15.00</td>
</tr>
<tr>
<td><strong>Elemental analysis (wt. % dry basis,</strong></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>45.80</td>
</tr>
<tr>
<td>H</td>
<td>6.24</td>
</tr>
<tr>
<td>N</td>
<td>0.09</td>
</tr>
<tr>
<td>O</td>
<td>47.20</td>
</tr>
<tr>
<td>HHV (MJ/kg)</td>
<td>19.61</td>
</tr>
</tbody>
</table>
Roasting has been made at three different temperatures, 230, 260 and 290 °C. The results on Table II indicate that roasting temperature increase reduces biomass thermal degradation. Carbon, Hydrogen, Nitrogen and Oxygen % and HHV of raw and roasted biomasses are also shown on Table II. It is observed that Carbon weight percentage increases significantly whereas Oxygen weight percentage decreases with roasting temperature.

<table>
<thead>
<tr>
<th>Material</th>
<th>Temperature(°C)</th>
<th>Elemental analysis (wt.%, dry basis)</th>
<th>Ash (wt.%)</th>
<th>HHV (MJ/Kg)</th>
<th>Enhancement in HHV (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow</td>
<td>Raw</td>
<td>C: 45.80 H: 6.24 N: 0.09 O: 47.20</td>
<td>0.67</td>
<td>18.45</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>230</td>
<td>C: 56.59 H: 6.41 N: 0.14 O: 34.21</td>
<td>2.65</td>
<td>23.71</td>
<td>1.286</td>
</tr>
<tr>
<td></td>
<td>260</td>
<td>C: 65.16 H: 7.10 N: 0.23 O: 24.3</td>
<td>3.18</td>
<td>28.53</td>
<td>1.547</td>
</tr>
<tr>
<td></td>
<td>290</td>
<td>C: 67.55 H: 7.06 N: 0.22 O: 20.92</td>
<td>4.25</td>
<td>29.64</td>
<td>1.607</td>
</tr>
</tbody>
</table>

From this information, Willow biofuel is chosen for green coal study. It has already been used as an energy source in some countries like Sweden. Its high energy in-energy out ratio has been experimented along with large carbon migration and fast growth. Willow trees are easily found near the riversides.

**Process Selection:** After raw material selection, next step is to process it in most adequate way. This very important part is determinant for end product final characteristics, such as yield, calorific value, humidity percentage, carbon level and moisture content. Of biomass processes, the most used one today is carbonization which is a good choice, but roasting is even better option [11].

**Carbonization:** Carbonization is a thermal pre-treatment process in which the biomass is heated up to 300-700°C in the absence of oxygen (usually under nitrogen atmosphere). The process splits into 4 different stages:
1) Transformation of biomass water into steam. Water evaporation requires a large energy so using the sun to pre-dry as much as possible the wood before carbonization greatly improves efficiency
2) Biomass dries out at 100°C or below to reduce moisture content to 0.
3) Owen temperature rise to about 280°C. The energy for these steps comes from partial combustion of part of biomass charged to the kiln or pit (endothermic reaction).
4) After biomass dry-out and heating to around 280°C, it spontaneously breaks down to produce charcoal plus water vapour, methanol, acetic acid and more complex chemicals in the form of tars and non-condensable gas consisting mainly of hydrogen, carbon monoxide and carbon dioxide.

The spontaneous biomass breakdown or carbonization above 280°C liberates energy in an exothermic reaction. The process continues until only the carbonised residue (charcoal) remains. Unless further external heat is provided, the process stops and the temperature reaches a maximum of about 400°C. This charcoal, however, will still contain appreciable amounts of tarry residue, together with ashes of original biomass, see Table III.

<table>
<thead>
<tr>
<th>Carbonization Temperature °C</th>
<th>Charcoal Fixed Carbon %</th>
<th>Charcoal Volatile Material %</th>
<th>Green Coal Yield from Oven Dried Biomass (Moisture %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>68</td>
<td>31</td>
<td>42</td>
</tr>
<tr>
<td>500</td>
<td>86</td>
<td>13</td>
<td>33</td>
</tr>
<tr>
<td>700</td>
<td>92</td>
<td>7</td>
<td>30</td>
</tr>
</tbody>
</table>

**Roasting:** Roasting is a five-step thermal pre-treatment process in which the biomass is heated up to 200-300°C in the absence of oxygen (usually under nitrogen atmosphere):
1) Initial heating: The temperature is increased until moisture evaporation and biomass drying begins.
2) Pre-drying: At 100 °C the free water is evaporated from the biomass at constant temperature.
3) Post-drying and intermediate heating: Further biomass heating to about 200 °C.
4) Roasting: During this stage the actual roasting process takes place. The temperature is further increased to about
270 to 310 °C and the biopolymers especially hemicelluloses are undergoing condensation and dehydration reactions resulting in gas release (roasting gas) and roasted biomass

5) Solids cooling: Cooling of biomass below 200 °C.

The resulting product has a lower oxygen and moisture content, higher calorific value, and less hydrophilic compared to untreated biomass. The fibrous and tenacious nature of biomass is reduced, resulting in a brittle material easily transformable into smaller particles [y]

**Discussion:** Low carbonization temperatures (300°C) give a higher charcoal yield. This charcoal is low grade, is corrosive due to its content of acidic tars, and does not burn with a clean smoke-free flame. Good commercial charcoal should have a fixed carbon content of about 75% and this call for a final carbonizing temperature of around 500°C. Unless this operation is carried out as efficiently as possible, it puts the whole operation of charcoal production at risk since low yields in carbonization reflects back through the whole chain of production as increased costs and resources waste.

**Table IV. Overall Performances of Carbonization and Roasting processes**

<table>
<thead>
<tr>
<th></th>
<th>Carbonization</th>
<th>Roasting</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yield</strong></td>
<td>33%</td>
<td>94%</td>
</tr>
<tr>
<td><strong>Temperature</strong></td>
<td>500°C</td>
<td>&lt;300°C</td>
</tr>
<tr>
<td><strong>Mass Efficiency</strong></td>
<td>40%</td>
<td>70%</td>
</tr>
<tr>
<td><strong>Energy Efficiency</strong></td>
<td>&lt;80%</td>
<td>90%</td>
</tr>
</tbody>
</table>

As seen from Table IV, roasting process consumes much less energy than carbonization because of lower required temperature with much higher yields - 94% - , to be compared to 33% with carbonization. Moreover, the infrastructure required for roasting (especially the reactor) does not have to support temperatures above 300°C, which means a much cheaper price. Roasting efficiency is 70% of initial material with 90% of energy, against respective carbonization efficiency of 40% of initial biomass with 80%. Moreover, energy densification (energy required per kg of material to be densified), is lower for roasting than for carbonization, which means less energy is required for densifying roasted biomass. Overall, roasting process is better concerning environment, saving energy and money, simplifying the process and obtaining higher yields.

**3. Thermo-Chemical Reactor Design:**

Thermo-chemical reactors are enclosed vessels where the raw samples are subjected to both chemical and thermal reactions to obtain the necessary end product. There are five major kinds of reactor existing today industrially for torrefaction process [12-17]. The fluidized bed reactor is selected here for its efficient heat transfer and homogeneous heat dissipation. In this reactor, solid material is usually supported by a porous plate (the distributor plate). The fluid (usually gas) is then forced through the distributor plate through the solid material. Gradually, the reactor content begins to expand with increasing velocity and swirl leading to maximum mixing and homogeneous heat transfer.

Roasting is a process in which the inbound moisture and volatile material are removed in absence of air at a temperature around 250-290°C. Since roasting requires no air, inert Nitrogen gas can be used comfortably. So it will create an inert atmosphere, and leaves will not catch fire and charring can be done easily. Therefore, solid (dried leaves) can be fed from the top and gas enters from bottom through the distributor plate. Thus, after 20-30 min, leaves can be taken out from bottom, and flue gas outlet is there on top.

**Reactor Design:** The mechanical design of a fluidized bed reactor has been numerically developed with FLUENT 15.0, after initial drawing with CATIA software, and meshing in GAMBIT. Then by using multiphase model in FLUENT, the various investigations can be detailed out.
Fig. 1. Display of Reactor Structure

Fig. 2. Temperature Distribution
Results on general vessel structure, and temperature, velocity and pressure distributions inside the vessel are respectively shown on Figures 1, 2, 3, 4. Heat is externally provided into the reactor by using steam through the jacket wall. The pipe is thermally insulated to avoid heat loss from the reactor.

**Energy Requirement**: The energy requirement is met out by solar thermal concentrator through which sunlight is transferred to the water, see Table V where power requirements are indicated, and produced steam is passed through the jacket of the reactor to roast the leaves.

Table V. Solar Station Power Requirements for Roasting Reactor
The roasting properties and the selected leaves show that the temperature needs to reach between 290-360 °C to properly run the process. Comparison of available different technologies with respect to cost, required space and temperature range singles out here the parabolic trough technology to capture solar input to heat up the reactor and roast the leaves, see Figure 5.

![Figure 5: Solar Concentrator Structure](image)

Pelletization: It is a common technology for densifying materials originally in a loose form, which gain in density and become more uniform in terms of shape. This makes it easier to operate with it and enables much more efficient loading and unloading operations. On the other hand the energy content of produced roasted material is not modified by the density change due to pelletization. There are two main pelletization processes:

1) High pressure briquetting, which uses a power-driven press to make a pressure of about 1,500 bar (150 MPa). This compression heats the biomass to a temperature of about 120°C, which melts the lignin in the woody material. The press forces the hot material through a die at a controlled rate. As the pressure decreases, the lignin starts cooling and re-solidifies, binding the biomass powder into uniform, solid briquettes.

2) Low pressure briquetting: this process can only be used for densifying materials with low content of lignin. The process consists in mixing the biomass into a paste with a binder (such as starch or clay) and water which is injected into a mould or through an extruder to produce the briquettes dried out before use.

Conclusion: Analysis of conventional energy sources points to the needs of alternative ones without the defect of large pollution. Aside classical attempts to limit its production by absorbing interfaces usually drastically reducing overall efficiency, an alternative way is discussed here which consists in directly using specific leaves with a good proportion of basic chemical elements as concerns both energy requirements to transform raw leave material into charcoal briquettes, and to generate low pollution. The entire transformation to briquettes has been analysed from willow leaves with a solar power source making the complete production cycle energetically neutral. It is shown that with such material the process is economically viable, and represents an interesting alternative way to generate clean
conventional energy source via a short cycle which is only limited by leave production. The principle of present short cycle energy source is extendable to other raw material showing same properties.

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