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Torrefaction of Biomass: Effect of Temperature and Time

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Abstract

This paper presents a work on the torrefaction of biomass in a laboratory scale with a reactor. Rice husk was used as the raw material. The samples were reduced to a smaller size by grinding and sieving. The reactor was heated to desired temperatures (200°C, 260°C and 300°C) and was kept at the pretreatment temperatures for variable torrefaction time (10,20,30,60 and 120)minutes in nitrogen atmosphere. The effect of different temperatures and residence time on the properties of torrefied products is studied. The torrefied products were characterized by moisture content and volatile fractions. During torrefaction, biomass undergoes physical and chemical property changes. The fixed carbon and energy density both were increased with increasing time and temperature of torrefaction. The torrefied biomasses are hydrophobic in nature and have higher calorific values than that of raw biomass.

Keywords: Torrefaction, Biomass Pretreatment, Hydrophobic, Energy.

1. Introduction

The world is facing a common challenge which is to lessen the reliance on fossil fuels. The main perspective is to acquire a sustainable, environment-friendly and renewable energy source. Biomass is a prominent source of green energy because the energy produced by various trending treatment of biomass is considered carbon neutral as the carbon dioxide released during conversion is already a part of Carbon cycle. [1] Regular use of biomass for energy production helps to reduce greenhouse gas (GHG) emissions and fulfill the targets established in the Kyoto Protocol. [2] Energy production from biomass can be possible from various processes. Different biological (anaerobic digestion and fermentation), chemical (esterification) and thermochemical (combustion, pyrolysis, and gasification) processes yield energy from biomass, where direct combustion can provide a near term energy solution. [1] This new technology to use biomass as a solid-state fuel involves combustion to generate steam for electrical power and commercial plant uses and gasification to produce combustible gas and syngas. Carbon dioxide and nitrogen in huge partial pressure altogether is called producer or combustible gas and less amounts of nitrogen, carbon dioxide with carbon monoxide and hydrogen is syngas on the contrary. The use of syngas or producer gas in modern-day gas or reciprocating turbines, or to produce high-value chemicals and fuels, is still at stake due to biomass feedstock preparation, accumulation logistics, and economics limitation. [3]

Biomass has several drawbacks to be used as a direct fuel source such as high moisture content, low calorific value, hygroscopic nature, smoking while combustion, etc. Torrefaction is considered to be one of the most feasible and sustainable procedure for improving biomass properties as a fuel. It can be defined as the preheat treatment of biomass in an inert environment from a temperature range of 200°C to 300°C (maximum). [4] The process breaks the intermolecular hydrogen, C-O and C-H bonds leading to the emission of hydrophilic and oxygenated compounds producing a solid uniform brown to a black color product, with lower moisture content and higher calorific value or energy content compared to the initial biomass characteristics. This treatment to achieve a better fuel can be called mild pyrolysis in assistance with the reduction and removal of smoke producing compounds and generation of a solid product, clinging to nearly 70% of the initial weight and 80-90% of the original energy content. [5]

The overall torrefaction process can be classified into four steps which are drying at (50-150) °C, post-drying at (150-200) °C, torrefaction at (200-300) °C and cooling. The drying stage is followed by a nonreactive and reactive step. The inclusive term torrefied biomass is a group of products resulting from the partially controlled and isothermal mild pyrolysis of the sample biomass occurring in a temperature range of 200-230°C and 270-280°C. Initially, when biomass start to heat, in the first step it goes through is drying that follows thermo-condensation process which removes a new amount of water from a chemical reaction with further heating. This takes place just above 160°C temperature where carbon dioxide formation begins simultaneously. In between 180°C and 270°C temperatures the degradation of hemicellulose compounds carries on with an exothermal reaction. The sample biomass starts to change color to brown. In this step it continues to emit moisture, carbon dioxide and a huge amount of acetic acid associated with phenols, these lower energy compounds degrade the fuel quality by holding the tenacity and fibrous structure of biomass making it less energy dense. Though reduction of these compounds biomass manages to retain most of its energy density, becomes more friable than the untreated biomass by losing most of its hygroscopic character. When the system reaches 280°C temperature it completely enters into exothermic reaction where the gas production is increased as carbon monoxide and hydrocarbon-like cresols, phenols and other heavier products. The Torrefaction process is not recommended over 300°C temperature because pyrolysis initiates instead of torrefaction at this stage. [6]

Torrefied biomass can be blended and mixed with coal and co-fired in a Pulverized Coal Boiler (PBC). Some advantage of torrefied biomass compared to untreated biomass is its uniformity, less tenacity, and fibrous structure. Due to the low moisture content of torrefied biomass, transport cost is lower and the quality of biomass as fuel is better. Packaging and transportation are easy, and thus constitutes an efficient fuel. The properties of torrefied biomass should lead to an improved operation in gasifiers for which the stability of the process is important [6].

2. Experimental

Around 2 grams of sample was weighted. The sample was placed inside the reactor and the thermocouple of the reactor was connected to the control system. The reactor was thoroughly inspected for leaks using a soap bubble on all inlets and covers. Then nitrogen gas, which acted as an inert media, was allowed to flow through the system at 1.5 bar pressure to remove air from the reactor. After filling with nitrogen gas the gate valve was closed and again checked for leaks. The reactor was then turned on and the temperature was set. In this experiment, the same procedure was applied for three different temperatures- 200°C, 260°C, and 300°C. The sample was allowed to heat for 10,20,30,60 and 120 mins at each specific temperature. Then the heater was turned off. When the sample was cooled to room temperature, it was removed from the reactor and weighed. Then the sample was kept in an electric oven for 20 mins and after that was kept in a vacuum desiccator to cool down. The cooled sample was weighed and the moisture content was calculated. The effect of experimental condition (temperature and residence time) on the properties of products was investigated.

In order to do the torrefaction process, a reactor was required to be designed and constructed which is shown in figure 1(a). A Stainless steel 304 pipe of 8.5 cm inner diameter and 37.7 cm height was constructed. This is the main chamber of the reactor. Two other cylindrical bars of the same SS of 2 cm height and 12 cm diameter was bought as the cover for the pipe on both sides. Two other cylindrical bars were also installed inside the reactor for creating a surface for the sample to hold. Three holes were drilled on the top side of the reactor. One was for the thermocouple, one for the gas inlet and the other was kept for a gas outlet in case the process is considered to be continuous. The reactor body was coiled using copper wire and insulated. The insulation material is made of asbestos. An autonics TZ series Dual speed PID temperature controller and a magnetic contactor were installed which is shown in figure 1(b) and the coil was connected with the controller. A wire connected the thermocouple with the controller. The lower part of the reactor was sealed with Araldite glue in order to prevent leakage. The reactor was designed and constructed which was completely leak-proof.

3. Results and Discussion

The rice husks used as raw materials were collected from Kushtia rice mills. The samples were about 7-8 mm in length and 1-2 mm in diameter. The samples were ground by using an electric grinder and the ground material was sieved. For the sieving process, sieves of -18+35 range were used. The volatile matter of the sample was measured by following ISO 18123, the moisture content was measured by following ISO 18134-1, ash content was measured following ISO 18122 method and the fixed carbon is the result of subtraction of the summation of volatile and ash content in a dry basis.

Fig. 1. (a)Torrefaction Reactor, (b) Electric Controller (Left) and Magnetic Contactor (Right)

Table 1.Raw Material properties

Sample	Volatile matter (%)	Moisture content (%)	Ash content (%)	Fixed carbon (%)
Rice husk	67.23	7.83	18.46	6.48

Figure 2 is a column chart representation of all the data acquired from the torrefaction process. It shows the experimental data for torrefaction done at 200°C, here all the samples taken were almost nearly 2g. The samples were torrefied at different residence time (10, 20, 30, 60 and 120) mins to investigate the effect of temperature and time on the sample. The sample no. 1 for this experiment had a moisture content of 5.53%, volatile content of 1.7% and dry weight 92.76%. On the other hand no. 5 sample had moisture content of 1.29%, volatile content of 9.055% and dry weight 89.66%. Proximate analysis of various biomass samples, show a varied region of different fuel properties. Used raw samples in the torrefaction process also show almost similar characteristics range. Moisture content varies from 1%~5.5%.Volatile matter, a key component of solid fuels, were used to measure the combustion characteristics. Volatile matter in large extent which is usually the barrier to attain better fuel properties. It ranges from 1%~9.1% generally but most common is 7%. It is clear that the samples which were pretreated at this temperature don't have a better fuel characteristic. To attain better fuel property the samples should have lower volatile matter and moisture content.

Figure 2 also shows the experimental data for torrefaction done at 260°C it shows the effect of temperature increase, though weight loss and change in moisture content for several biomasses. Temperature effect is significantly introduced on these samples. While the temperature increase biomass constituent, hemicellulose undergoes a depolymerization reaction thus smaller hydrocarbon molecules (volatile and gas) with low energy density escapes, which in return increases the weight loss. The first sample for this experiment had a moisture content of 1.12%, volatile content of 9.91% and dry weight 88.88%. On the other fifth sample had moisture content of 6.3%, volatile content of 9.4% and dry weight 85.41%.Proximate analysis of various biomass samples, showed various regions of different fuel properties. Used raw samples in torrefaction process also showed almost similar characteristics range. Moisture content varies from 0.44%~6.3% where dry weight varies from 73%~89%. As in the case of moisture content, it followed a different trend as for weight loss. For all sample moisture content were increased with increasing temperature with few exceptions as predicted before that there might be sample non uniformed or weather effects. It is clear that the samples torrefied at 260°C had better fuel characteristics than the samples of previous experiment.

Finally the experimental data for 300°C with the increasing temperature hemicellulose which are the constituents of biomass undergoes depolymerization. Smaller molecules (volatile and gas) with low energy density escapes more than the previous experiments which decrease the remaining weight of the sample. The sample experimented for 120 mins at 300°C temperature has the less dry weight 63.74%. Which is considered to be the most acceptable torrefied sample among all the experiments due to its lesser dry weight as it can be considered that most of its volatile component and gas (34.34%) has escaped making it a better fuel component. The gross calorific value of that sample was 15769.3 kJ/kg which has 1569.3 kJ/kg more heating value than sample (rice husk) which has a calorific value of 14200 kJ/kg. So, it can be noted that no.5 sample for this experiment has the best fuel characteristics among all the other samples.

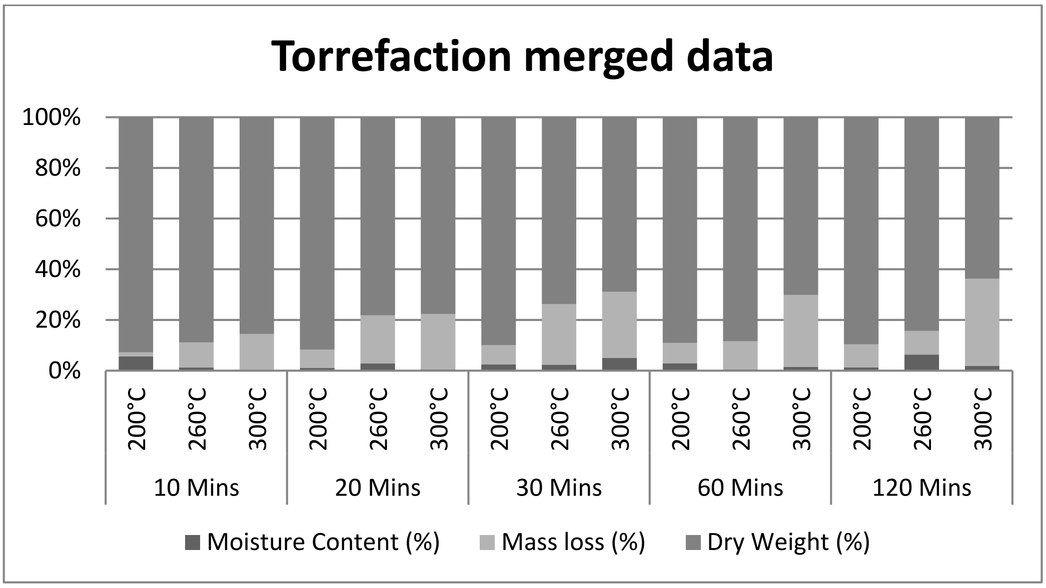

Fig. 2. Presentation of torrefaction product composition

Figure 2 is a visual presentation of the research work done where the y-axis represents percentage (%) and the x-axis represents time (min) and temperature. The moisture content, mass loss and dry weight is shown in different colors in the column chart. For 200°C temperature, the significant weight loss was not much but for 260°C temperature the biomass started to lose weight significantly till 30 min but after 60 and 120 min data for 260°C temperatures showed that the biomass again gaining weight. Finally, for 300°C temperature, the biomass gradually lost its weight and the sample at 120 min lost the maximum weight.

4. Conclusion

Torrefaction process leads to biomass (rice husk) to changes in various physical and chemical properties. These changes are responsible for increased energy density, increased calorific value, reduced O/C ratio, improved hydrophobicity, and increased resistance to microbial degradation, and increased grind ability, as well as mass and energy losses in the process. Residence time has been a factor that affected the performance of the biomass properties. It was found that with longer residence time the fuel properties of the biomass increased, which made an agreement with other researchers [7,8,9]. The temperature being the most consequential factor for the improved properties of biomass, moisture content had an important effect on energy density, mass, and energy yield, and generally caused a reduction in each of these parameters.

Biomass is a renewable form of energy having many advantages as carbon neutrality, less dependency on fossil fuel, availability, versatile, lost cost compared to fossil fuel, wastes reduction, etc. Torrefied biomass being friable, less biological activity (decomposition, mold), more hydrophobic, more cost economic will be the next most feasible source of energy production. The power generation market will bound to move towards more production of torrefied biomass in the near future.

6. References

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