Wood briquette torrefaction

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Several torrefaction experiments using wood briquettes are reported in this paper. The torrefied briquettes weight yield lies between 43 and 94 %, and energy yields ranged from 50 to 97 % depending on the operating parameters. After torrefaction the briquettes showed an increase of approximately 15 % in heating value, and a decrease of approximately 73 % in equilibrium moisture. It was shown that torrefied briquettes achieved hydrophobic character and remained unaffected when immersed in water. This research also provides information on proximate and elemental analysis, showing that temperature has more influence than residence time. The aforementioned data indicate that torrefaction is a feasible alternative to improve energy properties of ordinary briquettes and prevent moisture absorption during storage.

1. Introduction

Biomass residues have a great potential in most developing countries, since they are able to replace energy sources such as firewood [Suárez et al., 2000]. However, only a small proportion of biomass residues are being used as fuel because of their high moisture, high polymorphism and low energy density. These troublesome characteristics increase costs for transport, handling, and storage, making the use of biomass as a fuel impractical. Some of these drawbacks can be overcome if the biomass residues are densified into briquettes, in order to provide more energy per unit volume and uniformity in shape and size [Bhattacharya, 1990].

Some disadvantages of briquettes are their high sensitivity to moisture and low combustion efficiency. For example, briquettes are seen to crumble when exposed to water or high humidity. Also, during the initial combustion stage briquettes emit a great amount of smoke because of their high volatile matter content, causing losses as unburnt fuel gas. A way to eliminate some of the disadvantages mentioned above could be the torrefaction of briquettes [Felfli et al., 1998].

Torrefaction consists of thermally treating the briquettes at temperatures between 230 and 280ºC in a non-oxidizing environment. In this process the biomass hemicellulose is degraded, maintaining its cellulose and lignin content [Bourgeois, 1984; Doat, 1985]. In this manner, briquettes are converted into a more stable product with higher energy content.

Torrefaction takes place at low heating rate and temperature below 300ºC in an inert atmosphere, with short residence time (about two hours) [Bourgeois and Guyonnet, 1985]. Torrefied biomass has advantageous properties (such as low moisture, lower emission of smoke and increased heating values) that improve fuel quality [Arcate, 2002; Pach et al., 2002; Girard and Shah, 1991]. Torrefaction also makes biomass hydrophobic, that is, it practically does not reabsorb moisture during storage. The mechanical properties of torrefied biomass are similar to those of raw biomass. However, torrefied biomass presents lower friability than carbonized biomass [Bourgeois and Guyonnet, 1985; Antal and William, 1990].

Research was conducted to investigate the characteristics of torrefied briquettes and the relationship between these characteristics and the torrefaction process parameters. The tests were carried out in a torrefaction unit, which consisted of a biomass combustion chamber for heat generation and an overhead torrefaction chamber.

2. Characterization of torrefied briquettes

Torrefaction tests were run on briquettes obtained from wood residues, whose characteristics are shown in Table 1. Experiments were performed under different torrefaction conditions.

2.1 Proximate analysis and heating value

ASTM D 1762-82 (standard method for proximate analysis of wood charcoal) and ASTM D 3286-85 (standard test for higher heating value of coal) were utilized to characterize the torrefied briquettes. As can be noted from Table 2, when the torrefaction temperature (TT) was

Table 1. Characteristics of wood briquettes

C (%)	H (%)	O (%)	Ash (%)	Fixed carbon (%)	HHV (kJ/kg)
49.37	6.59	40.24	2.8	19.2	20,020

Table 2. Proximate analysis and higher heating value of torrefied wood briquettes

Temperature (ºC)	Time (hour)	Volatile content[1] (%)	Fixed carbon[1] (%)	Ash[1] (%)	HHV (kJ/kg)
220	0.5	75.2	18.2	6.6	20,426
	1	74.6	19.0	6.4	20,989
	1.5	73.6	19.8	6.6	21,065
250	0.5	65.2	27.0	7.8	21,209
	1	65.0	27.2	7.8	22,061
	1.5	60.0	32.1	7.9	22,674
270	0.5	55.7	34.6	9.7	22,772
	1	52.1	38.2	9.7	22,981
	1.5	41.0	49.2	9.8	23,066

Note

1. Dry basis

increased from 220 to 270ºC the HHV (higher heating value) increased by around 10 %. On the other hand, when the residence time (RT) was increased from 0.5 to 1.5 hours the HHV increased only 4 %. A similar behavior was observed when analyzing the relationship between torrefaction parameters and fixed carbon content. From these results, we can conclude that the temperature has more effect on the briquettes than the residence time.

There was little change in briquette properties at 220ºC. However, at TT between 250 and 270ºC the volatile emissions were more intensive, causing perceptible changes in fixed carbon, volatile content and HHV (see Table 2). The highest HHV was obtained at 270ºC. At this TT the effect of residence time (RT) on the HHV was negligible. For example, when RT was increased three-fold the HHV increased just 1.29 %, while at 250ºC the HHV went up 7 %.

Since combustion and torrefaction processes take place in separate chambers, it is relatively easy to control biomass TT and RT inside the torrefaction chamber. This allows a high degree of standardization in production of torrefied briquettes for different energy applications. Table 2 shows standard values for torrefied briquettes.

2.2. Elemental analysis

Data from elemental analysis was obtained from a CH analyzer (D 3178-84: standard test method for carbon and hydrogen). Table 3 shows a summary of elemental analysis results for briquettes torrefied under different conditions. It can be observed that as torrefaction parameters increase the elemental carbon fraction rises too, suggesting a decrease in the molecular H/C and O/C ratios. Thus, the degree of aromatization and oxygenation of briquettes decreases proportionally with the increase of the torrefaction parameters TT and RT.

From the combustion point of view, decreases in the O/C and H/C ratios are favorable since less smoke and water vapor are formed, improving the performance of the briquettes and contributing to energy loss reduction.

Analyzing the molecular ratios, torrefied briquettes could be classified as an intermediate product between raw biomass and charcoal, i.e., adjusting temperature and process time it is possible to make the product more or less similar to charcoal. As can be observed in Table 3, the highest elemental carbon content was reached at 270ºC. At this temperature, significant changes occurred in the molecular ratios compared to the few changes that took place at 220ºC. This happens because around 270ºC practically all hemicellulose has been degraded and the cellulose degradation process also starts, releasing most of the oxygenated and aromatic compounds.

2.3. Moisture and hydrophobic characteristics

Figure 1 indicates that the briquette equilibrium moisture decreased by approximately 73 % after torrefaction. The lower moisture could be the result of the tar condensation inside the pores, obstructing the passage of moist air through the solid, and then avoiding the condensation of water vapor. Another reason for this could be the apolar character of condensed tar on the solid, also preventing the condensation of water vapor inside the pores.

Figure 1 also shows that the equilibrium moisture increases when the torrefaction parameters are raised. This happens because the emission of volatiles becomes more intensive as TT is raised, increasing the porosity and hygroscopic characteristics.

The hydrophobic characteristics of torrefied briquettes were investigated by immersing several torrefied briquettes in water and determining the moisture content by

Table 3. Elemental analysis of wood briquettes

Temperature (ºC)	Time (hour)	C (%)	H (%)	O (%)	Ash (%)	H/C[1]	O/C[1]
220	0.5	51.58	6.87	34.95	6.60	1.59	0.50
	1	52.02	6.50	35.08	6.40	1.49	0.50
	1.5	53.79	6.28	33.33	6.60	1.40	0.46
250	0.5	54.66	6.10	31.44	7.80	1.34	0.43
	1	55.81	6.60	29.79	7.80	1.40	0.40
	1.5	57.63	6.00	28.47	7.90	1.24	0.37
270	0.5	58.85	5.52	25.93	9.70	1.12	0.33
	1	59.82	5.26	25.22	9.70	1.05	0.31
	1.5	63.00	4.28	22.92	9.80	0.81	0.27

Note

1. Molecular basis

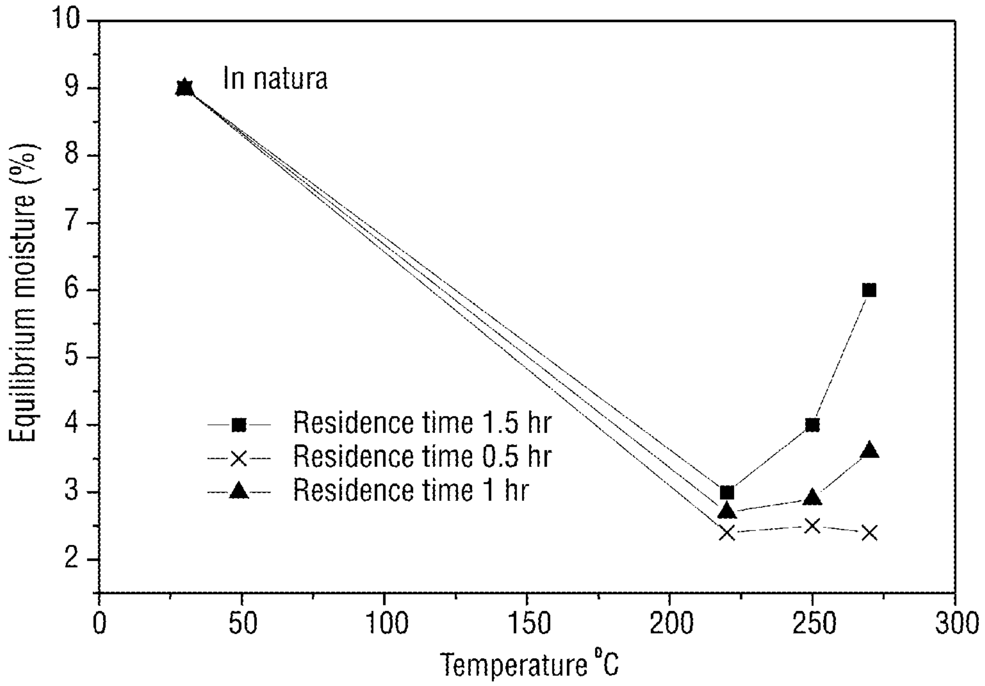

Figure 1. Equilibrium moisture of torrefied briquettes

measuring the change in briquette weight. Figure 2 displays the results as a function of immersion time and TT. It is estimated that the absorbed humidity does not exceed 10 % over the 70-minute retention time and the briquette remains intact, while ordinary briquettes disintegrate in a 10-minute test.

The test was repeated, increasing the water immersion period to 17 days. Dissolution of impregnated tar in briquettes torrefied at 220ºC allows the penetration of water in the solid matrix, thus elevating the final moisture to 116 %. However, no crumbling of the torrefied briquette was observed. On the other hand, the final moisture of briquettes torrefied in a temperature range of 250-270ºC was 28 % and no dissolution of impregnated tar was found, while the briquettes remained unaffected as well.

2.4. Torrefaction yields

Weight and energy yields values are showed in Table 4. Energy and weight yields ranged from 43 to 94 % and from 50 % to 97 % respectively, depending on the torrefaction time and temperature parameters.

3. Conclusions

It has been shown that the composition of torrefied briquettes at 220ºC does not undergo many changes. However,

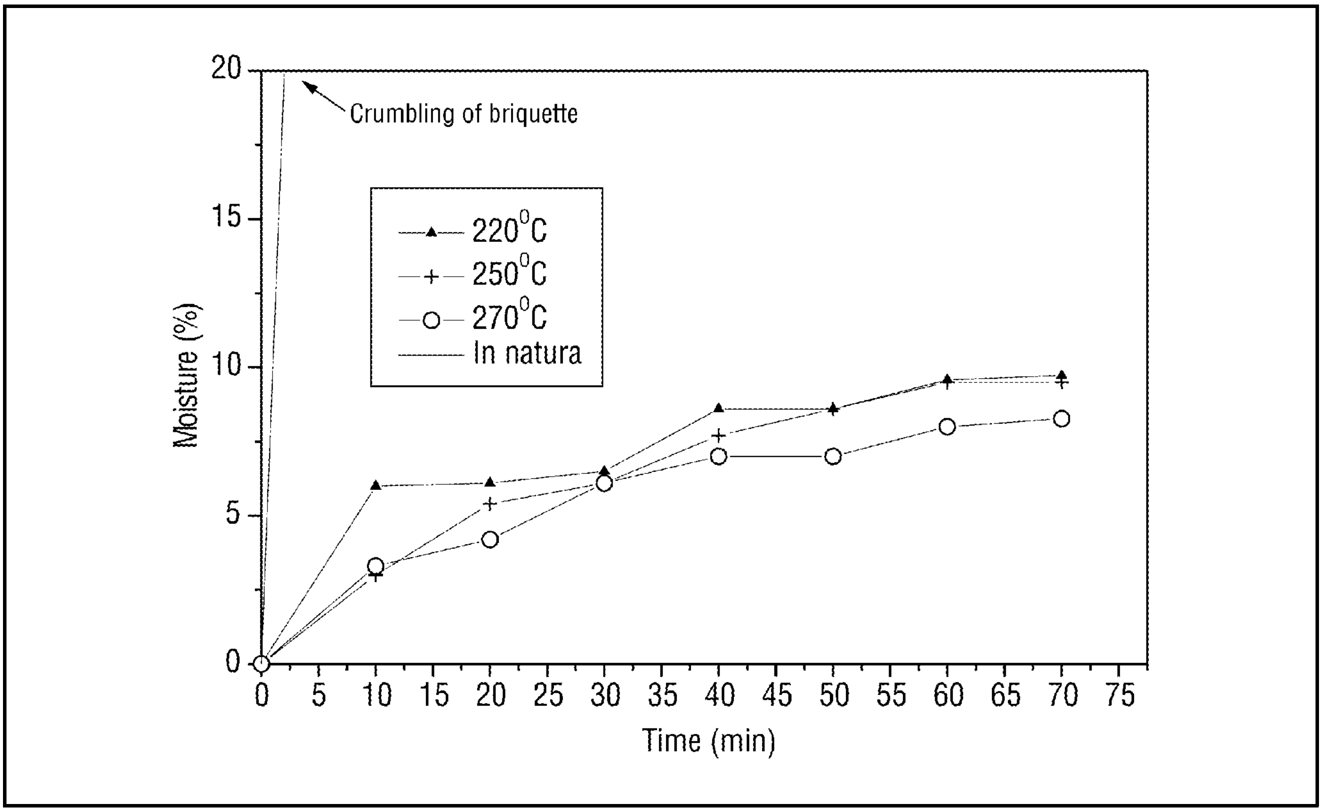

Figure 2. Hydrophobic test

Table 4. Torrefaction yields

Temperature (°C)	Time (hour)	Weight yield (%)	Energy yield (%)
220	0.5	94	97
	1	90	94
	1.5	72	77
250	0.5	74	80
	1	65	72
	1.5	60	67
270	0.5	56	65
	1	54	62
	1.5	43	50

at higher temperatures, changes in the composition are perceptible, with the briquette hemicellulose practically degraded and cellulose depolymerization process initiated. Residence time did not affect the final composition of torrefied briquettes much, no matter what the temperature at which they are treated. For this reason, we can conclude that TT has a greater effect on the torrefied briquettes than RT. Therefore it is recommended that temperatures are set in the range of 250-270ºC and residence times long enough to assure complete torrefaction, i.e., to the center of the briquettes. Torrefaction at temperatures of 250-270ºC would also make the briquettes hydrophobic, thus improving storage in humid locations.

Torrefaction can be a viable method to eliminate some of the disadvantages of raw biomass briquettes as it significantly improves the briquettes' energy content and prevents absorption of moisture during storage. ■

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