

Effect of Temperature and Time Torrefaction on the Energetic Properties of Bracatinga Wood

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Abstract Torrefaction of Bracatinga wood was realized to determine the effect of temperature (200°C, 220°C and 240°C) and time (30 min, 60 min and 90 min) on its energetic properties. We found that the gravimetric yield of torrefied wood decreased from 99.27% to 85.60%. The heat treatment at 240°C for 60 min produced the less hygroscopic sample as evidenced by an equilibrium moisture content of 37% lower than fresh wood (control sample). In addition, torrefaction produced samples of higher fixed carbon and lower levels of volatile content, reaching a maximum increase of 21% and decrease of 9%, respectively. As the most important, the gross calorific value of torrefied wood is about 5% higher than control. The increase of fixed carbon together with the reduction of both moisture and volatiles content show that this thermal treatment improve the energy content of torrefied wood that becomes a promising option for biofuels.

Keywords Heat treated wood, Biomass combustion, Exotic wood species

1. Introduction

In Brazil Bracatinga (*Mimosa scabrella* Benth.) has a natural occurrence in the Southeastern and South regions. It is a fast growing species and can be harvested to use directly as fuel or transformed in charcoal. Bracatinga is mainly used as firewood for domestic cooking stoves in rural areas and heating boilers in small industries [1-3].

The potential energetic of bracatinga's wood can be increased by applying heat. Torrefaction is a mild pyrolysis that promotes a controlled thermal degradation of wood, and happening at lower temperature (from 200 to 280°C) than carbonization (from 300 to 700°C) [4].

Torrefaction produces a solid biofuel that has its properties between wood and charcoal and retaining approximately 70% of the initial mass. The torrefied wood has hydrophobic properties and a higher calorific value than the fresh wood. Fresh wood has about 50% and 10% lower energy content than charcoal and torrefied wood,

respectively. Thus, submit wood to heat is a method that modifies its chemical and physical properties to obtain a biomass fuel with a higher energetic density.

The torrefaction causes chemical changes in the constituents of cell wall (cellulose, hemicelluloses and lignin) and extractives. The extractives, which are compound by a wide range of organic substances of low molecular mass, evaporate rapidly when exposed to heat. Additionally, among the macromolecules and having a relative lower thermal stabilities, the high hydrophilic hemicelluloses are the most affected by heat than other constituents of wood, as cellulose and lignin. As lignin is the highest thermal stable macromolecule, it is the less affected by heat, and therefore contributes to increase the energy content because the lignin is the most energetic macromolecule of the wood [5].

Furthermore, the thermal treatment promotes the desacetylation of hemicelluloses that produces acetic acid, which act as a depolymerization catalyst of polysaccharides. The hemicelluloses degradation can lead to darkness of the wood fuel. During heat process, the dehydrating of hemicelluloses induces the formation of furfural and hidroximetifurfural, the latter compound contribute to the darkness of the wood [1, 6].

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Under heat effect, crystalline cellulose increases because of the degradation of amorphous cellulose and additionally the hemicelluloses decomposed almost completely; as a result, the accessibility of the hydroxyl groups to the water molecules decrease and the moisture content of heat treated wood is lower. The lower moisture content produce a better fuel by decreasing the transport cost and turning the torrefied wood more resistant to attack by rot fungi [7].

For energetic purposes, the main goals of this research is to investigate and compare the changes in chemical and physical properties of heat treated wood of *Bracatinga* at temperatures of 200, 220 and 240°C; and time of 30, 60 and 90 min. For better understanding how the heat treatment affects the Calorific value of bracatingas's wood, we are using the results of the Approximate Analyses (fix carbon, volatile compounds and ash content), gravimetric yield, and equilibrium moisture content.

2. Material and Methods

The specie selected for the present investigation was Bracatinga (*Mimosa scabrella*). The trees were obtained from a farm plantation belong to the Forest College in Irati city, São Paulo state, Brazil. To have representative samples, the wood was collected by cutting boards from a trunk and the boards were then cut into test-pieces.

The heat treatment was carried out in a laboratorial Ética electric furnace, model 400.4. Eleven pieces of wood, with dimensions of 2 cm length, 3 cm width and 5 cm thick, were used by each treatment in the temperature at 200, 220 and 240°C and in the times at 30, 60 and 90 min. The time of each treatment was recorded after reaching the required temperature.

Determination of the equilibrium moisture content: the test pieces were heated in the oven at 100±3°C until the mass constant. The measure was done in three times by each treatment, using the following equation:

$$U_{eq} = [(m_i - m_s) / m_i] \cdot 100 \quad (1)$$

where: The initial mass is m_i and the dry mass is m_s , U_{eq} is the equilibrium moisture content from the conditioned test piece in a climated room under temperature at 20.5°C ± 3.45 and relative humidity at 73.8% ± 6.80.

Gravimetric yield: After cooling the test-pieces in a desiccator, the torrefied wood was weighed and determined the gravimetric yield as follow:

$$R_g = (m_r / m_{nr}) \cdot 100 \quad (2)$$

where m_r is the dry mass of the torrefied test-pieces and m_{nr} is the dry mass of non-heated test-pieces.

Immediate analysis: the Immediate analysis of a fuel provides the percentage of volatile matter, fixed carbon and ash. The torrefied and non-torrefied samples were ground and sieved, and the material used was obtained after sieving with a particle size between 40 and 60 mesh. To determine the volatile content, 1.0 g of moisture-free sawdust was placed in

a crucible with a lid and Heated in the oven at 600°C for 10 minutes, according to [8]. The fixed carbon content (FCC) is an indirect measurement and was calculated by the equation:

$$FCC(\%) = 100 - (AC + CVM) \quad (3)$$

where AC is the ash content and CVM is the content of volatile materials.

The test for determining the ash was conducted in a muffle oven at 700°C for 6 hours and calculated as follow:

$$R_g = (m_r / m_i) \cdot 100 \quad (4)$$

where m_r is the residue after heat process and m_i is the initial dry mass.

Estimation of Heat Power: the gross calorific value (PCS - kcal/kg) of torrefied and non-torrefied wood was estimated using data from the Immediate analysis, according the following equation proposed by [6] (Equation 5).

$$PCS = 84.5104 \cdot CF + 37.2601 \cdot CV + 1.8642 \cdot CZ \quad (5)$$

Being CF the Fixed Carbon content, CV the content of Volatile fraction and CZ the content Ash content.

3. Results and Discussions

Wood is composed of polysaccharides (cellulose and hemicellulose) and lignin, which are responsible for their physical and chemical properties. The torrefaction promotes changes in these variables. Figure 1 illustrates the results of gravimetric yield referring to the nine treatments.

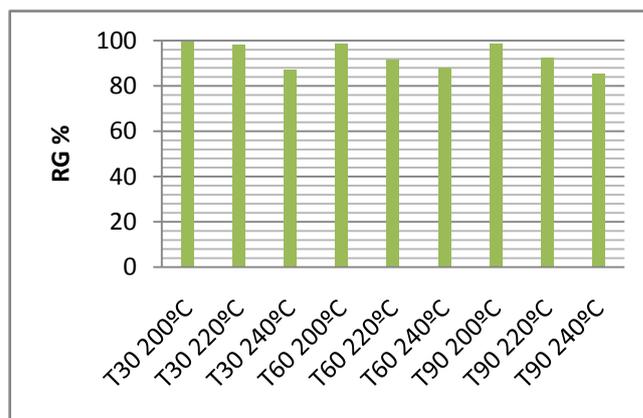


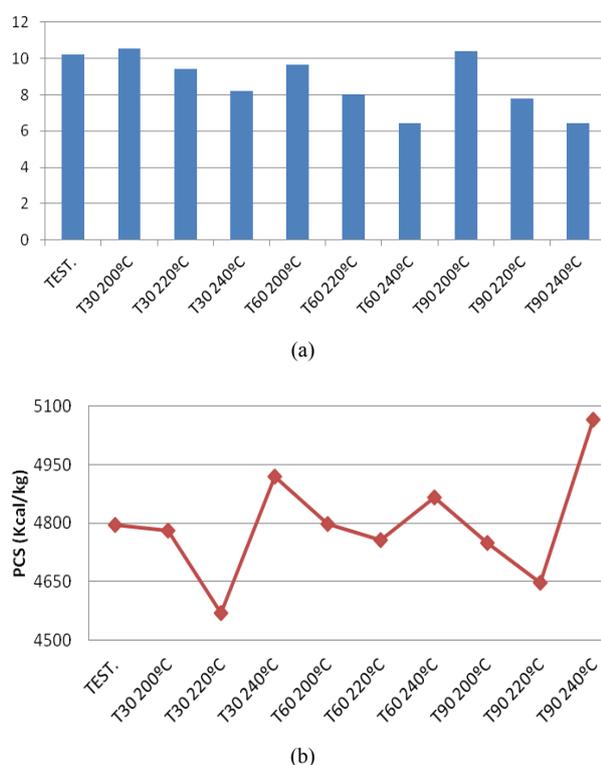
Figure 1. gravimetric yield resulting from the torrefied process at T30 200°C, T30 220°C and T30 240°C (samples treated for 30 min at 200, 220 and 240°C respectively); T60 200°C, T60 220° and T60 240°C (samples treated for 60 min at 200, 220 and 240°C respectively); and, T90 200°C, T90 220°C and T90 240°C (samples treated for 90 min at 200, 220 and 240°C, respectively)

The torrefaction leads to a decrease in mass of wood, mainly due to thermal degradation of the hemicelluloses that decompose and release volatile compounds. Thus with the increasing of time and temperature treatment, it occurs a maximum of 14% reduction in gravimetric yield from 99.27% (sample T 30 200°C) to 85, 60% (sample T90 240°C) Table 1.

Table 1. Gravimetric yield (R_g), Equilibrium moisture content (U_{eq}) and Higher Calorific Value (PCS) of torrefied and non-torrefied wood

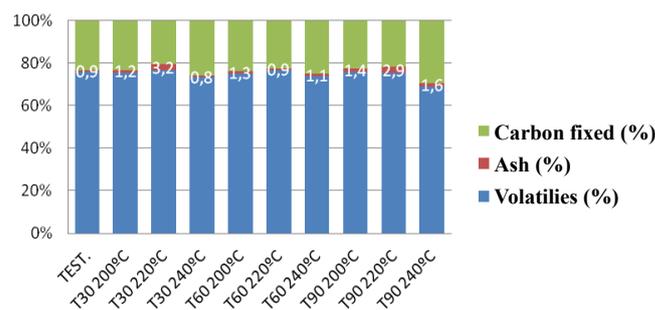
Properties	R _g (%)	U _{eq} (%)	PCS (kcal/kg)
Reference	---	10.23 ± 0.4 a (3.88 %)	4795.33 ± 22.48 cd (0.47 %)
T30200	99.27 ± 1.03 a (1.04 %)	10.56 ± 0.27 a (2.58 %)	4780.67 ± 29.50 cd (0.62 %)
T30220	98.43 ± 1.10 a (1.12 %)	9.43 ± 0.71 abc (7.55 %)	4568.00 ± 40.93 f (0.90 %)
T30240	87.81 ± 13.10 b (14.92 %)	8.22 ± 0.84 bcd (10.17 %)	4920.33 ± 33.86 b (0.69 %)
T60200	98.44 ± 0.66 a (0.67 %)	9.64 ± 0.28 ab (2.91 %)	4798.00 ± 9.64 cd (0.20 %)
T60220	91.48 ± 9.83 ab (10.75 %)	8.00 ± 0.41 cd (5.16 %)	4755.67 ± 34.53 cde (0.73 %)
T60240	89.54 ± 3.81 b (4.26 %)	6.45 ± 0.33 e (5.17 %)	4865.67 ± 38.37 bc (0.79 %)
T90200	98.36 ± 0.69 a (0.70 %)	10.42 ± 0.72 a (6.93 %)	4748.00 ± 28.51 de (0.60 %)
T90220	91.26 ± 6.60 ab (7.23 %)	7.81 ± 0.52 de (6.67 %)	4648.00 ± 43.00 ef (0.93 %)
T90240	85.60 ± 4.86 b (5.68 %)	6.42 ± 0.20 e (3.18 %)	5064.00 ± 77.54 a (1.53 %)

The means followed by the same letter are not statistically different. Tukey's test was applied at the level of 5% probability.

**Figure 2.** Equilibrium moisture content (a), calorific power higher of torrefied samples including the reference condition (control) (b)

Regarding the hygroscopicity of the torrefied samples, Table 1 and Figure 1 show the results of variance analysis and graph related to experimental design. The equilibrium moisture content values tend to decrease when the temperature and time increase, so there is a variation in the hygroscopic properties of the wood with the heat treatment. The hemicelluloses are very hygroscopic components of wood, its degradation promotes a reduction in the capacity of wood to absorb ambient water; consequently, providing a reduction in the equilibrium moisture content with a maximum reduction of 37% than the control sample, in the temperature at 240°C and time at 30 min.

The Torrefaction increased the energy content of Bracatinga wood (Figure 2). Fuels from biomass with higher fixed carbon content and consequently lower volatile content are those with the highest energy content, Table 2.

**Figure 3.** Immediate composition of torrefied and non-torrefied samples

The samples treated for longer times and temperatures have higher fixed carbon content, the treatment of 90 min at 240°C has an increase of 21% in carbon content than the control sample as well as lower volatile levels, decrease of 9%, Table 2 and Figure 2.

4. Conclusions

These results indicated that torrefaction increases the energy content of Bracatinga wood making it more suitable for applications such as fuel in heating plants whose power supply comes from biomass burning.

The samples treated for longer times and temperatures showed lower hygroscopicity, as evidenced by a lower equilibrium moisture content: reduction of 37% compared to control, at the temperature of 240°C and time of 30 min; as well as the higher carbon content fixed (21% increase) and lower volatile content (decreased 9%).

As the most important factor, it was found that the gross calorific value increased in 5% with increasing temperature and roasting time.

Table 2. Composition of Immediate data (CV is the volatile content, CF is the fixed carbon content and the CZ the ash content) and Higher Calorific Value (PCS) of terrified and non terrified wood

	CV (%)	CF (%)	CZ (%)	PCS (kcal/kg)
Reference	75.75 ± 0.48 ab (0.64 %)	23.32 ± 0.48 cd (2.07 %)	0.93 ± 0.08 ab (8.31 %)	4795.33 ± 22.48 cd (0.47 %)
T30200	75.64 ± 0.63 abc (0.83 %)	23.19 ± 0.63 cd (2.70 %)	1.17 ± 0.20 ab (17.32 %)	4780.67 ± 29.50 cd (0.62 %)
T30220	76.45 ± 0.85 a (1.11 %)	20.24 ± 0.87 e (4.30 %)	3.22 ± 1.94 a (60.09 %)	4568.00 ± 40.93 f (0.90 %)
T30240	73.24 ± 0.71 c (0.98 %)	25.92 ± 0.71 b (2.76 %)	0.85 ± 0.18 b (21.16 %)	4920.33 ± 33.86 b (0.69 %)
T60200	74.98 ± 0.21 abc (0.27 %)	23.69 ± 0.21 bcd (0.87 %)	1.34 ± 0.07 ab (5.09 %)	4798.00 ± 9.64 cd (0.20 %)
T60220	76.64 ± 0.73 a (0.95 %)	22.46 ± 0.73 de (3.25 %)	0.89 ± 0.03 ab (3.22 %)	4755.67 ± 34.53 cde (0.73 %)
T60240	73.89 ± 0.81 bc (1.10 %)	24.98 ± 0.81 bc (3.24 %)	1.14 ± 0.02 ab (2.17 %)	4865.67 ± 38.37 bc (0.79 %)
T90200	75.91 ± 0.60 ab (0.79 %)	22.68 ± 0.60 cd (2.66 %)	1.41 ± 1.03 ab (72.85 %)	4748.00 ± 28.51 de (0.60 %)
T90220	75.38 ± 0.92 abc (1.22 %)	21.70 ± 0.92 de (4.23 %)	2.92 ± 0.77 ab (26.30 %)	4648.00 ± 43.00 ef (0.93 %)
T90240	68.96 ± 1.64 d (2.38 %)	29.49 ± 1.64 a (5.57 %)	1.56 ± 1.10 ab (71.00 %)	5064.00 ± 77.54 a (1.53 %)

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