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Original Article

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Different Types of Lignocellulosic Materials for Energy Generation in the Ceramic Industry

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ABSTRACT

This work aims at the physicochemical characterization of four species: Eucalyptus sp, Pinus sp, Citrus sinensis and Hevea brasiliensis for use in ceramic furnace. Immediate analysis, chemical analyses were carried out (total extractives, Klason lignin, holocellulose and alpha-cellulose content). Results were applied to ANOVA and Tukey for statistics. The ash content of Pinus sp was 1.60%, for volatile material content Eucalyptus sp presented 83.61%, for fixed carbon values, Citrus sinensis presented 20.03%. Chemical analyses in the total extractive content, Citrus sinensis presented 21.76%, Klason lignin content, Pinus sp had 39.24%, Eucalyptus sp 60.29% had the highest holocellulose and alpha-cellulose, which was 42.72%. Pinus sp sample was the one with the highest heating value of 20.090 J/g. According to results obtained in the analyses, it is possible to conclude that all species have potential for applications in ceramic furnace.

Keywords: ceramic furnace, characterization, biomass, bioenergy.

1. INTRODUCTION

The demand for energy has greatly increased due to the vast productivity expansion in the industrial sector. It represents an important factor for the economy competitiveness. There are many options of energy sources, but fossil fuels still represent an important share of the world's energy resources. However, most industrial sectors have been searching for other options which may be cheaper and more environmental friendly, such as renewable resources (Ciacco et al., 2017; Al-Hamamre et al., 2017).

Biomass is one of renewable resource that should be highlighted since it produces biofuels in several forms, one of them is solid fuels (briquettes and pellets), such as wood and charcoal, liquid fuels such as ethanol, all of them with low production cost, low acidic gas and greenhouses gas emissions (GEE), contributing to the environment (Hansted et al., 2016). It results in clean combustion when compared with fossil fuels (Herbert & Krishnan, 2016), and it is estimated that about 30 million tons of wood wastes are annually generated in Brazil, and the main source is the timber industry (Aló et al., 2017).

The ceramic industry is an important sector in Brazil, with more than 7.431 industrial units (Prado & Bressiani, 2013). These industries have a mix of energy sources varying from natural gas, firewood, to different types of biomass such as wood chips, sawdust, waste pruning, among others (EPE, 2017). Using biomass may represent heterogeneity in the energy generation process, since at the time of collection, it contains very irregular moisture content, different sizes, and diverse elemental compositions (Singh et al., 2017). Therefore, it is necessary to provide previous studies and characterization in the use of biomass in order to predict the material behavior in the combustion process.

Physical characterization is necessary even among same species, as composition may vary due to elements such as cellulose, hemicellulose and lignin, presenting significant differences in lignocellulosic materials. For energy production, high lignin content is recommended since it increases the high heating value (HHV). Another recommendation is to perform the proximate analysis of the material due to the negative influence of the ash content during the energy generation process (Singh et al., 2017). Under certain conditions, the ash content can be reduced by carrying out some type of cleaning process (Hansted et al., 2016).

The biomass moisture content is also an important parameter. There is a direct and inversely proportional relationship between moisture content and HHV. This occurs since the energy released during combustion is used in the sample drying process (Posom et al., 2016).

The objective of this study was to perform the physicochemical characterization of four different types of biomass: *Eucalyptus* sp., *Citrus sinensis*, *Pinus* sp. and *Hevea brasiliensis*, and verify the viability of using these materials in the energy generation of a ceramic industry.

2. MATERIAL AND METHODS

A total of four species were evaluated: *Eucalyptus* sp, *Citrus sinensis*, *Pinus* sp. and *Hevea brasiliensis* sp. *Citrus sinensis* samples were collected in the municipal farm of Tatuí/SP-Brazil, firewood shaped; *Hevea brasiliensis* was collected in São José do Rio Preto/SP-Brazil as chips. Both *Pinus* sp. and *Eucalyptus* sp. were collected from ceramic units in Tatuí/SP-Brazil as chips.

Biomasses were submitted to milling in order to reduce the particle size to dust.

After material milling, only particles larger than 250 μm were used for conducting the analysis.

Proximate analyses (i.e., moisture content, volatile matter, ash content and fixed carbon) of materials were performed according to Nakashima et al. (2017). HHV of materials was measured in a calorimeter according to Nakashima et al. 2017.

For extractives, 4.5 g were collected from each species. The experiment was performed with cyclohexane/ethanol (ECE) and for hot water (HWE), according to Nakashima et al. 2017. The procedure was carried out for 8 and 2 h, respectively. SOXHLET extraction apparatus was used.

Klason lignin (KL) was calculated according to Nakashima et al. (2017). The extractive-free biomass was treated with 78% H_2SO_4 solution (15 cm^3) for 2 h at 25 ºC. Samples were diluted with water (560 cm^3) for 4 h. The residue was washed in filter using hot water until reaching neutral pH. The dry insoluble residue was the lignin content.

The procedure used for preparing holocellulose (HC) involved treatment of the milled extractive-free wood (4 g) with acid solution (160 cm^3 sodium acetate solution) at 75 ºC for 5 h. Sodium chlorite (4 cm^3) was added every hour for 4 h. The mixture was cooled down and the residue filtered and washed first with water (1 dm^3) and then with acetone (15 cm^3). The residue was finally dried at room temperature. An aliquot was weighed and dried at 105ºC for the determination of the HC content. The standard for this procedure was TAPPI T 249-85 (TAPPI, 1985).

Extraction of α-Cellulose was based on Coldebella et al. (2018). For the test, 1 g of HC was added to 17.5 wt% NaOH solution (100 cm^3) at 25 ºC for an incubating period of 30 min. The reaction was ground for 5 minutes. The residue was filtered and washed with water and dried at 105 ºC. The amount of α-cellulose was gravimetrically determined.

Statistical analyses using ANOVA and Tukey's test were performed using R 2.11.1 and Tinn-R 1.19.2.3 statistical software.

3. RESULTS AND DISCUSSION

Proximate analysis is presented in Table 1 for the four materials.

When a given material has high moisture content, it is necessary to dry it before the initial burning stage, but this process requires energy. Most wastes contain high moisture content, and the high moisture content in biomass is one of the major disadvantages of using this material (Róz et al., 2015; Yamaji et al., 2013). However, biomasses were already collected within the indicated moisture content for use in heat generation according to Hansted et al. 2016, thus, these materials do not require drying treatment .

The ash content in all materials can be considered low, since it is indicated for use in energy generation. The European quality for pellets states that to be considered as a good fuel, the ash content should be less than or equal to 3.0% (Spanhol et al., 2015), and the material with the highest value was *Pinus* sp., 1.6%. This result indicates that it can be considered high-quality fuel, with low external contamination (Hansted et al., 2016). It is also important to determine the ash content of a material since it can be responsible not only for reducing HHV but also to increase the erosive process of the equipment in which the biomass is consumed, thus affecting the maintenance demand, and resulting in extra production costs (Garcia et al., 2014).

Regarding volatile matter and fixed carbon, the expected values for the fuel to be considered for energy generation are from 75 to 85% and 15 to 25%, respectively, and all materials presented values within this range. Volatiles promote faster burning of the material by providing a quick but initially non-lasting and continuous burning during the process. In contrast, fixed carbon is responsible for the fuel thermal resistance, which means that it promotes slower and longer lasting burning (Brito & Barrichello, 1982; Santos et al., 2011). Table 2

Table 1. Proximate analysis of the four materials. Means followed by different letters differed by the Tukey test at 5% significance.

Sample	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)
Eucalyptus sp.	11.00	0.76 (±0.23) a	83.61 (±0.77) a	15.62 (±0.63) a
Citrus sinensis	11.20	1.51 (±0.51) a	78.44 (±0.39) b	20.03 (±0.84) b
Pinus sp.	10.40	1.60 (±0.62) a	82.56 (±0.40) a	15.83 (±0.68) a
Hevea brasiliensis	12.72	1.21 (±0.31) a	82.78 (±1.22) a	16.00 (±1.13) a

Value in parenthesis represents the standard deviation for 3 replicates.

Table 2. Chemical analysis of the four materials.

Chemical analysis	*Eucalyptus* sp.	*Citrus sinensis*	*Pinus* sp.	*Hevea brasiliensis*
TE (%)	8.00 (± 0.27) b	21.76 (± 0.79) a	19.15 (± 0.64) b	9.87 (± 1.05) c
KL (%)	24.62 (± 2.71) bc	20.49 (± 1.25) c	39.24 (± 0.14) a	26.52 (± 3.28) b
HC (%)	60.29	35.31	51.38	53.07
AC (%)	42.72	18.30	30.36	21.01
HHV (J/g)	19.680	18.920	20.090	19.560
LHV (J/g)	18.351	17.585	18.757	18.226

TE: Total Extractives; KL: Klason Lignin; HC: Holocellulose Content; AC: Alpha-Cellulose; HHV: High Heating Value; LHV: Low Heating Value.

presents the chemical analysis, with Total Extractives, Klason Lignin, holocellulose content, α-Cellulose and High and Low Heating Value for the four materials.

The composition of a lignocellulosic material may vary even within the same species. The analyses of compounds are essential to verify the energy potential. Total extractives (TE) and lignin content (KL) are compounds that present a direct relationship with energy potential (Hansted et al., 2016). These two elements provide a better thermal resistance to the material, keeping combustion at higher temperatures for longer period (Tenorio & Moya, 2013). The material presenting the highest KL (*Pinus* sp. 39.24%) was biomass that provided the highest HHV. This relationship was already reported in many studies (Hansted et al., 2016; Fahmia et al., 2008; Demirbaş, 2001).

Regarding heat production, the four species presented similar values with no significant differences. These values are considered high when compared with other species analyzed for use in bioenergy (Hansted et al., 2016), and can also be compared with commercial eucalyptus plantation, which presents HHV values from 18.100 J/g to 19.500 J/g according to Gominho et al. (2012).

For the elaboration of this work, intermittent production furnaces, vault-shaped (*paulistinha*) and tunnel, were analyzed. Burning and drying processes consume most fuel used for the manufacture of ceramic products. Firing provides the ceramic product with characteristics such as strength, color, among others, when it is submitted to heat. Firing temperatures are in the range from 750 to 900 °C to provide a more homogeneous product. Failure to follow firing parameters may cause deformation, cracking or breakage of parts.

Knowing the needs of the Ceramic Industry and how energy is essential for this activity, the results presented in Table 1 and 2 confirm the potential of *Pinus* sp species as fuel for the generation of energy in the form of heat. These results are in accordance with the preference of ceramic industries, which opt for this species.

4. CONCLUSION

The physicochemical evaluation of the four materials was carried out, and the results were satisfactory for the use of these biomasses in energy generation, in ceramic furnaces. All evaluated components presented satisfactory results in their use for bioenergy production.

It was possible to verify the viability of including both *Citrus sinensis* and *Hevea brasiliensis* species in the energy generation requirements of the ceramic industry.

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