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Energy enhancement of the eucalyptus bark by briquette production

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ABSTRACT

The aim of this article is to evaluate the use of eucalyptus bark, in the form of briquettes, as an energy source. Bark of a *Eucalyptus grandis* x *Eucalyptus urophylla* (*E. urograndis*) hybrid was obtained from the processing (debarking) of eucalyptus poles before industrial preservation treatment. For comparison purposes, wood discs were cut from the same poles. Two conditions of granulometry of the bark (crushed and crushed + milled) were separated to verify the effect of the particle size on the quality of briquettes. Biomass of the bark and wood, in its natural form, were evaluated and briquettes were produced for energy and physic-mechanical characterization. The direct application of bark in its natural form, as a source of bioenergy, presents disadvantages when compared to the wood, due to the high ash content and the low heating value. The *E. urograndis* wood and bark biomass residues can be used as a source of raw material to produce high quality briquettes. It was possible to verify a gain of the energy density through the process of briquetting, when compared to the raw biomass, as well as an improvement on the physic-mechanical characteristics.

1. Introduction

The participation of renewable energy in the Brazilian energy matrix has shown continuous growth over the years, reaching 43% at the end of 2016 and can be attributed to the good performance of hydroelectric, wind, and biomass generation (MINISTÉRIO DE MINAS E ENERGIA, 2016). In this scenario, Brazil has the potential to increase the share of biomass in the energy matrix, among other factors, due to the large amount of residues generated in the agricultural and forestry sectors, both in the field and in the industry.

In the forest-based industries, it is estimated that the generation of wood residues was approximately 13.8 million tons in 2016, with 66% used in the generation of energy and 24% processed into chips and sawdust. Most of the wood used (wood chips, wood-based panels, paper and cellulose) depends on the removal of bark from logs during the industrialization process (Lopes et al., 2016). These activities that depend on debarking, represent 78% (151 million m^3) of the industrial wood consumption in Brazil in 2016 (Indústria Brasileira de Árvores – IBÁ, 2017). Therefore, bark is a significant residue from the processing of eucalyptus wood.

The direct use of the residual biomass in a natural form, for energy purpose, presents some unfavorable characteristics related to the high moisture content, hygroscopic nature, varied dimensions and volumes, and low mass and energy density (Araújo et al., 2016; Hansted et al., 2016). One of the possibilities for reducing or eliminating the main problems associated with the direct use of biomass is through compaction processes, such as pelletization and briquetting (Sette et al., 2016).

The characteristics and quality of the briquettes can be influenced by variables related to the raw material (granulometry, chemical composition of the biomass, moisture content, etc.) and to the production process (pressure, temperature, etc.) (Nakashima et al., 2017; Zhang et al., 2018). The study of the effects of these variables on the quality of the briquettes is important, as it can present solutions regarding the energy demand, mainly on the use of the residual raw material for industrial processes.

The energy utilization of the residues and their application in the form of briquettes can be evaluated with parameters such as apparent and energy density, durability, mechanical strength by diametral comprehension, and volumetric expansion (Sette et al., 2016; Freitas et al., 2016; Castro et al., 2017). These parameters will determine the characteristics of the biomass and the best technique that can be used

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on the briquettes for energy uses (Eufrade et al., 2017).

Scientific studies have evaluated residues of forest and agricultural species (Paredes-Sánchez et al., 2016; Castro et al., 2017; Bentsen et al., 2018) and in their densified form (Moreno-Lopez et al., 2017; Gryazkin et al., 2017) for energy generation. However, studies focused exclusively on the bark, mainly of the eucalyptus, are still scarce; noteworthy are the studies of Eloy et al. (2016). In this context, the aim of this article was to evaluate the use of eucalyptus bark as an energy source in the form of briquettes.

2. Material and methods

2.1. Area characterization, sample collection and preparation

Eucalyptus grandis x *Eucalyptus urophylla* (or *E. urograndis*) bark was obtained from the processing (debarking) posts, before the industrial preservative treatment. The posts (2.20 m long) were cut from seven-year-old trees of commercial planting, located in the central region of the state of Goiás in Brazil (16°18′28.85″S and 49°13′3.80″W), with an altitude of 852 m. The climate was classified as Aw, according to Köppen, with wet and rainy summers (October to April) and dry and relatively cold winters (May to September).The average annual rainfall was 1432 mm, and average temperature was 20.4 °C and 24.4 °C in the colder and warmer months, respectively.

The eucalyptus bark was crushed and transformed into sawdust using a shredder. Part of the crushed bark biomass was separated and the remaining material was milled with Willey-type knives. This separation was performed to evaluate the effect of the biomass particle size on the characteristics of the briquettes. The two treatments with the eucalyptus bark comprised of: crushed (C) and crushed and milled (C + M).

Discs of wood were cut from the same *E. urograndis* posts used to obtain the bark and were crushed in a grinder and milled with Willey-type knives.

2.2. Biomass characterization

The samples of eucalyptus wood and bark that were crushed and milled underwent a mechanical separation with an international sieve No. 24 (American Society For Testing and Materials, 1982, of 60 mesh, in the orbital shaker. From the milled biomass in the 60 mesh, the high heating value (HHV) was determined by calorimeter, according to ASTM (American Society for Testing and Materials), ASTM D5865-13, and the volatile matter, ash and fixed carbon contents as recommended by ASTM E872-82 and ASTM D1102-84.34. The bulk density was evaluated according to according to ABNT (Brazilian Association of Technical Standards), ABNT NBR 11941, and the granulometric profile, were determined for the biomass bark in two conditions (crushed and crushed + milled) and wood in the crushed + milled condition. The energy density was obtained by multiplying the high heating value by the apparent density of biomass.

2.3. Briquette production and characterization

For the production and characterization of the briquettes of eucalyptus bark and wood, the biomass was used under the following conditions:

a) Bark: crushed (C) and crushed and milled (C + M)
b) Wood: crushed and milled (C + M)

The biomass of bark and wood were dried at 105 °C (± 2 °C) until constant weight and the moisture content adjusted to 12%, using a water sprayer and a precision weighing balance, as proposed by Silva et al. (2015). The moisture content of 12% is considered ideal for briquettes manufacturing (Nakashima et al., 2017; Eufrade et al., 2017).

The compaction of the urograndis bark and wood biomass in the form of briquettes was carried out in a laboratory machine with a pressure of 13.7 MPa, at 120 °C, for five minutes, followed by a cooling time of 10 min, under forced ventilation. The briquetting conditions were experimentally defined from preliminary tests of pressing and cooling time, choosing those in which the briquettes presented the best compaction. The pressure exerted was within the range used by several studies (Quirino et al., 2012). For each briquette, 40 g of milled biomass was used, to finally obtain a briquette of approximately 4 cm in length and 3 cm in diameter, producing 15 briquettes for each condition (C bark, C + M bark and C + M wood), with a total of 45 briquettes.

The apparent density of the briquettes was obtained through Eq. (1).

$$d_{ad} = \frac{Mi}{\pi * r^2 * h} \quad (1)$$

Where:

D_{ad} = apparent density ($kg\,m^{-3}$)
M_i = initial weight of the briquettes at 12% of moisture content (kg)
r = briquettes radius (m)
h = briquettes height (m)

The volumetric expansion of the briquettes was calculated by measuring the height and diameter, with the aid of the digital caliper, at two different times: (i) immediately after the briquetting and (ii) at 72 h after the briquetting; the necessary time for the dimensional stabilization of the briquettes. This period was chosen due to the records in the literature regarding stabilization of the volumetric expansion of the briquettes (Hansted et al., 2016).

The diametric compression tensile strength was calculated using a universal test machine: EMIC-DL30000, with a 500 kgf load cell at a constant speed of 0.3 mm min^{-1} (Quirino et al., 2012), where a load in the transverse direction was applied on the samples. The test was carried out from an adaptation of ABNT (Brazilian Association of Technical Standards), ABNT NBR 7222 that was proposed to determine the tensile strength by diametrical compression in cylindrical samples of concrete and mortar.

The durability of the briquettes was determined by mass loss, as described by Toscano et al. (2013) and Liu et al. (2014), using Eq. (3). The briquettes were weighed to obtain the initial mass and taken to a vibrating sieve for 10 min, at 80 rotations per minute. After this procedure, the briquettes were again weighed, and the final mass was obtained.

$$Dur = \left[\frac{m_{fd}}{m_{id}} x100\%\right] \quad (3)$$

Where:

Dur = durability (%)
m_{id} = briquettes initial mass (g)
m_{fd} = briquettes final mass (g)

The energy density was calculated by multiplying the high heating value of the biomass by the apparent density of each briquette, according to Eq. (4).

$$ED = HHV * AD \quad (4)$$

Where:

ED = energy density ($kJ\,m^{-3}$)
HHV = HHV ($kJ\,m^{-3}$)
AD = apparent density ($kg\,m^{-3}$)

The HHV of the samples were also calculated before and after the briquetting process, in order to verify if the briquetting process affects the heating generation.

2.4. FTIR

The spectroscopic characterization of the biomasses (bark and wood) was performed before and after briquetting. It was analyzed the absorbance signal in the Fourier transform infrared spectroscopy (FTIR)