BRIQUETTES PRODUCTION FROM LIGNOCELLULOSIC WASTE FOR ENERGY PURPOSES AS AN ALTERNATIVE FUEL

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ABSTRACT

The briquetting process was developed seeking to reuse the waste generated both in forestry production and in industrial processes. The compression of lignocellulosic waste concentrates the available energy in terms of volume and facilitates the handling and storage of these materials. The present work aims to verify the influence on the quality of briquettes of different compositions between the residues of coffee grounds, pine sawdust and cambará sawdust by evaluating the physical, chemical and mechanical characteristics of the briquettes generated from the compaction of these waste. For this, several tests were carried out with the briquettes, analyzing the properties of particle size, resistance to diametrical compression, moisture and ash for each composition of the briquette. The briquettes were produced on a 12-tonne hydraulic press. The waste used showed a high concentration of fine particles, with pine sawdust being 50.5% of particles with a diameter of 0.425mm. Coffee beans have moisture content above 50%, positively impacting the ash content and negatively impacting briquetting and tensile strength by diametral compression. In the production of briquettes, material with up to 60% addition of coffee grounds was obtained. The compression tests showed good results for the treatments, highlighting the treatments with a high concentration of pine. It is also concluded that the coffee grounds can be used in the production of briquettes with sawdust, however, it is suggested for future articles, the correction of moisture in the briquettes for better compaction.

Keywords: briquettes; coffee grounds; diametrical compression; lignocellulosic waste.

NOMENCLATURE

A	ash content
B	mass of the crucible with the lid, g
C	mass of sample before burning, g
L	mass of the crucible with the lid plus the ash residues, g

INTRODUCTION

The greatest challenges for the sustainable development of contemporary society are represented by the degree of waste generation and the growth in energy consumption by industries. Both challenges are associated with population growth and industrial development. Although population growth and industrial development collaborate with increased waste generation and increased energy consumption, respectively, they will also be applied to run a waste destination and obtain new energy sources in a more environmentally safe and economical way (Kongprasert et al., 2019).

Based on this information, in the last years, in a search for alternative and sustainable sources of grown energy and, within this context, the use of residual biomass is seen as an alternative for reducing the consumption of fossil fuels and for the mitigation of damage to the environment (Kongprasert et al., 2019).

The use of biomass can also be defended in terms of its reuse and carbon neutralization, which is equivalent to zero global carbon dioxide emissions to the atmosphere (Madiedo et al., 2019).

In Brazil, biomass for energy generation corresponds to 8.81% of power in the energy matrix. The paper and cellulose industries, in addition to using wood for paper production, use bleach and bark residues for energy production (CANAL, 2020). However, these residues are often not used energetically due to some inadequate characteristics of biomass, such as: low calorific value and specific mass, high moisture content and, consequently, high costs in the transport and storage of biomass (Felfi et al., 2011).

These characteristics can be changed, transforming biomass into a final product with high potential for the Brazilian energy matrix, one of the alternatives is through the compaction of these residues through briquetting. Because compaction is the most suitable process for the best energy use of waste. In addition to the consequent increase in energy concentration, the compaction of biomass contributes to the uniformity of the size and shape of the product, increase in specific gravity, reduction in the content of volatile materials, facilitating storage and transportation and adding value to the residual biomass (Lubwama and Yiga, 2017).

Figure 1. Same weight of biomass in bulk and compacted format, respectively.

The compaction of these residues occurs in hydraulic equipment or mechanical presses, generating a product, usually in cylindrical or disk form. This product is called briquette and becomes directly competitive with other fuels, such as firewood and charcoal, and can be used in an oven or boiler for direct burning. Establishments such as bakeries, pizzerias, industries, refrigerators and potteries receive this material for burning.

As a way to reduce the direct exploitation of natural resources as a fuel source, waste from agro-industrial activities is used in the production of briquettes, usually by wood residues such as sawdust. However, in addition to wood residues, other residues started to be studied for the production of briquettes, such as coffee grounds from commercial establishments (Sant'Anna, 2012).

Coffee grounds are a solid residue generated daily in considerable quantities through the extraction of soluble compounds from roasted coffee, which can be generated both in the production of soluble coffee and in consumption during the preparation of the drink.

Tokimoto (2005) points out that almost 6 million tons of coffee grounds are generated annually in the world. In the production of soluble coffee, approximately half a ton of sludge is obtained for each ton of coffee.

According to research by the Brazilian Coffee Industry Association (ABIC, 2019), coffee consumption in Brazil grew by 4.8% from 2017 to 2018. These figures represent the per capita consumption of 6.02 kg / year of raw coffee and 4.82 kg / year of roasted and ground coffee, keeping Brazil as the second largest consumer of coffee in the world. Therefore, the large consumption of coffee in Brazil leads to high generation of coffee grounds residues in the country.

Sawdust residues were widely available in Brazil and are also generated in large quantities, mainly in companies that process wood for the manufacture of furniture and other utilities. In this work, the use of pine and cambará sawdust in the composition of briquettes is related to the potential for briquetting of these residues.

The coffee sludge residue and pine and cambará sawdust residue used for the preparation of briquettes in this study is justified, among several reasons, by the easy availability in Brazil, the opportunity to reuse them for the production of renewable fuel, contemplating aspects linked to bioenergy and cleaner production and cost reduction through the replacement of fuels used in heating systems for industrial, residential and other establishments (Martinez et al., 2019).

To optimize the yield of the briquettes produced in the briquetting process, some parameters must be evaluated and controlled. The granulometry of the coffee to be used is the initial parameter to be adopted as a quality and control criterion. Other important factors are the temperature of the production of the briquettes and the drying of the material, as these directly influence the release of oil from the coffee grounds, an important factor for burning. To preserve the integrity of the briquette during transport, its elasticity module must be considered, since the higher the value, the greater the materials resistance (Rajaseenivasan et al., 2016).

Several factors affect compaction and influence the quality of the briquette. The factor that obtains great influence on the quality of the briquette produced is the granulometry of the raw materials used, as they directly impact on the mechanical resistance and durability of the briquettes. Thus, it is not recommended to use large particles, small particles such as sawdust, can be used directly in the briquetting process. In this way, biomass that has a larger particle size must be treated to obtain smaller particle sizes.

Density, humidity and the size of the waste are other factors that influence the production and quality of briquettes (Padilla et al., 2016). Another important factor for the quality of the briquette is the temperature. Heat transfer is related to the degree of compaction of the biomass particles and the diameter of the briquettes, in addition to other factors. In the briquetting process, the greater the compression, the more compact the biomass particles become. The diameter of the briquettes also influences the heat transfer. According to Li et al (2018), the larger the diameter of the briquettes, the lower the core temperature of the biofuel. That is, the heat transfer decreases as the diameter increases.

The volume of the raw material is directly related to the density of the briquettes. The smaller the volume, the greater the density. Low density briquettes need more energy in compaction, disadvantage the briquetting process. The size of the particles also influences the density of the briquettes, the smaller the particles, the better the compaction of the briquettes and, consequently, the better the density.

The biomass compaction process is carried out by applying pressure. This pressure inserted in the system generates an increase in temperature. High temperatures reduce the moisture of the biomass, causing a product with better heating power. The moisture content has a direct influence on the conversion efficiency and product quality (Kang et al., 2017). However, a briquette must keep the moisture content balanced, indicating the value of 12%, because a briquette with high humidity or below the indicated has low resistance, damaging it in its packaging and transport process.

The briquettes receive several impacts and falls in the stages of handling, transport and storage, compromising their integrity and efficiency. For this reason, the importance of obtaining briquettes with high mechanical resistance (Lourenço et al., 2017).

One way of assessing mechanical strength is through the compression tensile strength test, which indicates the maximum load that a specimen can withstand until it breaks. This test is used to estimate the compression stress between the weight of the upper briquettes in the lower briquettes during storage, transport and handling, the higher the value of the compressive strength, the better the integrity of the briquettes (Okot et al., 2019).

The ash content is the fraction that remains as an inorganic residue after the ignition of the combustion of a certain material. According to Chen et al (2017), the percentage of ash that remains varies from 0.5% to 5%, depending on the type of solid fuel and the amount of inorganic materials present in the sample. It is recommended that the briquette is composed of a material with an ash content of less than 4%.

MATERIALS

Two biomass materials were studied: coffee grounds (Coffea Arabica) and wood sawdust from Pinus sp and Cambará sp.

The coffee grounds residues were provided by a coffee shop in the engineering block of the Pontifical Catholic University of Paraná - Campus Curitiba were used, from automatic coffee machines that process coffee beans. The coffee grounds collected for the production of briquettes come from 100% Arabica coffee (Coffea Arabica).

The wood sawdust from Pinus sp and Cambará sp were donated by a company located in the city of Curitiba, Paraná, which collects wooden pallets for reuse by companies such as Volkswagen and Renault do Brasil.

Coffee grounds and sawdust go through the granulometric determination process separately. After that, the materials are packed separately to prepare the briquettes.

Two different briquetting treatments were performed: Pine sawdust and Cambará sawdust. For each treatment, nine different briquette compositions with coffee grounds were produced.

EXPERIMENTS

CLASSIFICATION OF BIOMASS AND BRIQUETTES PREPARATION

The granulometric classification of coffee grounds and sawdust is carried out through a sequence of sieves with different openings. These screens are coupled to an orbital screen shaker with intermittent strokes, as shown in Fig. (2).

The coffee grounds must be tested on 10-16-20-32 Mesh sieves, according to preliminary tests.

The sequence of sieves used to determine the granulometry of sawdust and straw was 10-16-20-28-35-60 Mesh, according to preliminary tests. An amount corresponding to 100 g is used for each material and agitation of 5 minutes.

Figure 2. Screening system.

For the briquetting process, a hydraulic press with compacting of 12 tons and molds with a diameter of 58 mm is used. The pressing time of the briquettes was 23 s.

Chrisostomo (2011) demonstrated the efficiency of the pressing process without the use of temperature and without the use of binders and, therefore, we worked with the same model. Three BRICKS were made for each set. After pressing, the diameter and height of each briquette were measured with the aid of a digital caliper. The mass of each briquette was measured using a digital scale.

Table 1. Types of treatment.

Treatment	% Coffee Grounds	% Sawdust
1	20%	80%
2	40%	60%
3	60%	40%
A	0%	Pine Sawdust
B	0%	Cambará Sawdust

The briquettes produced were packaged in a climatic chamber with temperature and humidity control. After producing the briquettes, they were measured on an analytical balance and the mass of each was recorded. With the aid of a caliper, the thickness and diameter of each briquette produced was measured, Fig. (3) shows the measured parameters.

Figure 3. Representation of the dimensions of the briquettes.

CHARACTERIZATION

Moisture, ash and superior calorific power were determined accordind to ASTM standard. The moisture content is determined according to the ASTM D 3173-87 (1991) standard, through a humidity equipment based on the calculation of the weight reduction of a given sample when subjected to heating under certain conditions (Kongprasert, 2019).

The ash content can be determined according to ASTM D 1102-84 (2007), by weighing the material remaining after burning the sample under strict conditions to control the sample weight, temperature, time and atmosphere.

The analysis occurs with the gradual heating of one gram of sample, in a porcelain crucible, in a muffle furnace. The heating starts at room temperature and the heating temperature gradually increases until reaching 500ºC during the first hour, after that, until it reaches 750ºC at the end of the second hour, maintaining that last temperature for another two hours.

During the heating process, an air flow rate of 2-4 changes in the relative volume of the oven per minute is maintained. In sequence, the sample is cooled and measured again.

The masses were used to calculate the ash rate using the Eq. (1).

$$A = [(L - B)/C] \times 100 \quad (1)$$

The tensile strength by diametrical compression of the briquettes was performed according to the guidelines of the ABNT NBR 7222/94 standard. The mechanical tests of the briquettes produced were performed on the EMIC machine model DL 500, using a load cell with a capacity of 500 kgf and a test speed of 100 mm / s, as shown in Fig. (4), in which the effort was carried out on the top of the briquette individually.

Figure 4. Diametrical compressive strength test equipment.

RESULTS AND DISCUSSION

The first stage of the process was the granulometric determination of coffee grounds and pine sawdust and cambará in sieves with intermittent strokes. Fig. (5) shows the particle size distribution of the biomasses used for the production of briquettes in this study.

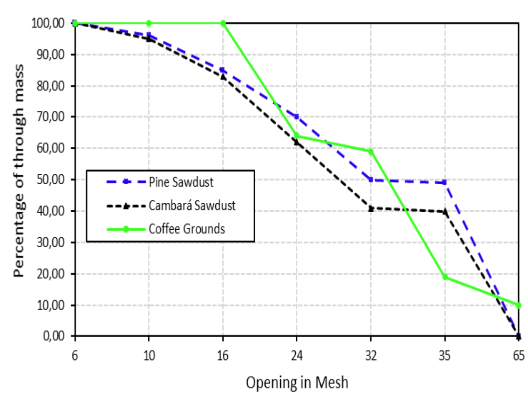

Figure 5. Particle size distribution.

The coffee grounds, despite undergoing a grinding process in the production of coffee powder, present different granulometries due to humidity and the extraction process that passed during its preparation. During the sieving stage of the coffee grounds, it was found that the largest portion (40.2%) was retained in the 35 Mesh sieve, indicating that the grain size of the coffee grounds refers to the 32 Mesh sieve, with an opening 0.50 mm. Approximately 10% of the particles passed through the 65 Mesh, diameter corresponding to 0.21 mm, and were retained at the bottom. The larger particles (36%) have a diameter between 0.71 mm and 1 mm, however, when kneading this portion, its granulometry decreases, the larger diameters of the coffee grounds can be used in the briquetting process.

Figure 6. Particle size distribution of coffee grounds.

Pine sawdust had the greatest presence of fine particles among the studied residues with a diameter of 0.425 mm (50.5%) and its lowest percentage of particles refer to diameters between 1.7 and 3.36 mm (3, 7%). The sawdust of Cambará presented the largest presence of large particles, corresponding to the diameter between 1.7 and 3.36 mm (5.1%). The particles retained in the 10 Mesh (1.7 mm) were excluded from the briquetting process of the other particle sizes, as they negatively influence the process.

Figure 7. Particle size distribution of pine and cambará sawdust, respectively.

Another important factor that must be considered in the preparation of lignocellulosic waste briquettes is the moisture content, the desirable being that the humidity is in the range between 8 to 15%, as the high moisture value compromises the burning efficiency of the briquette due to the relationship between calorific value and humidity, and the low moisture content compromises the stability of the briquette. Fig. (8) shows the average humidity of the triplicates of the waste used and the treatments produced.

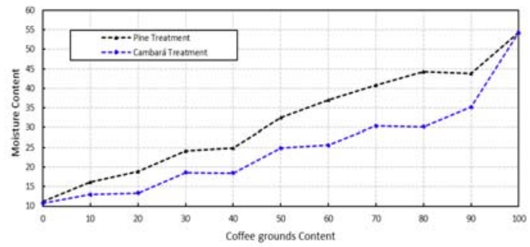

Figure 8. Moisture Content in treatments.

The average moisture of the coffee grounds is 54.31%, higher than all other analyzes, while the sawdust from Pinus and Cambará have a lower moisture content, 11.2 and 10.71%, respectively. For this reason, it can be seen that as the proportion of sawdust decreases in the treatment with coffee grounds, the moisture content also decreases.

The production of briquettes from lignocellulosic residues: Coffee grounds, Sawdust from Pinus and Cambará, resulted in uniform briquettes, with no breaks and with smooth and shiny surfaces for briquettes with sawdust composition: 100%; 80% and 60%, as shown in Fig. (9). The briquetting process in the hydraulic press of the treatments, both of pine and Cambará, generated material losses for treatment 3, where the briquettes suffered ruptures.

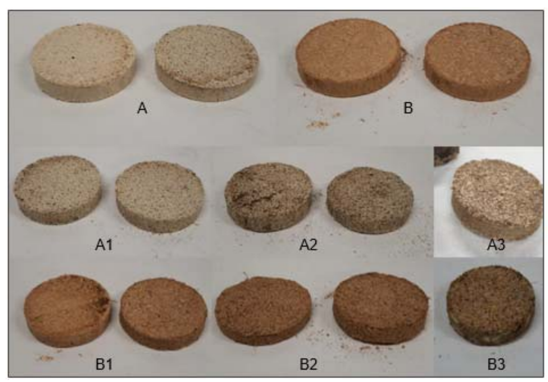

Figure 9. Diametrical compressive strenght test equipment.

It can be observed that as the sawdust concentration decreases, the briquette produced becomes less compact, this can be related to the relative humidity of the briquette that increases proportionally.

According to Navalta et. Al (2020), the ash content indicated for burning briquettes in boilers and ovens must be less than 20% w / w, to maintain the efficiency of the firing equipment. The high ash content can cause incrustations in the boiler components and negatively influences the heating of biomass as it is an incombustible material.

Figure 10. Ash Content of samples.

The ash content in the briquettes produced ranged from 1,3% to 3,3%, as indicated in Fig. (11).

The briquettes that presented the highest ash content correspond to the briquettes with a greater representation of coffee grounds in their formulation. This is because sawdust has a high silica content and which constitutes most of the ash.

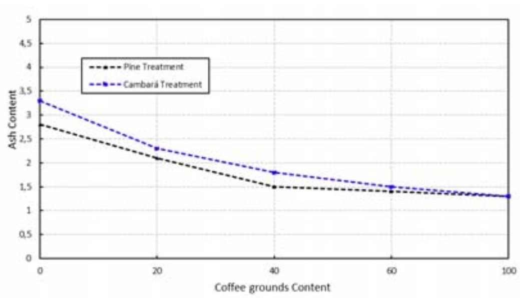

Figure 11. Ash Content of treatments.

The tensile strength test by diametrical compression was used to determine the mechanical resistance to traction efforts of cylindrical specimens (briquettes), in order to determine the mechanical behavior of each briquette composition subjected to a given load. The tensile strength value is obtained after the specimen breaks, according to the NBR 7222/94 standard. The equipment includes thickness and diameter information to calculate the maximum applied force. The tensile strengths by diametrical compression in each briquette can be seen in Table 2.

The treatments with pine are the ones with the greatest resistance to compression, it is observed that the greater the proportion of cellulosic residue (pine sawdust) in the briquette composition, the greater its mechanical resistance. The area in which the briquette compression was applied corresponds to 12 cm², transforming the maximum applied force into the maximum applied pressure, obtaining the tensile strength range from 0.392 MPa to 0.086 MPa. The treatment 100% of pine and cambará sawdust showed resistance to traction by diametrical compression of 0,468 and 0,408 MPa, respectively. These the values are consistent with the tests.

Table 2. Results of the test of resistance to diametrical compression of briquettes.

Treatment	Maximum Force (N)
A1	470,3
A2	322,1
A3	219,7
B1	392,6
B2	283,2
B3	103,4
A	561,4
B	484,0

CONCLUSIONS

In this work, among the residues used for the production of briquettes, it was observed that the sawdust of pine obtained the greatest presence of fine particles of 0.425 mm (50.5%) and the sawdust of cambará the greatest presence of large particles, with a diameter above 1.7 mm (5.1%). The coffee grounds presented 40.2% of particles with 0.50 mm granulometry.

In the moisture analysis, it can be concluded that the coffee grounds have a high moisture content directly impacting the sawdust treatments. The treatments with the highest concentration of coffee grounds have the best values for ash content.

According to the results of molding and tensile strength by diametrical compression, it can be concluded that the briquettes produced with coffee grounds and sawdust proved to be viable for the generation of energy and the use of this material, which are residues from commerce. and the pulp and paper industry, among others. It was observed that it was not necessary to add binder to obtain briquettes of greater density and mechanical resistance, indicating the stability and durability of the briquettes produced, facilitating their handling and transportation. However, the briquettes from the pine treatment showed the best results. It is also concluded that the higher the concentration of sawdust in the treatment, the better the tensile strength by diametrical compression. This result may be related to the high humidity of the coffee grounds, which negatively impacts the briquetting.

Thus, it was concluded that the treatments carried out with lower proportions of coffee grounds in pine sawdust (20 to 40%), resulted in briquettes with better quality of mechanical resistance. It is also concluded that the coffee grounds can be used in the production of briquettes with sawdust, however, it is suggested for future articles, the correction of moisture in the briquettes for better compaction and perform the analysis of the calorific power of these treatments.

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