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Comparative analyses of fast growing species in different moisture content for high quality solid fuel production

Ana Larissa Santiago Hansted [a], Gabriela Tami Nakashima [a], Mariana Provedel Martins [a], Hiroyuki Yamamoto [b], Fábio Minoru Yamaji [a,*]

[a] Federal University of São Carlos, Biomass and Bioenergy Laboratory, Department of Environmental Sciences, Sorocaba 18052-780, Brazil
[b] Nagoya University, Biomaterial Physics Laboratory, Department of Biomaterials Sciences, Nagoya 464-8601, Japan

HIGHLIGHTS

- We examined biomass from two different fast growing species.
- A physical-chemical analysis was performed.
- The results showed that the moisture content can be used up to 15% for briquette production.

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ABSTRACT

Biomass is nowadays a very important alternative to energy consumption, since it provides less environmental harms. Briquettes come as an option since they include logistical and efficiency advantages. This study aimed to characterize *Leucaena leucocephala* (leucena) and *Gonoacantha piptadenia* (pau-jacaré) biomass, to define their energy potential and verify the briquettes' moisture content and the mechanical resistance. Six treatments were provided: 2 species and three different moisture contents (10%, 12% and 15%). Fifteen briquettes were produced for each treatment. The results showed that moisture content changes the stability of the briquettes. The pau-jacaré showed a better performance, in every aspect analyzed, superior chemical characteristics (ash content of 1.83%), higher heating value (18,956 kJ kg^{-1}) and better mechanical resistance (0.5255 MPa). However, both species provided fine results toward this proposal. Therefore, they can be used in every moisture content tested here, offering satisfactory results for bioenergy.

1. Introduction

The use of biomass residues for sustainable heat and power production is an important part of future energy concepts [1]. Among alternative energy resources, biomass becomes an important renewable resource due to its appealing properties, such as low production cost, low acidic gas emissions and its independence on weather and seasonal change, since biomass can be stored and utilized when needed, thereby providing a continuous energy source [2,3]. In order to make the biomass materials available for energy purposes, some unfavorable handling properties must be solved. Usually, biomass has high moisture content, irregular shapes and sizes and low bulk density [4]. As a result, biomass is very difficult to handle, transport, store and utilize in its original form; thus, it is clear that there is a present-day need to study logistical, social, ecological and economic challenges [5]. One solution to these problems is the densification of biomass materials into solid fuels such as pellets and briquettes [6].

Mechanical densification of biomass into solid fuels has shown several advantages, such as higher density, more homogeneity, lower transport costs and higher energy conversion efficiency, while reduced moisture content increases the long-term storage capability [7,8].

The raw materials used for solid biofuel production today are mainly wood residues, such as wood shavings, sawdust and wood chips. However, at the same time agro-residues, grasses, energy crops and waste products from the food industry are becoming increasingly important [9]. According to IBA [10], Brazil has 76,000 km^2 hectares of planted trees. Eucalyptus plantations represent 72% (55,000 km^2) of this total, and pine trees 20.7% (16,000 km^2). Brazil has also a lot of other fast growing species that

* Corresponding author.
E-mail address: fmyamaji@ufscar.br (F.M. Yamaji).

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can be used as biomass for energy. The *Leucaena leucocephala* (leucena) and *Gonoacantha piptadenia* (pau-jacaré) are from the Leguminosae family and characterized as a fast growing species. Leucena is a native species of Central America and it has a wide variety of uses (firewood, timber, green manure, shade and erosion control). It was spread to most countries of the tropical world [11,12]. Pau-jacaré is a native species from Brazil, and counts with a variety of uses (construction, furniture and fences). This species is also known for its potential in bioenergy, and the burning is lasting [13]. There is no commercial plantation of these species, and both are found in natural fragments.

The physical quality of solid biofuels may vary depending on the raw material properties and the manufacturing process. These variables such as density, particle size, compression strength, temperature and moisture absorption can be controlled to optimize production efficiency and improve the quality of the finished product [14]. So far, various authors analyzed the effect of process parameters and biomass properties on the mechanical quality of solid biofuels produced with herbaceous crop residues or wood residues [1,15].

The moisture content of the raw material is an important parameter for the biomass compression process [15]. Water acts as both a binding agent and a lubricant in lignocellulosic materials. As a binding agent, water helps in the development of van der Waals' forces and hydrogen bonds by increasing the contact area between particles, which is essential to raise their cohesion strength [6,9,16].

Several studies showed that strength and durability of solid biofuels expanded with increasing moisture content until an optimum level was reached [2]. In general, the optimum moisture content for wood species was found to be between 5 and 15 wt%, while it was slightly higher for agricultural grasses (10–20%) [13]. Optimum moisture content varies for different raw material types, and it is relevant to determinate its value since excessive moisture increases the gap between particles and may cause a reduction in durability [6]. If moisture content exceeds 20%, bacterial growth might occur and cause material degradation and self-heating, which in the worst case can result in self-ignition [13]. On the other hand, too low moisture content reduces the particle plasticity and increases the friction during the compaction process [16].

In this context, the aim of the present work was to evaluate the biomass properties and the effect of moisture content on the briquetting process of *L. leucocephala* and *G. piptadenia.*

2. Materials and methods

The materials used were *L. leucocephala* and *G. piptadenia.* The trees were selected and collected in natural fragments. They were obtained in the cities of Sorocaba/SP (23°30′05″S; 47°29′50″W) and Itapetininga/SP (23°35′40″S; 48°3′14″W) – Brazil, respectively. These two cities are inserted in an area, which is formed by a transition vegetation of Atlantic Forest and "Cerrado". According to the Köppen classification, the climate is Cfa. [17].

The trees were collected with the characteristics: medium heights of three meters and diameter at breast height (DBH) of 15–25 cm.

The materials (wood and bark for both species) were fragmented into small pieces and it was milled in a crushing machine. The moisture content of each material was calculated using a moisture determiner balance. The two materials (leucena and pau-jacaré) were submitted to three different moisture contents: 10%, 12% and 15%, so the treatments were as follows: T1 (leucena 10%), T2 (leucena 12%), T3 (leucena 15%), T4 (pau-jacaré 10%), T5 (pau-jacaré 12%) and T6 (pau-jacaré 15%).

2.1. Bulk density

The bulk density of the materials was calculated for the two species with moisture content of 12%, according to standard NBR 6922 [18], by means of three replicates and using Eq. (1):

$$\gamma = \mathrm{m} \cdot \mathrm{v}^{-1} \tag{1}$$

The variables shown in the formula represent the following: 'γ': density in kg m^{-3}; 'm': the mass available in kg; e 'v': the volume given in m^3.

2.2. Particle size analysis

The *L. leucocephala* (leucena) and *G. piptadenia* (pau-jacaré) sawdust were placed in a stack of sieves arranged from the largest to the smallest opening. The sieves were selected based on the range of particles in the sample (sieve sizes: 10, 20, 30, 60, 100 mesh). The set of sieves was placed on the Ro-Tap sieve shaker. The duration of sieving was 3 min and after sieving, the mass retained on each sieve was weighed. Sieve analysis was held according to the Brazilian Association of Technical Norms (ABNT) Standard NBR NM 248 [19].

2.3. Biomasses characterization

Proximate analyses (moisture content, volatile matter, ash content and fixed carbon) of biomass were held according to the Brazilian ABNT Standard NBR 8112 [20]. High heating values (HHV) for the materials were measured in a calorimeter according to the standard ASTM D2015-96 [21].

2.4. Briquette preparation

Briquettes were prepared using leucena and pau-jacaré sawdust adjusted at three moisture contents (10%, 12% and 15%). Briquette compaction was held with 20 g of each material using a steel cylindrical mold with an internal diameter of 35 mm and a hydraulic press. The compression force used was 122.58 MPa for 30 s. No heat and no binder was applied to the process. The procedure was the same as used by Silva [22]. For each treatment, 15 briquettes were prepared, resulting in a total of 90 briquettes.

2.5. Briquette expansion

To evaluate the briquette expansion, the measure was taken in a longitudinal axis. The measurements were made in steps: just after the briquette compaction, 1 h, 2 h, 4 h, 6 h, 12 h, 24 h and seven days after briquetting (during the mechanical assay). It is known that the briquettes have the biggest expansion within the first 24 h after being produced, so the measurements are commonly performed in this period [22].

2.6. Mechanical resistance and durability

Mechanical resistance is the maximum pressing load that a briquette can withstand before cracking or breaking. The briquette mechanical resistances were determined by a diametrical compression assay. A universal testing machine was used, fitted with 5 kN of load cell. The tests were done with ten briquettes for each treatment, seven days after the compaction. The speed test was 3 mm min^{-1}.

Mechanical durability assays were held according to the Brazilian ABNT Standard NBR 8740 [23]. This tumbler test simulates the mechanical handling of briquettes and predicts the possible fines produced due to mechanical handling. During