USE OF SUGARCANE BAGASSE AND CANDEIA WASTE FOR SOLID BIOFUELS PRODUCTION

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Abstract

The use of agroforestry residues as an energy source acts as an alternative to conventional fossil fuels like petroleum and coal. The aim of this study was to evaluate the energy recovery of candeia sawdust and sugarcane bagasse wastes in the preparation of blends for the production of briquettes. Residues characterization took place by their size classification, proximate analysis and calorific value. Six treatments were applied: T_1 (100% cane bagasse), T_2 (90% cane bagasse + 10% candeia), T_3 (75% cane bagasse + 25% candeia), T_4 (50% cane bagasse + 50% candeia), T_5 (25% cane bagasse + 75% candeia) and T_6 (100% candeia sawdust). Briquettes were assessed by their density, dimensional stability and mechanical strength. It was observed that the higher the proportion of candeia sawdust in the treatment, the lower the volumetric expansion of the briquettes and the larger their mechanical strength. Results indicated that the mixture of sugarcane bagasse and candeia sawdust wastes in the blends was an efficient alternative to overcome the problems related to the high hygroscopicity and low durability of briquettes made using only sugarcane bagasse, thus allowing production of stable and resistant briquettes in all the studied treatments.
Keywords: Biofuel; biomass; wastes; briquettes.

Resumo

Aproveitamento de resíduos de bagaço de cana-de-açúcar e candeia para a produção de biocombustíveis sólidos. A utilização de resíduos agroflorestais como fonte de energia funciona como uma alternativa aos combustíveis fósseis convencionais como o petróleo e o carvão mineral. O objetivo deste trabalho foi avaliar o aproveitamento energético dos resíduos de serragem de candeia e bagaço de cana-de-açúcar na confecção de blendas para produção de briquetes. Os resíduos foram caracterizados a partir de sua classificação granulométrica, análise imediata e poder calorífico. Foram realizados seis tratamentos: T_1 (100% bagaço de cana), T_2 (90% bagaço de cana + 10% candeia), T_3 (75% bagaço de cana + 25% candeia), T_4 (50% bagaço de cana + 50% candeia), T_5 (25% bagaço de cana + 75% candeia) e T_6 (100% serragem de candeia). Os briquetes foram avaliados quanto a sua densidade, estabilidade dimensional e resistência mecânica. Observou-se que quanto maior a proporção de serragem de candeia nos tratamentos, menor foi a expansão volumétrica dos briquetes e maior foi a sua resistência mecânica. Os resultados indicaram que o uso das blendas foi uma alternativa eficiente para contornar os problemas relacionados à alta higroscopicidade e à baixa durabilidade dos briquetes confeccionados apenas com o bagaço de cana-de-açúcar, permitindo assim a obtenção de briquetes estáveis e resistentes para todos os tratamentos testados.
Palavras-chave: Biocombustível; biomassa; resíduos; briquetes.

INTRODUCTION

Since the industrial revolution and appearance of steam machines, global standards of production and consuming have been based on use of fossil fuels, like mineral coal and petrol, which are constantly associated to high concentrations of pollutants in the atmosphere and environmental impacts like greenhouse effect and climate changes. Besides the environmental aspect, debates on dependence and availability of fossil energy raise questions on necessity of diversification of the world energy matrix to ensure energy provision in the long term (GOLDEMBERG; LUCON 2007).

In this context, Brazil is in a quite favorable condition in terms of renewable energy sources use, mainly concerning use of vegetal biomasses to produce energy. However, the observable scenario of nowadays is that increase of forest raw matter demand is not accompanied by offer and availability of this material (COUTO *et al.*, 2004). Furthermore, industries based on forestry and agriculture produce great quantities of residues, whose disposal is frequently treated as an environmental problem, because of pollution caused by improper disposal or even direct burning of this waste (BRAND *et al*., 2002).

Briquetting, which consist in the reconstruction process of particulate material, raised as an alternative for the energetic reutilization of residues. Disadvantages associated to direct burning of biomass in its raw condition like its low density, variable grading and humidity content may be bypassed by compacting it in briquettes, which allows more uniform burning and better handling conditions, besides greater energy concentration per biofuel mass unit (FLORES *et al.*, 2009; FURTADO *et al.*, 2010).

One of the disadvantages of briquetting process is the great heterogeneity of residues in terms of moisture content. Sugarcane bagasse, which is the residual obtained in greatest quantity in Brazil (180 millions of tons per year), is normally extremely humid, with contents above 50% (UNICA 2013; COSTA; BOCCHI 2012). This condition may cause explosions due to vapor formation inside biomass (QUIRINO *et al.*, 2012) and produce unstable briquettes due to the high hygroscopicity of this material (YAMAJI *et al.*, 2013).

One way to reduce heterogeneity problems of different materials in the briquetting process is using blends, in other words composite briquettes, produced from more than one type of residue. This way, it is possible to obtain weighted means of their properties and compositions, allowing better quality control on briquettes and their adaptation to final use, being also an alternative to avoid economic dependence on only one type of raw matter (RODRIGUES *et al.*, 2002; GIL *et al.*, 2010).

Considering valorization of native species, candeia (*Eremanthus erythropappus*) would have potential for production of briquettes and blends. The species is widely used in pharmaceutic and cosmetic industries by extraction of its oil, appreciated for medicinal properties. This extraction process forms a wooden residue with potential use in alternative energy production (SANTOS *et al*., 2008).

This work had the objective to characterize and produce briquettes made of sugarcane bagasse and candeia sawdust in different proportions, to assess energetic potential of these residues in compacted form, looking for better quality solid biofuels.

MATERIAL AND METHODS

Candeia residue used in this work was collected in Pouso Alegre, in the state of Minas Gerais, at the company ATINA – Ativos Naturais. This residue was collected after the oil extraction . Sugarcane bagasse was collected from a plant in the municipality of Porto Feliz – SP. Both residues collected were stored in plastic bags and sealed, to save their physical conditions until the moment of the analyses.

Six treatments were prepared, with different material proportions: T_1 (100% sugarcane bagasse); T_2 (90% sugarcane bagasse and 10% candeia sawdust); T_3 (75% sugarcane bagasse and 25% candeia sawdust); T_4 (50% sugarcane bagasse and 50% candeia sawdust); T_5 (25% sugarcane bagasse and 75% candeia sawdust); T_6 (100% candeia sawdust). Moisture content of the six treatments was adjusted at 12%. Candeia sawdust was used as substitute of binder, with a particle size of 60 mesh.

Chemical-physical characterization of biomasses

Candeia sawdust and sugarcane bagasse were milled using a vertical rotor mill with mobile and static blades, model Willey MA-340. Lately, residues went through a separation process in an orbital shaker with sieves and intermittent shaking action, type Marconi – MA 750, to determinate the particle size distribution of biomass. To determine moisture content of materials, a determiner balance of moisture MX-50 was used. Density and particle size of residues were determined according to the norm ABNT NBR 6922/81.

The proximate analysis (ashes content, volatiles matter and fixed carbon) was conducted according to the norm ABNT NBR 8112/86 and the high calorific value of residues was obtained according to the norm ABNT NBR 8633/84, in the Calorimetric Analyses Laboratory of the Universdade Estadual Paulista – UNESP *campus* Itapeva, in a calorimeter C5000 IKA® WERKE.

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Briquetting procedure of residues

A hydraulic press Marconi-MA 098 with 15 tons power and a cylindrical stainless steel mold with 3.5 cm diameter and 16 cm height were used for the briquetting process. Twenty g of each mixture were put inside the mold to produce briquettes, which were compacted with a pressure of 61.48 $kgf.cm^{-2}$ for 30 seconds. Fifteen briquettes were produced per each treatment. No binders or temperatures were used in the pressing process.

Dimensional stability and mechanical test of briquettes

Right after pressing, briquettes were weighted and measured, checking height and diameter with a digital caliper, to evaluate their volume expansion and apparent density variation. Lately, briquettes were stored in plastic bags for 15 days, necessary period to stabilize volume variation, with new measurements done during this period to evaluate diameter and height variations of briquettes. Mechanical strength of briquettes was determined by traction test, with diametric compression, adapted from the norm ABNT NBR 7222/11, using a universal test machine type EMIC with maximum capacity of 300 kN, with a 500 N load cell, at a speed of 3mm/min.. The load was applied in the transverse direction to the test sample, perpendicularly to the compacting force.

Statistical analyses

Results were analyzed according to an entirely randomized experimental design. Results obtained went through analysis of variance and comparison between treatments was verified by the test F, at 5% of significance. For the properties where null hypothesis was rejected, means were compared by the test of Tukey at 5% of significance too. Statistical analyses were conducted using the software R version 2.11.1.

RESULTS AND DISCUSSION

Physical-chemical characterization of biomass

Particle size analysis of biomass showed how sugarcane bagasse and candeia sawdust particles are distributed between 20 and 200 mesh sizes (Figure 1).

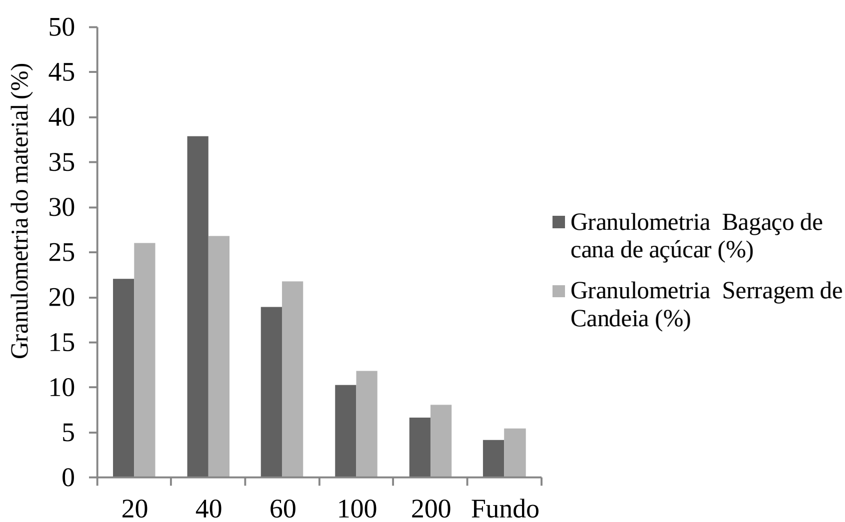

Figure 1. Particle size distributions of sugarcane bagasse and candeia sawdust biomass.
Figura 1. Distribuição granulométrica das biomassas de bagaço de cana-de-açúcar e serragem de candeia.

It was possible to observe that biomass presented greatest retention of residues in the mesh 40 size sieve (38% for sugarcane bagasse and 27% for candeia sawdust), which corresponds to particles with diameters of 0.42mm and higher. It was observed a small difference in particle size distribution of residues, with the bigger particles made of sugarcane bagasse, which had greatest concentration in 20, 40 and 60 mesh sieves (81.26%), while proportion of candeia in the same sieves was 68.46%. This particle size difference of residues may be associated to different natural and structural characteristics of the biomass used and somehow favors compacting of blends, since mixture of differently sized particles provides greatest adherence between residues due to reduction of empty inter-particle spaces in compacted biomass (PROTÁSIO *et al.*, 2011; KALIYAN; MOREY, 2009).

Particle size classification of materials is of great importance, since particle size influences both grain density of biomass and durability and strength of briquettes (KALIYAN; MOREY, 2009). Thus, it was observed that candeia sawdust, the material with smaller particle size, showed grain density of 0.475 $g.cm^{-3}$, which corresponds to approximately three times the grain density obtained in sugarcane bagasse grains, equal to 0.178 $g.cm^{-3}$. A big grain density is essential for economic viability of a fuel, since it favors its energetic density and reduces costs related to its transport and storage.

Sugarcane bagasse showed moisture content 13.81%, while moisture content of candeia sawdust was 9.40%. Moisture content of biomass is one of the most important parameters in the briquetting process (ARSHADI *et al.*, 2008). Compacting of lignocellulosic residues, for example, water acts both as a binder, favoring molecular interactions increasing contact area between particles, and also as lubricant agent, which allied to lignin has a fundamental role to allow biomass cohesion in form of briquette (RYU *et al.*, 2008; STELTE *et al.*, 2011).

Moisture content of material contributes to its application as biofuel, because this parameter had direct influence on high calorific value of biomass, due to heat loss associated to evaporation of water contained.

High calorific value determined for sugarcane bagasse and candeia sawdust residues were respectively 17.570 J/g e 19.538 J/g.

Both candeia sawdust and sugarcane bagasse are residues formed by and heterogeneous and complex mixture of organic and inorganic constituents, which makes the proximate chemical analysis of these biomass mandatory for their characterization, because their chemical composition has direct influence on combustion process (SANTOS et al., 2011). Chemical analysis of treatments T_1-T_6 is described on table 1.

According to Brito and Barrichello (1982), volatile contents vary between 75 to 85% and fixed carbon content between 14 to 25%, in lignocellulosic materials. In the six tested treatments, volatile matter and fixed carbon contents were similar to what indicated by the authors, with the exception of T_1 and T_2, which presented fixed carbon content respectively of 12.87% and 13.60%, due to the greater ash content of these two treatments.

Table 1. Proximate analysis of the treatments.
Tabela 1. Análise imediata dos tratamentos confeccionados.

Material	Volatiles content (%)	Ashes content (%)	Fixed carbon (%)
T_1	84.70	2.43	12.87
T_2	84.26	2.14	13.60
T_3	82.89	2.01	15.10
T_4	79.99	2.05	17.96
T_5	76.81	1.52	21.67
T_6	76.02	1.48	22.50

Ashes content of candeia sawdust (T_6 = 1.48%) was high compared to values registered in literature, like what observed by Mori (2010), which was 0.39%. The higher ashes content found in the material after the oil extraction process could be cause by presence of inorganic residues resulting from storage and handling of residues. Ashes content determined in sugarcane bagasse (T_1 = 2.43) meets values reported by Santos *et al.* (2011) and Costa and Bocchi (2012).

Dimensional stability and mechanical test of briquettes

To monitor volumetric expansion of briquettes, their height and diameter were measured four times, for all treatments. Volumetric expansion of test samples during a 15 days period is showed in figure 2.

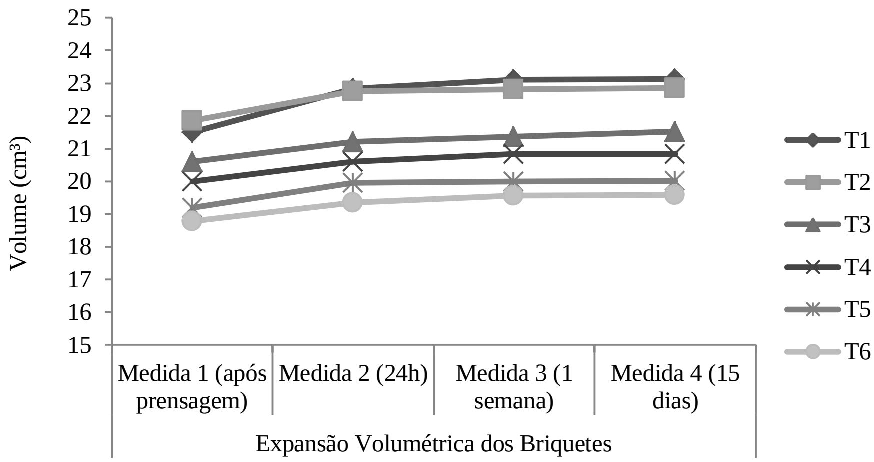

Figure 2. Volumetric expansion evolution in the different treatments.
Figura 2. Evolução da expansão volumétrica nos diferentes tratamentos.

It was observed that, on average, 74% of the volumetric expansion of all treatments occurred in the first 24 h after briquetting and that, after one week, volume of briquettes stabilized. It was also observed that the bigger was candeia sawdust proportion in briquettes, the smaller was the observed volumetric expansion. Volumetric expansion of briquettes as time passes may be caused by various factors like nature of raw-matters, densification magnitude and compression technique, geometry of compacted material and storage conditions (NDIEMA *et al*., 2002). One effect of volumetric expansion is diminution of the initial bulk density, due to volume increase, as shown in figure 3.

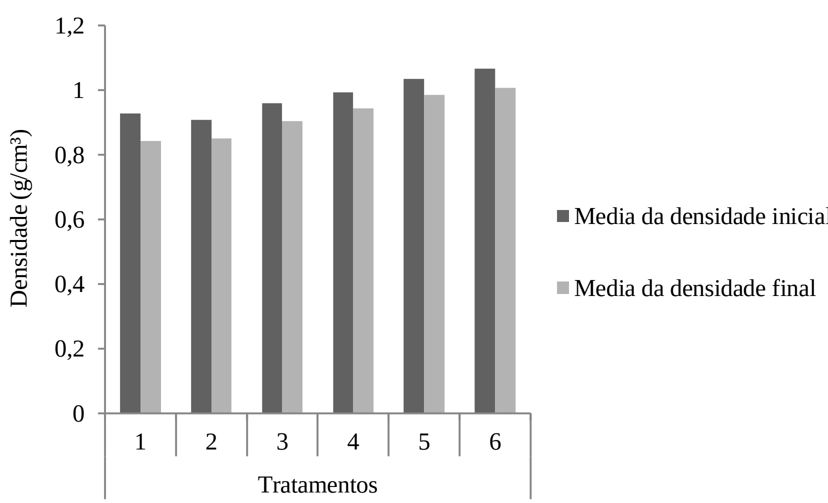

Figure 3. Initial density (after pressing) and final density (after 15 days) for each treatment.
Figura 3. Densidade aparente inicial (após prensagem) e densidade aparente final (após 15 dias) para cada tratamento.

It was possible to observe that initial mean bulk density obtained in the six treatments was 0.99 g.cm^{-3}, corresponding to approximately 2 times the grain density of candeia sawdust and 5 times the sugarcane bagasse, which highlighted efficiency of briquetting in production of denser solid biofuels. After 15 days, final mean bulk density of the six treatments diminished, reaching the value of 0.93 g.cm^{-3}. Mean values of volumetric expansions and variations between initial (soon after compacting) and final (after 15 days) bulk densities of briquettes from each treatment are shown in table 2.

Table 2. Volumetric expansion (cm^3) and density variation ($g.cm^{-3}$) for each treatment.
Tabela 2. Expansão volumétrica (cm^3) e variação da densidade aparente ($g.cm^{-3}$) para cada tratamento.

Material	Volumetric expansion mean (cm^3)	Density variation ($g.cm^{-3}$)
T_1	1.648 a	0.083 a
T_2	0.994 b	0.062 b
T_3	0.925 b	0.055 b
T_4	0.842 b	0.050 b
T_5	0.829 b	0.050 b
T_6	0.802 b	0.015 c

Means followed by the same letter in the column are not statistically different by the test of Tukey at 5% level of probability.

Statistical analyses referring to mean expansion and density variation of briquettes showed that there was significant difference between the treatments. It was observed that treatments T_2 - T_5, corresponding to blends composed by sugarcane bagasse residues and candeia sawdust in different proportions, were not statistically different in terms of volumetric expansion and bulk density, indicating that candeia sawdust, in variable proportions from 10 to 75%, helped to minimize the bigger volumetric expansion observed in briquettes made only of sugarcane bagasse (T_1). T_1 treatment showed the greatest density loss and T_6 (100% candeia sawdust) showed the smallest density loss, and these two treatments were statistically different between them and when compared to the other treatments.

Volumetric variation is a property deserving great attention, after the compacting process, since it is inversely proportional to mechanical strength of briquettes, influencing their durability. After 15 days of storage, briquettes were submitted to tensile test by diametrical compression, with the intention to define which was the maximum load that each briquette could withstand before cracking or totally breaking. Table 3 shows the results obtained during these mechanical strength tests.

Table 3. Values of force and tension calculated by tensile test by diametrical compression.
Tabela 3. Valores de força e tensão calculados pelo ensaio de tração por compressão diametral.

Material	Force (kgf)			Tension (MPa)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
T_1	27.13	31.70	35.31	0.20	0.23	0.26 a
T_2	27.40	34.27	38.36	0.21	0.25	0.28 a
T_3	42.60	47.49	52.72	0.31	0.35	0.39 b
T_4	50.16	54.31	57.86	0.37	0.41	0.43 c
T_5	72.36	74.83	77.42	0.53	0.55	0.57 d
T_6	101.10	104.70	109.96	0.91	0.94	1.00 e

Means followed by the same letter in the column are not statistically different by the test of Tukey at 5% level of probability.

The statistical analysis for the maximum tensile stress withstood by briquettes revealed that T_1 (100% sugarcane bagasse) and T_2 (90% sugarcane bagasse and 10% candeia sawdust) treatments were not significantly different between them, but they differed from the others, which differed between them too. Thus, it was observed that the bigger is candeia sawdust proportion in briquettes, the bigger is mechanical strength measured, such that briquettes from T_6 treatment (100% candeia sawdust) were the strongest. In case of blends (T_2 – T_5), although they did not present significant differences in terms of volumetric expansion, it was observed that their mechanical strengths were directly influenced by candeia sawdust content in their composition.

CONCLUSIONS

- This work allowed to evaluate the energetic use of residues like candeia sawdust and sugarcane bagasse to produce briquettes. The use of biomass blends showed to be efficient to solve problems like fragility and high volumetric variation typical of sugarcane bagasse briquettes, since candeia sawdust presence improved quality of briquettes, increasing their mechanical strength and reducing their expansion, working as an alternative to binders.
- It was concluded that briquetting process of selected residues allowed, in general, production of high quality solid biofuels, with low ash content, small volumetric variation and good mechanical strength, which confirms viability of briquetting for the reutilization of these agroforestry residues.

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