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Production and Characterization of Fuel Briquettes from Banana Leaves Waste

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The use of agricultural and agro-industrial waste as biomass fuel for power generation like briquettes can be an alternative solution to the problems related at their disposal. Briquettes produced from lignocellulosic waste, through a simple process and low cost are an excellent source of cheap energy and environmentally correct, in many cases, ideal for replacing fossil fuels in use today, with significant economic and environmental advantages. The banana cultivation generates a significant amount of waste, but little used, it would be important to add value to them. In this work banana semi-dried leaves were crushed to particles with sizes between 2 and 5 mm and its moisture content was determined. The briquettes were produced in a hydraulic press with compaction pressure of 18 MPa and two different compression times and were evaluated by proximate and ultimate chemical analysis, high heating value (HHV), thermogravimetric analysis (TGA), differential thermal analysis (DTA), linear shrinkage, mechanical compressive strength, bulk and energy density. Briquettes presented moisture content of 7.2 %, high contents of carbon (44.3 %) and volatile matter (75.3 %), low sulphur and nitrogen contents and HHV of 17.7 MJ/kg. These results are similar for other biomass used to produce briquettes. Under combustion in TGA and DTA analysis, the briquettes showed high loss mass and maximum energy release between 200 and 500 °C. The mechanical compressive strength for 1 second compression was 5.3 MPa and the briquettes density was 0.99 g/cm^3. The thermal properties and physicochemical characteristics of the banana leaves briquettes demonstrate its potential for use as biomass fuel.

1. Introduction

The banana production occurs in many countries, and Brazil is the third largest producer and the world's largest consumer. It is estimated that the acreage in the country reaches about 491,000 acres (IBGE, 2012). The banana cultivation generates a significant amount of waste. The most significant residues are leaves, stalks and pseudostem because they are generated in greater amounts and occupy large volumes. In the city of Joinville (southern Brazil), where banana production is 19,800 tons per year (IBGE, 2012), the amount of waste leaves represent 29,700 tons of waste that is not recovered.
The use of agricultural and agro-industrial wastes as biomass is being increasingly studied and could be an alternative solution to the problems related to them (Fernandes et al., 2013). However, is very difficult to handle, transport, store, and utilize biomass in its original form due some factors including high moisture content, irregular shape and sizes, and low bulk density (Karunanithy et al., 2012).
Densification process can produce briquettes with uniform shape and sizes that can be more easily handled using existing handling and storage equipment and thereby reduce cost associated with transportation, handling, and storage (Karunanithy et al., 2012). For successful densification is required that the waste presents moisture content between 5 and 10% and particle size can be varied from 1 to 10 mm (Wilaipon, 2009).

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The production of briquettes from agro-industrial waste has been studied on a large scale in the USA, Europe and Southeast Asian countries. Banana peel was studied by Wilaipon et al. (2006) and Wilaipon, (2009). In these studies the briquettes were produced by applying compaction pressures from 3 to 11 MPa. The briquettes subjected to a pressure of 7 MPa showed better compressive strength results. Olive tailings were briquetted and studied by Yaman et al. (2000) and wheat straw by Stelte et al. (2010).
Aiming at the use and valorization of waste from banana crop, the production and characterization of fuel briquettes from banana semi-dried leaves were evaluated in this work.

2. Methodology

2.1 Materials

Semi-dried banana leaves, *Musa cavendishii*, were obtained directly from banana trees. The banana leaves presented average moisture content of 7.8 % (according to ASTM E1871-82, 2006). The samples were milled to obtain particles with 2.5 mm-average size.

2.2 Methods

The briquettes were produced in a briquetting hydraulic press – BHP, using compaction pressure of 18 MPa and compression times of 0.6 and 1 s. The briquettes were produced with dimensions of 50 mm diameter and 50 mm length and then were characterized by proximate chemical analysis, following procedures of ASTM E1871-82 (2006) for moisture, ASTM E872-82 (2006) for volatile materials, ASTM E1755-01 (2007) for ash. Fixed carbon was determinate using the data previously obtained in the proximate analysis and according García et al. (2012) using the formula % FC = 100-(% Ash + % VM). All analyses were performed in triplicate. Elemental chemical analysis (carbon, nitrogen and hydrogen) by elemental analyzer and sulfur by atomic emission spectrometer with inductively coupled plasma. The oxygen was calculated by difference.
The samples were subjected to mechanical tests using an Emic Universal test machine, with a load speed of 1 mm/min. For mechanical tests six briquettes were used for each waste. The same briquettes samples were also used, previously, to determine the bulk density (relation between mass and volume of the briquettes). The energy density was determined by multiplying the waste density by the high heating value of briquettes produced with compression time equal to 1 s.
The briquettes thermal behavior were performed by Thermogravimetric Analysis (TGA) and Differential Thermal Analysis (DTA), under oxidizing atmosphere (synthetic air), temperature range of 22 up to 900 ºC and heating rate of 10 °C/min. The high heating value (HHV) was determined using a bomb calorimeter, following the ABNT MB-2850 and ABNT NBR 8628. To complement the TGA analysis, a linear shrinkage curve was obtained for the briquettes (sample with 1 x 1 mm), into an optical dilatometer at a heating rate of 5 °C/min up to 900 °C in an oxidizing atmosphere.
To evaluate the behavior of the briquettes during burning processes they were subjected to combustion on a home grill. Four briquettes from semi-dried banana leaves and 20 g of alcohol were used to initiate the ignition. To quantify the emissions, a multi flue gas analyzer was used. Measurements were taken every 3 min, totaling 5 measurements in 15 minutes, positioning the probe equipment above the briquettes at the base of the grill opening. The parameters monitored were carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO, NO_2, NOx) and sulfur dioxide (SO_2). The oxygen supply was not controlled during the burning of the briquettes.

3. Results

3.1 Chemical analysis and high heating value

Table 1 shows the high heating value (HHV); average moisture (M), volatile matter (VM), fixed carbon (FC) and ash contents; and C,H,N,S and O elemental composition for the semi-dried banana leaves briquettes and for different briquettes cited in the literature.
The banana leaves briquettes had a higher HHV, of 17.7 MJ/kg, very similar to other biomass studies. These results can be explained by the low moisture content present in other lignocellulosic biomass, which have higher levels of carbon and hydrogen.
The briquettes ash showed values of 10.70 ± 1.03%. The amount of ash is an important data when biomass is used as fuel in boilers, because at high temperatures can melt and cause fouling of equipment. The residual ash is undesirable, so the lower level is the best fuel quality (Oladeji, 2010). According to García et al. (2012), ash is expected to have values for commercial fuels from 0.6% to 9.8%, energy crops

from 1% to 9.6%, cereals from 1.8% to 4.8% and industrial waste from 0.4% to 22.6%. General values may appear in a range from levels below 5–20%.

Low levels of nitrogen and sulfur were found for the briquettes produced as obtained by Oladeji (2010) for briquettes rice husk and corn husks. These results for all samples are favorable because they imply low generation of nitrous oxides and sulfur during the combustion process, which are toxic and corrosive gases (Oladeji, 2010; Sanger et al 2001). Briquettes of rice husk studied by Morais et al. (2006) also showed reduced amounts of nitrogen and sulfur.

Table 1: High heating values and chemical compositions for the briquettes.

Measurements	Banana leaves briquette	Banana pseudostem briquete (Sellin et al., 2013)	Rice rusk briquette (Oladeji, 2010)	Corn cob briquette (Oladeji, 2010)	Sawdust briquette (Roy and Corscadden, 2012)
HHV (MJ/kg)	17.70 ± 0.20	14.90 ± 0.10	13.38	20.89	17.93
M* (%)	7.17 ± 0.31	9.74 ± 0.37	12.67	13.47	8.20
VM (%)	75.30 ± 0.85	71.70 ± 1.13	67.98	86.53	-
FC (%)	14.00 ± 1.52	18.45 ± 1.29	13.40	12.07	-
Ash (%)	10.70 ± 1.03	9.85 ± 0.25	18.60	1.40	1.12
C (%)	44.28 ± 0.18	37.69 ± 1.80	42.10	19.72	47.40
H (%)	6.23 ± 0.03	5.58 ± 0.43	5.80	15.56	6.28
N (%)	0.80 ± 0.01	0.19 ± 0.09	0.38	0.38	0.33
S (%)	< 0.3	< 0.3	0.05	0.82	0.28
O **(%)	37.9 ± 0.22	46.39	33.07	62.12	55.41

*dry basis; ** Oxygen was calculated by difference.

3.2 Density and mechanical analysis

Table 2 shows the mechanical compressive strength and bulk density results for the banana leaves waste briquettes.

Table 2: Mechanical compressive strength and bulk density for the briquettes.

Measurement	Leaves briquette	
Compaction time (s)	0.6	1
Compressive strength (MPa)	3.60 ± 2.30	5.30 ± 1.50
Bulk density (g/cm³)	1.00 ± 0.06	0.99 ± 0.05

The banana leaves briquettes showed lowest compressive strength when compared with pseudostem banana briquettes produced by Sellin et al. (2013) using the same operational process conditions and compared with briquettes from forest biomass studied by Furtado et al. (2010) using compacting pressure of 5 MPa and compressive strength of 16.38 MPa. The compression time did not significantly influence the briquettes compressive strength and bulky density. The different behavior for the briquettes presented on Table 2 can be explained by the biomass characteristics and the briquetting process, as hydraulic piston or extrusion briquetting (Sellin et al., 2013). The higher the proportion of fiber in the entire material, the greater will be its compressive strength (Furtado et al., 2010).

The banana leaves waste has energy density of 786.6 MJ/m³ and after compression the briquette from this waste presented energy density of 17,523 MJ/m³, an increase of approximately 2,200 %. The compaction of the lignocellulosic waste provides better energy utilization of biomass when used as fuel for power generation.

3.3 Thermal analysis

Figure 1 and 2 (a and b) shows TGA/DTA and linear shrinkage curves and images, under an oxidizing atmosphere, respectively, for banana leaves briquettes.

The moisture loss representing the first stage was 9.2 % for the leaves briquette, Figure 1. In the second stage, in the temperature range between 200 and 500 °C, occurred the largest mass loss, Figure 1, and the highest linear shrinkage, Figure 2 (a) and (b), resulting from the volatile matter degradation, as hemicellulose, cellulose and lignin portion, with a mass loss of 87.8 %. In studies with maize cob briquettes, Wilaipon (2007) got the maximum mass loss, of 55 %, at 353 °C.

Above 500 ºC up to about 1000 °C, the mass loss was less significant. In this third stage, occur the degradation of cellulose and lignin remaining.

The thermal behavior for the sample indicates potential for the use of biomass waste as fuel in the form of briquettes in the combustion process.

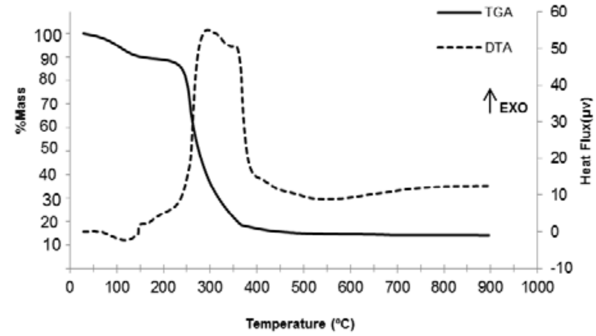
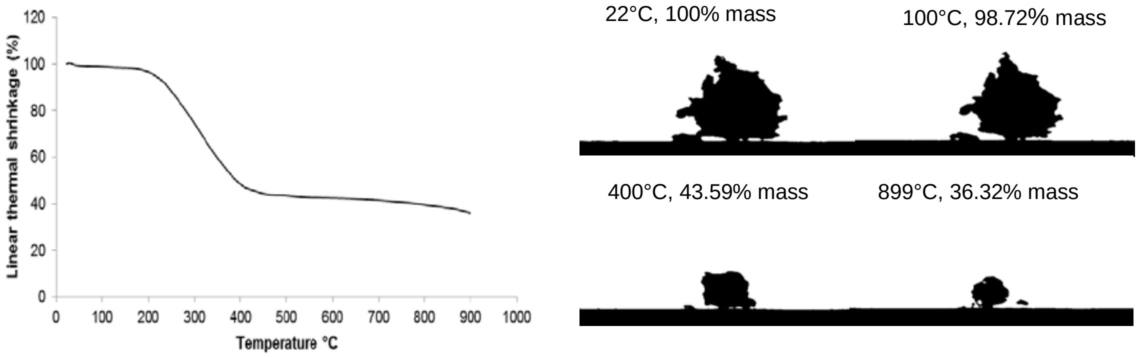


Figure 1: TGA and DTA for banana leaves briquettes.

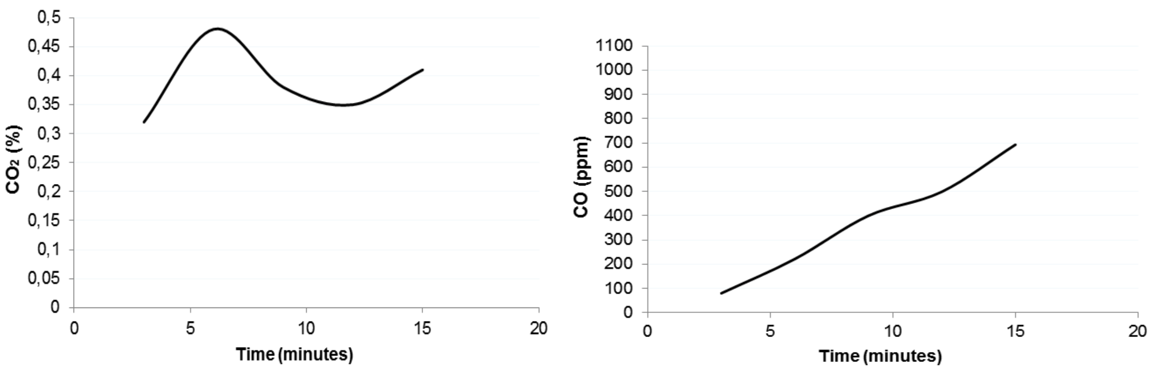


(a) *(b)*

Figure 2: Linear thermal shrinkage curve (a) and images of mass degradation (b) for banana leaves briquettes.

3.4 Evaluation of the briquettes combustion

Briquettes from banana leaves subjected to combustion process exhibited complete carbonization after 15 min. of monitoring. Figure 3 presents the CO_2 (a) and CO (b) levels released during the banana leaves briquettes combustion.



(a) (b)

Figure 3: CO_2 (a) and CO (b) levels released during the briquettes combustion.

As result of the combustion process occur the generation of carbon dioxide, water vapor, sulfur oxide and nitrogen oxides and in addition to these substances (incomplete combustion), it was also produced carbon monoxide. The banana leaves briquettes showed a greater release of CO_2 with a peak of 0.48 % in 6 min of combustion. Although CO_2 is released by combusting biomass, the quantity does not exceed the amount produced during photosynthesis during plant growth (Fernandes et al., 2013).
The high levels of CO, observed during the burning of the briquettes, are mainly due to the decrease of oxygen during combustion. During the banana leaves briquette combustion tests, the oxygen supply was not controlled, so was generated a lot of smoke. The oxygen present in the biomass provides some of the oxygen necessary for combustion but it is not enough to promote complete combustion and it is necessary to introduce oxygen in excess into the combustion chamber (MORAIS, 2007) to minimize the smoke and CO. Fernandes et al. (2013) explain carbon, hydrogen and oxygen are the main components of biomass fuels. Carbon and hydrogen become oxidized during combustion by exothermic reactions (formation of CO_2 and H_2O) and therefore influence the higher heating value of the fuel. The organically bound oxygen provides a part of the oxygen necessary for the combustion process, additional oxygen must be supplied by air injection.
Figure 4 present SO_2 and NOx levels released during the combustion of the banana leaves briquettes.

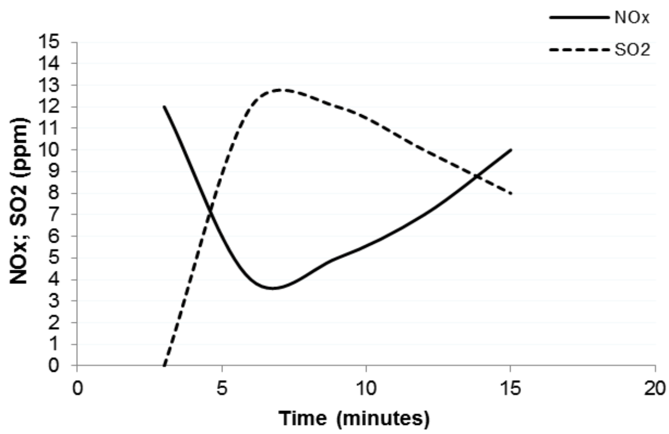


Figure 4: NOx and SO_2 levels relased during the briquettes combustion.

The concentration of NOx (NO and NO_2) and SO_2 released during the combustion of the briquettes were low. The reduced amounts of nitrogen oxides and sulfur dioxide are due mainly to the low levels of nitrogen and sulfur found in the biomass waste and briquettes, determined by elemental analysis. These results are favorable when considering the environmental impact that may be caused by greenhouse gas emissions in the atmosphere. According to Fernandes et al. (2013), the sulfur and nitrogen contents present in the biomass are generally low, resulting in low pollutant gas emissions, such as SO_2, NOx and N_2O during the combustion process. Although there are many studies, the market for briquettes in Brazil is still scarce, mainly due to lack of standardization in the production of briquettes and of their properties, which hinders large-scale production. The briquettes combustion is an activity that should be evaluated carefully and must be done an adjustment to the pollutants emissions regulated by environmental standards.

4. Conclusions

The banana leaves briquettes showed thermal behavior and physical and chemical characteristics similar to others biomass already used as fuel for energy generation. The high HHV of 17.7 MJ/kg and energy density of 17,523 MJ/m³ provide a good combustibility of the briquettes. The maximum energy released was observed at 300°C for the briquettes. The time compression exerted little influence on the physical properties of the briquettes. The compaction of the wastes increases their energy density and reduces the problems associated with their disposal in the environment. Banana leaves briquettes demonstrate potential for use as biomass fuel for energy generation.

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