Industrial Crops & Products 108 (2017) 641–648

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Research paper

Sugarcane trash for energy purposes: Storage time and particle size can improve the quality of biomass for fuel?

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

[a] Federal University of São Carlos (UFSCar) – Campus Sorocaba, Rodovia João Leme dos Santos, km 110, Sorocaba, SP, Brazil
[b] Nagoya University – School of Agricultural Sciences, Furo-cho, Chikusa-ku, Nagoya, 464-8601,Japan

ARTICLE INFO

Keywords:
Biomass
Mineral impurities
Briquettes
Bioenergy
Ashes

ABSTRACT

In sugarcane (*Saccharum officinarum*) plantations, it was common to use fire to facilitate the cutting and harvesting of the sugarcane crop. The largest sugarcane producing state in Brazil is São Paulo, which has a planted area of about 4.7 million hectares. In the state of São Paulo law 11241/02 provides for the gradual elimination of the burning of sugarcane trash. It is estimated that one hectare produces about 14 tons of trash. The mills are trying to incorporate this trash with bagasse for power generation. The high concentration of mineral impurities is a problem in its use for energy purposes. The aim of the study was to investigate the influence of storage time and particle size on the physicochemical characterization of the sugarcane trash. The treatments were based on: the position of the bale (inner and surface), the storage time (0, 1 and 2 years) and the particle size (> 0.420 mm, 0.250–0.420 mm, < 0.250 mm and mix), totaling 24 treatments. The performed analyses were particle size distribution, proximate analysis, the higher heating value (HHV), the chemical analysis of the components of the ashes by Wavelength Dispersive X-ray Fluorescence (WDXRF) and the Scanning Electron Microscope (SEM) images. There were variations in the results of the ash content with different particle sizes. A higher concentration of mineral impurities in smaller particles (< 0.250 mm) was observed. The HHV varied from 15.9 to 18.3 MJ kg^{-1} and showed no statistical difference between the treatments. The results indicate that the sugarcane trash presents problems related to mineral impurities which constrain its use as a solid fuel in industry. The particle size interferes in its physicochemical characteristics. The trash can be stored in the field and did not affect the quality for use as a solid biofuel.

1. Introduction

The estimated planted area of sugarcane (*Saccharum officinarum*) in Brazil is 8.84 million ha for 2017–18 (CONAB, 2017). It was estimated that an average generation of 14 ton ha^{-1} of trash (top and leaves) (Hassuani et al., 2005). According to Leal et al. (2013), the two most promising uses for sugarcane trash are the fuel for the generation of energy or feedstock for second generation biofuels. The use of trash offers the possibility to increase the use of renewable energy in the country's energy matrix (Rípoli et al., 2000).

The use of this trash for energy purposes requires adequate recovery from the field (Leal et al., 2013). An alternative to recover the trash would be a combination of raking and baling. Raking is the accumulation of trash to feed the balers. The recovery system is a process that must be performed with high efficiency because it can significantly affect the raking and other operations due to mineral impurities (Gómez et al., 2010). The material recovered is used to form the bales.

Depending on the performance of the raking operations, the amount of soil contaminants can adversely affect the material, resulting in higher ash content. Ashes can be the result of the material itself and/or from contaminants. The ashes are formed mainly by inorganic substances which do not burn at the end of the combustion process (Brand, 2010). Gómez et al. (2010) and Jenkins et al. (1998) pointed out some difficulties presented by the inorganic materials in ashes: they can form agglomeration, slagging, fouling on a boiler and abrade the equipment used for biomass densification. The ash content, ash composition, volatile, fixed carbon and moisture content test is the key to understanding the thermal behavior of the material (García et al., 2013; Nunes et al., 2016).

Biomass is a heterogeneous and complex material (Bridgeman et al., 2007; Vassilev et al., 2013). These characteristics can cause sampling errors (Bridgeman et al., 2007). The particle size may influence the

* Corresponding author.
E-mail addresses: gabi.tami@gmail.com (G.T. Nakashima), mareprovedel@hotmail.com (M.P. Martins), ana_hansted@hotmail.com (A.L.S. Hansted), hiro@agr.nagoya-u.ac.jp (H. Yamamoto), fmyamaji@ufscar.br (F.M. Yamaji).

http://dx.doi.org/10.1016/j.indcrop.2017.07.017
Received 20 September 2016; Received in revised form 12 June 2017; Accepted 6 July 2017
0926-6690/

characterization results (Jacob et al., 2013; Cai et al., 2017). According to Jacob et al. (2013), the poplar woody presented higher ash, lignin and extractive contents and lower carbon content in the particles below 0.2 mm. Bridgeman et al. (2007) studied two types of crop residues and also obtained higher ash contents for analysis with smaller particles (< 0.09 mm) and higher cellulose, carbon and volatile contents for larger particles (0,09–0,6 mm) which can increase the biomass heating value.

According to Nakashima et al. (2014), the particle size interfered in the production of crop residues briquettes. The briquettes with particles smaller than 0.25 mm obtained better results in the formation and mechanical resistance.

Other factor that may interfere with the characterization and the use of the feedstock is the storage time. Some properties may change during the storage generating degradation, due to the temperature and moisture content (Kymäläinen et al., 2014; Wang et al., 2017). Wiselogel et al. (1996) observed that switchgrass bale was degraded, mainly in the superficial layer.

Chemical composition may vary during the storage time and the feedstock is more preserved in indoor storage or when the bale is wrapped (Shinners et al., 2010). However, indoor storage or wrap mechanisms imply in high costs of production (Kymäläinen et al., 2014).

It is well known that the large availability of sugarcane trash is a problem for Brazilian producers of sugarcane. In a form to attend the industry, it was purposed to use the sugarcane trash as a briquette. In this work, it was studied some factors that may affect the fuel behavior of sugarcane trash. The factors were: storage time (0 year (control), 1 year and 2 years stored), the particle size (> 0.42 mm; 0.25–0.42 mm; < 0.25 mm and mix) and the presence of inorganic elements in the sugarcane trash (0 year cleaned and in natura). The aim of this study was to characterize the sugarcane trash to verify the influence of storage time and the particle size in its thermal properties.

2. Material and methods

2.1. Material

The sugarcane (*Saccharum officinarum*) trash used in this study was collected from Fazenda Corredeira, located in the municipality of Ibaté (21.9547°S, 47.9967°W) in the state of São Paulo, Brazil. The farm has an area of 800 ha planted with sugarcane and has an average yield of 87 ton ha^{-1} year^{-1}. The sugarcane varieties planted are RB 855453, RB 867515, RB 855536, SP 803280 and SP 813250.

The samples were randomly collected directly from the 10 bales stored for 1 year and 2 years on the field. Samples from the surface and the inner of the bales were collected. The purpose was to evaluate the surrounding (soil, rain, wind) effects on the bales and the variation of storage time of the sugarcane trash. The storage time was 0, 1 and 2 years.

The material "0 year" was applied to verify the influence of contaminants. The trash 0 year was collected directly from the ground just after sugarcane harvesting. The material was divided in 2 treatments: cleaned (washed) and in natura (non-washed). The cleaned treatment was washed under running water and dried in an oven at 100 °C. The contaminants analysis is important due to the extreme abrasion observed in the molds and pistons during briquetting process of sugarcane trash. Also, the contaminants can be problematic in combustion process (agglomeration, slagging, fouling, emissions).

The treatments were divided according to particle size to attend standards analyses: < 0.25 mm; 0.25–0.42 mm; > 0.42 mm and with unseparated particle sizes (mix). The treatments were based on 3 storage times (0, 1 and 2 years), 2 bale portions (outside and inside), 4 particle sizes (particle < 0.25 mm, 0.25–0.42 mm, > 0.42 mm and fraction mix) and cleaning treatment for the 0 year sample (washed and non-washed) for a total of 24 treatments (Fig. 1).

All the collected sugarcane trash was oven dried and crushed using a vertical rotor mill with fixed and mobile knives Willey MA − 340.

2.2. Particle size distribution

All the different storage times (0, 1 and 2 years) of the sugarcane trash were analyzed for particle size distribution. The sieves used were 12.70 mm (1/2 in.), 6.35 mm (1/4 in.), 4.00 mm (5 mesh), 2.00 mm (10 mesh) and 0.84 mm (20 mesh) for the sugarcane trash before grinding. The sieves used for sugarcane trash after grinding were 0.42 mm (40 mesh), 0.25 mm (60 mesh) and 0.15 mm (100 mesh). The particle size separation process was performed in an orbital shaker with these sieves and with an intermittent shaking action, using a Marconi − MA 750 type shaker.

2.3. Proximate analysis

Proximate analysis was provided with samples with a 0% moisture content and 3 repetitions for each treatment were performed. The ash content was based on the ASTM D1102-84 standard. The volatile content was based on ASTM E872-82. Fixed carbon was obtained by the following Eq. (1):

$$\%fixed\ carbon = 100 - (\%ash\ content + \%volatile\ matter) \quad (1)$$

2.4. Wavelength dispersive X-ray fluorescence (WDXRF)

The chemical composition of sugarcane trash ashes for 0 year (without cleaning) and 0 year cleaned was determined by Wavelength Dispersive X-ray Fluorescence (WDXRF) in a Rigaku Supermini 200. The samples (0% moisture content) were prepared in the mold filled with boric acid and ashes from the sugarcane trash. A hydraulic press (20 ton) was used to produce the tablet (densification). The tablet was placed in the sample holder and analyzed with a resolution of 26 eV.

2.5. Scanning Electron Microscopy (SEM) and energy dispersive X-ray analyzer (EDXA)

The morphology of sugarcane trash was analyzed by SEM-EDXA. Samples were placed on an aluminum base and fixed to a carbon tape. Prepared samples were kept in a desiccator until the time of analysis. Scanning Electron Microscopy was performed using a Hitachi TM3000 operated with an acceleration voltage of 15 kV and an Energy Dispersive X-ray Analyzer (EDXA).

2.6. Higher heating value (HHV)

The higher heating value (HHV) was obtained in triplicate, based on standard ASTM D5865-98, using an IKA Model C200 calorimeter with isoperibol method.

2.7. Statistical analysis

The proximate analysis and the HHV were statistically evaluated by analysis of variance (ANOVA). The Tukey test was applied at the 5.0% significance level for treatments that showed significant differences. All statistical analyses were performed using the R 2.11.1 software (R Studio, 2012; R Development Core Team, 2008).

3. Results and discussion

3.1. Particle size distribution

The particle size distribution of sugarcane trash before grinding is shown in Fig. 2 and the distribution after grinding is displayed in Fig. 3.

Before grinding, the highest percentages were retained in the sieve