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Characterization of sugarcane straw and bagasse as biofuels and its implications in thermochemical processes

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Abstract:

Besides sugarcane bagasse, the solid residues in sugarcane industry have been increasing due to the mechanical harvesting, in which the dry cleaning system residue (DCR) is yielded. The knowledge of the physical, chemical and thermodynamic properties from residual biomass resulting from this process is the first step to make it as an energy resource in thermochemical treatment, such as combustion in boilers. From this, the present work aimed to determine physicochemical properties of DCR and sugarcane bagasse. The samples were collected at Alta Mogiana sugarcane mill, located in São Joaquim da Barra, São Paulo, Brazil. The *in natura* samples were undergone analysis to determine their physical, chemical and thermochemical properties, such as particle size, ultimate composition, moisture content, volatile matter, fixed carbon ash content, metals content, bulk density and higher heating value. The volatile matter content of DCR were higher compared to bagasse samples, implying, consequently, in a faster combustion due to addition of this new residue in bagasse boilers. Ash composition analysis was performed through an Analytical Scanning Electron Microscope (JEOL JSM-6010 LA) with 4nm resolution in 20 kV and magnification from 5X to 300.000 X. The presence of significant amounts of K_2O, Cl, SiO_2, CaO and SiO_2 increasing fouling and slagging tendency in boilers. The ultimate content was determined through a elemental analyser (PERKIN-ELMER CHN 2400) and the results claim fuel properties of DCR and sugarcane bagasse, since they are composed in majority by carbon and hydrogen. the mean HHV value for DCR, according ASTM D2015-00, was around 17 $MJ.kg^{-1}$ and for the bagasse, around 18 $MJ.kg^{-1}$.Therefore, the potential application of these agricultural residues as a solid fuel boilers was analyzed according their physical, chemical and thermodynamic properties, which are important parameters regarding to the project and operation of biomass boilers.

Keywords:

Biomass, Characterization, Sugarcane, Bioenergy.

1. Introduction

According to the National Energy Balance (BEN) [1], during the year of 2010 the energy supply in Brazil reached 268.75 million tonnes of oil equivalent, from which 37.6% came from oil and 45.5% from renewable sources, where 64.4% is represented by wood, charcoal and sugar cane products. During the year of 2009, only 9.8% of energy supply came from renewable sources. According to this information, is possible to notice that Brazil has the possibility of becoming a world leader in the energy use of biomass.

However, the use of biomass as energy supply is associated with a careful utilization of natural resources and of productive lands to avoid environmental imbalance, destruction of ecosystems and the price increase of food. Giving these conditions, the wastes utilization as energy source is becoming a worldwide reality.

Considering that agricultural, agroindustrial and even urban solid wastes are all resulting from the biomass processing, they present high potential for energy use by biochemical (anaerobic digestion) or termochemical processes (combustion, gasification or pyrolysis).

Between residual biomass with higher energy potential, wastes native of forestry and agricultural activities can be highlighted, due to their termochemical properties and the great representation of these sectors, especially in developing countries as Brazil.

According to Food and Agriculture Organization of the United Nations (FAO) [2], during the year of 2012, 26,055,063 ha of sugarcane were cultivated in the whole world, in which 1,832,541,193 ton of sugarcane were produced. Brazil (721.07 ton), India (347.87 ton) and China (124.04 ton) are the three largest producers.

The energy potential of sugarcane is known, once that, at the sugarcane industry, for each unity of fossil consumed energy there is the production of 9 unities of renewable energy [3]. Besides that, it is possible to estimate that the heat value of the whole sugarcane (including 140kg of straw in dry basis) is of 7.4GJ per ton of harvested sugarcane (70% of moisture content). Therefore, the sugarcane cultivation has na impact at the energy matrix and the economic development of the producing countries [4].

Sugarcane wastes are particularly important at the energy point of view, once they are applied as fuel at the reuse thermal processes since the 1980's in countries from Asia and mainly in Latin America, presenting a great representativeness between renewable sources in these countries [5].

Nowadays, it is possible to observe a gradual technological and economic development that implies at the verticalization of the sugarcane agroindustry, from which there is a greater use of the by-products of the sector, given that the bioethanol represents only one third of the sugarcane energy and that two-thirds are available at straw and bagasse [3].

However, the sugarcane agroindustry is now exploring the concept of biorefinery, which includes integrated systems ranging from the process for obtaining feedstock to processes for obtaining the first and second generation biofuels, chemical products, electrical energy and steam for the own plant consumption and/or for the sale of surplus.

As consequence of the sugarcane mechanical harvest, which is improving in Brazil since the 2010/2011 crop, the straw is obtained as an agroindustrial waste. According to Bizzo (2014) [6], about 5% of the load transported by trucks are made of straw (tips, green leaves and dry). Besides the straw carried with the sugarcane, there is the straw leaved in the soil during the harvest process, which can subsequently be taken to the plant to be reused in cogeneration systems or leaved in the field where it will act as a soil protection, for example.

By this way, the sugarcane arrives in the plant with large impurities amount which are removed from soil and carried during the harvest. It is important to highlight that such impurities have great negative role in the industrial processo of sugar and alcohol production, as the wear of equipments and pipes, in addition to affect the fermentation processo of the sugarcane juice [7].

Therefore, after the harvest, the sugarcane passes through a cleaning step which may be performed using water or using dry system. During the dry process, sugarcane is separated from the impurities that were carried during the harvest process, thereby producing the dry cleaning cane residue (DCR). After the cleaning process, the sugarcane is chopped and sent to sugarcane juice extraction, which happen through a milling or a difusion process, in which the juice is separated from the fibers that are called bagasse. Both the bagasse and the DCR can be used as a fuel to the boilers that compose the cogeneration systems of the plants.

From this on, there was the advent of several technologies for the energy use of agroindustrial wastes, with the objective of improving the efficiency of energy conversion processes, such as the solution of problems as biomass storage and its low density.

For improving the efficiency of energy conversion processes, is necessary to know the physico-chemical, themodynamic and transport properties of biomass. It's necessary to study the optimal conditions in such a way that the conversion process happens with the best efficiency and with the highest yield of some products, considering the resulting energy from the conversion process in relation to the spend of energy for the preparation of the biomass.

The biomass characterization and the determination of its properties are fundamental activities, once they will provide essential information for the development of new equipment and for the determination of optimal conditions of the energy conversion processes.

At present, the most applied methodology for the energy reuse of agroindustrial wastes from sugarcane industry, such as straw and sugarcane bagasse, is the direct combustion inside boilers for the energy conversion in electricity and steam. However, these wastes present some problems related to their utilization in thermochemical processes, such as the low density and the high moisture content, that complicate the transport, handling and storage of biomass besides to reduce the energy efficiency of conversion processes, once about 20% of the heat from combustion process is consumed for the water removing process (drying).

From this, the present work aimed to determine physicochemical properties of DCR and sugarcane bagasse. DCR and sugarcane bagasse samples were collected after the dry cleaning system and milling process for the sugar and ethanol production, respectively, at Alta Mogiana mill, located in in São Paulo state countryside, Brazil. The choice of this sugarcane mill was led by the energetic use of these byproducts in a cogeneration boiler for steam and electricity supplying for the mill itself. The *in natura* samples collected were undergone analysis to determine their physical, chemical and thermochemical properties, such as particle size, ultimate composition, moisture content, volatile matter, fixed carbon ash content, metals content, bulk density and high heating value.

2. Materials and methods

2.1. Materials of study

2.1.1. Alta Mogiana mill processing

The sugarcane bagasse and DCR samples were collected from Alta Mogiana mill, located in São Joaquim da Barra city rural zone, São Paulo state, Brazil (20.475819º S, 47.888511º W). The Alta Mogiana sugarcane mill has been using dry cleaning process for the sugarcane from mechanical harvesting for four years, from which DCR is processed and burnt jointly with the sugarcane bagasse in boiler aiming at steam and electricity. The residue generation at Alta Mogiana mill, focus of this work, is shown in Figure 1 by a simplified scheme.

The Alta Mogiana mill process in majority chopped sugarcane plant, in other words, sugarcane plant from mechanical harvesting, aiming at as much sugar as ethanol production. An average of 79 tons of sugarcane is processed per day, from which 6% are composed by soil particles that usually is carried by the combine harvester to the mill. Besides this, green and dry leaves are also transported along with chopped sugarcane. These undesirable materials define the impurity degree of the harvested sugarcane.

After the harvesting process, the harvested sugarcane is stored up to 3 days to green leaves drying, since its presence implies directly in unwanted coloring during sugar production process due to its chloride oxide content. Moreover, the chlorine oxide content of green leaves is higher when compared to sugarcane bagasse and then, its attendance causes boiler negative effects, such as fouling and corrosion [8].

Thereafter to the green leaves drying period, part of the harvested sugarcane is carried directly to milling A (Figure 1), where the sugarcane juice and bagasse is obtained. Thus, the sugarcane bagasse from milling A (BMA) is led to the cogeneration boiler, as the flowchart in Figure 1 shows.

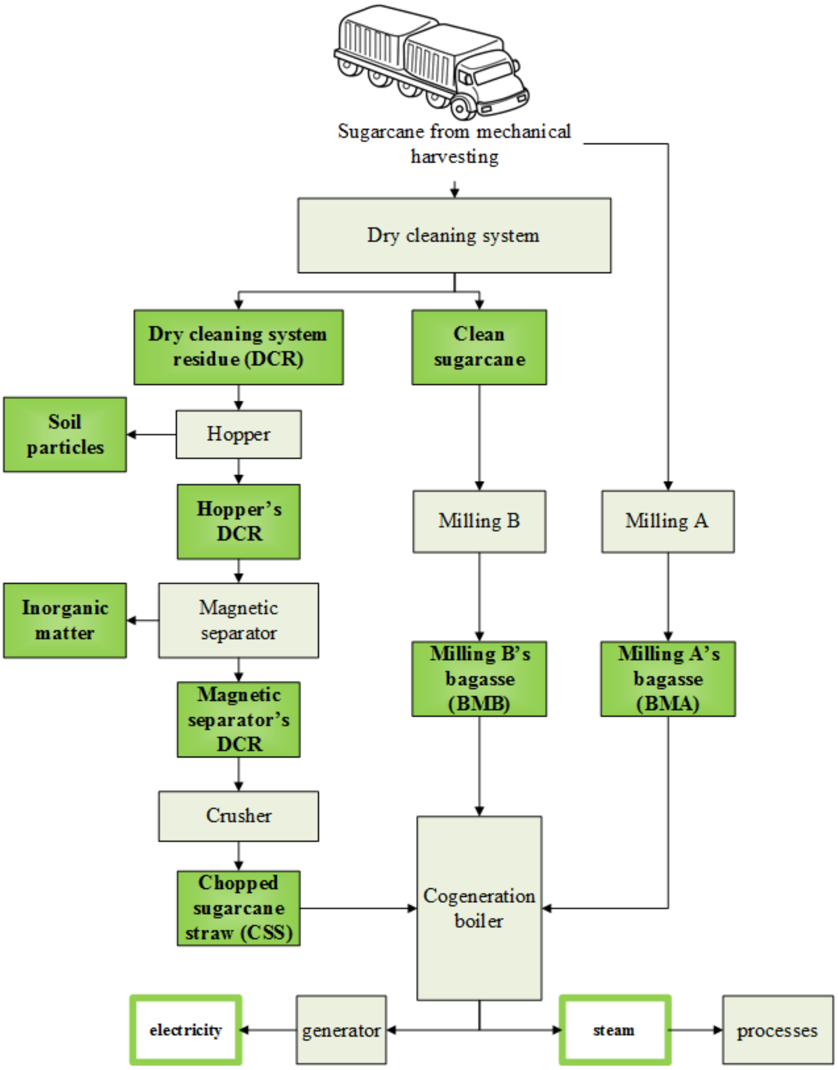

Figure 1. Scheme and identification of byproducts and residues generation from Alta Mogiana mill process.

On the other hand, the remaining amount of the harvested sugarcane, which has not been sent to the milling A, is carried to a dry cleaning system (Figure 2). This cleaning process is made by a fans bundle and it is called a dry process due to the water absence to obtain a chopped and clean sugarcane along with a dry cleaning system residue (DCR).

Figure 2. Dry cleaning system in Alta Mogiana sugarcane plant.

The DCR pass through a hopper in which the most soil particle content is removed and it is carried back to the sugarcane crops soil. Certain amount of soil particle and inorganic impurities still remain in the CDR after the hopper process, then, the CDR is led to magnetic separator for inorganic matter removing. Afterwards, the DCR without inorganic matter and with a lower soil particle content pass through a crusher when its particle size is reduced.

After these subsequent treatments stages of the DCR, it is composed mainly by sugarcane straw with lower particle size when compared to the DCR just after the dry cleaning system and, thus, it is defined as chopped sugarcane straw (CSS), which will supply the cogeneration boiler in the Alta Mogiana mill. Furthermore, 330 tons of CSS are yielded and 30 tons of soil particles are removal from DCR on average, since the DCR production just after the dry cleaning system to the obtaining of the CSS after the crusher process.

As described before and shown in Figure 2, an clean and chopped sugarcane is obtained as result of the dry cleaning system and from this, it is led to the milling B to sugarcane juice production and, consequently, sugarcane bagasse from milling B (BMB) is yielded and it also supplies the cogeneration boiler.

Maintenance need on milling B is substantially lower than on milling A, since the BMB pass through the sugarcane dry cleaning system and its impurity degree decreases. Besides, larger amount of sugarcane is processed on milling B in comparison with milling A.

Therefore, the direct combustion in cogeneration boiler is the main technologic route chosen to the energetic use of the agroindustrials residues at Alta Mogiana mill. The boiler supplying system is done through a conveyor belt, which leads both sugarcane bagasse from milling A as milling B, as well as the residue from the dry cleaning system. The amount of solid fuel required relies on the power and steam need, however, the amount of CSS is lower than BMA and BMB amount on average.

2.1.2. Biomass samples

Samples of chopped sugarcane straw (CSS) and sugarcane bagasse from milling A (BMA) and B (BMB) were collected at Alta Mogiana mill, according their positions of generation into the sugarcane and bioethanol process. These residues were selected since the dry cleaning system of the sugarcane was assembled and the cogeneration boiler have been supplied by them. A chemical and physical characterization was done on these three samples, according to the procedures specified in 2.2 topic, in order to determine the properties of them as a solid fuel as well predict some operational problems in the biomass boiler, such as fouling and corrosion, due to the ash amount and its composition. Furthermore, the equipment dimensioning relies on the fuel physical and chemical properties, such as mean diameter, proximate analysis and heating value for instance.

2.2. Physico-chemical analysis of sugarcane bagasse and DCR

2.2.1. Particle size analysis

The determination of particle size distribution of sugarcane bagasse and straw was carried according to ASTM D4749-87 [9]. The mesh of the sieves were defined according to Sosa-Arnao [10], Chrisostomo [11] and Pelaez Samaniego [12]. Thus, it was used sieves with mesh 4.75; 2.00; 0.85; 0.35; 0.25 and 0.150mm.

From this, it was estimated the mean particle size for each sieve, according to the equation defined by Foust et al. [13], which is described at equation 1 and, consecutively, it was estimated the mean particle size of the sample ($\overline{d_p}$), according to equation 2.

$$\ln(d_p) = \frac{\ln(e_s)+\ln(e_i)}{2} \tag{1}$$

$$\overline{d_p} = \frac{1}{\sum_{i=1}^{n}\left(\frac{x}{d_p}\right)_i} \quad (2)$$

2.2.2. Bulk density

The bulk density of sugarcane bagasse and straw was determined according to ASTM E873-82 [14]. It was applied a beaker with a volume of 1000 mL (0,001 m^3). For each sample, the density was estimated in triplicate. By this way, the bulk density was estimated according to equation 3.

$$D = \frac{M_2 - M_1}{V} \quad (3)$$

For determination of samples mass, it was applied a semi-analytical balance BEL - M1003i.

2.2.3. Higher heating value

The standard used as a guide for determination of high heating value was ASTM D2015 -00 [15], where the combustion of the sample is considered under oxygen atmosphere at a preset temperature (25°C). This determination was made in triplicate for both bagasse and straw samples.

Initially, the dried samples of bagasse and straw were milled and compressed as a pastille with the aid of manual press (IKA C21). The higher heat value was determined with a bomb calorimeter (IKA C2000), previously calibrated with benzoic acid.

2.2.4. Proximate analysis

The proximate analysis includes the determination of fixed carbon, volatile matter, ash and moisture content. The standards used as reference were ASTM E1755-01 [16] and ASTM E872-82 [17]. The temperature indicated in the standard for the determination of ash (575ºC) was different from the set temperature corresponding standard coal (750 ° C) due to the fact that some compounds can volatilize at higher temperatures and induce an error in the determination.

For determining the elementary composition of ash from waste biomass, porcelain containers were previously calcined at 575 ± 25°C for 3 hours. Containers with approximately 2g of samples were taken to the muffle furnace and heated to 250°C at a rate of 10K/min and kept at this temperature for 30 minutes to avoid flashing samples. Subsequently, the temperature was raised to 575 ± 25°C for at least three hours until constant mass of the inert material be reached.

For the determination of the volatile material content, 1 g of each sample was arranged in porcelain crucibles with cover and subjected to ignition in the muffle furnace at 950°C ± 20°C for 7 minutes, which underwent cooling in a desiccator for subsequent gravimetric analysis. The fixed carbon content was calculated as the difference between 100% and ash content and volatile matter when all measured on a dry basis.

For the moisture content evaluation, about 5g of *in natura* samples of bagasse and straw, just after the collection at Alta Mogiana mill, were undergone to a drying oven at 60ºC up to stable weight.

2.2.5. Ash analysis

To determine the major elements in the ash bagasse and straw samples, each sample in triplicate was calcined in a muffle furnace at 575 ± 25 ° C until constant weight. The resulting ashes were placed on copper plates and coated with gold in the sputtering (40A for 180 s).

The elemental analysis of the ashes was based on energy dispersive x-ray detector (EDS) and was made in the Analytical Scanning Electron Microscope equipment, which is an electron microscopy equipment Scan and microanalysis (JEOL JSM-6010 LA). Its resolution is 4 nm to 20 kV, and magnification 5X up to 300,000 X. Scanning electron microscope an electron beam is focused on a region of the sample, which are generated by the different signs of secondary electrons, backscattered, X-rays and others. These signals are detected and transformed into electrical signals that form the image of the surface, phase composition and compositional analysis [18].

The determination of the elemental composition of the ashes of straw and bagasse was made by triplicate in a scanning electron microscope with a resolution of 300X and then calculate the average of the nine tests.

3. Results and discussion

3.1. Physical analysis

As described, the particle size analysis aimed at determine de particle size distribution as well as the mean particle size ($\overline{d_p}$) of the samples. As Figure 3 shows, CSS sample had vast majority retained mass fraction percentage in sieves with average openings of 4.75 mm, while for the BMA and BMB samples the higher percentages of retained mass fraction was with average openings of 4.75 and 0.85 mm. From this analysis, two distinct structure are identified in the bagasse composition, such as the fiber fraction, which is retained mainly in the sieves with average opening size between 4.75 and 0.85 mm while the marrow fraction, evidenced as a powder, is substantially retained in the sieve with average opening less than 0.150 mm. The CSS samples consist in larger particles than the bagasse partcles.

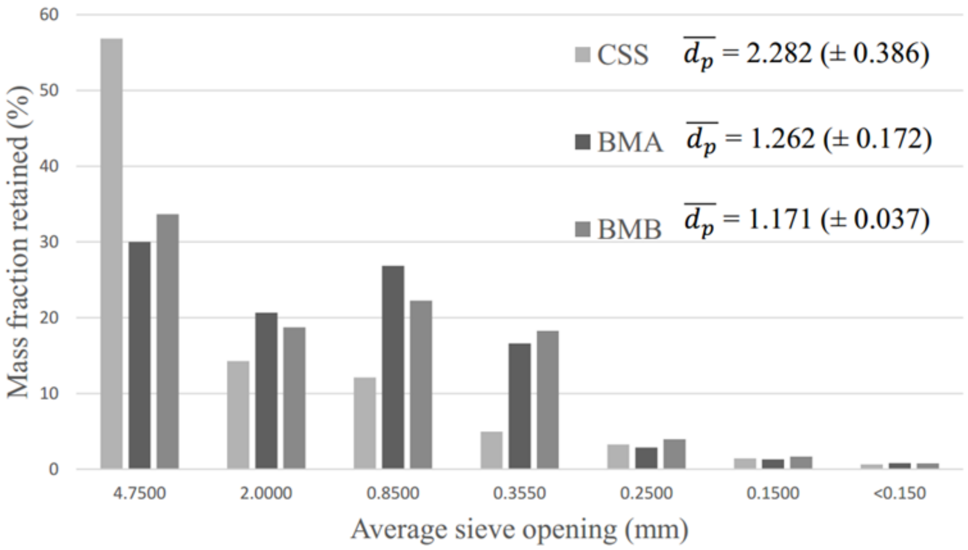

Figure 3. Granulometric analysis in different sugarcane bagasse and chopped straw samples.

From de particle size distribution, the mean particle size of the samples were determined, as it was described in equations 1 and 2 and the average values found are shown in Table 1.

According Table 3, the mean particle size for CSS was 2.282 mm and it is around 60% larger than the reported value in the literature of 062mm [12] even the CSS being composed in majority by a crushed part of the sugarcane straw. This difference can be based on heterogeneity of the samples that have been chosen.

The bagasse samples shown a slight difference between them about the mean particle size with 1.262 and 1.171 mm for BMA and BMB, respectively. Nevertheless, both values for the bagasse samples are on average 50% larger than the values found by Sosa-Arnao [10] 0,611mm. This author also performed this analysis for bagasse from milling process, however, the difference between the equipment (milling) should be considered about the final bagasse obtained. The mean particle size for CSS was on average 85% higher than the values found for the bagasse samples in the literaure, due to the powder fraction, which composes the bagasse samples and implies in a minor mean particle size of it when compared to the chopped straw.

Table 1. Mean particle size values for different samples of sugarcane straw and bagasse obtained in this work and from literature.

Sample	CSS*	BMA*	BMB*	Sugarcane Straw [12]	Sugarcane Bagasse [10,19]
$\overline{d_p}$ (mm)	2.282 (± 0.386)	1.262 (± 0.172)	1.171 (± 0.037)	0,62	0,61
Bulk density (kg/m³)	29.971 (± 3.425)	53.267 (± 4.543)	52.491 (± 4.440)	30.60	75 - 90

*Results obtained in this work

The bulk density results found for the CSS, BMA and BMB samples are also shown in table 1. On average, the bulk density for the chopped straw (CSS) is 29.971kg/m³ and this result is close to the reported by Pelaez Samaniego [12]. There was not consistent difference among the values found for the bulk density of the bagasse samples analyzed, implying in a non-considerable difference between the millings A and B as to the bulk density. Rein [19], reports an average bulk density for bagasse samples between 75 and 90 kg/m³, that is, from 30 to 40% larger than the values found for BMA (53.267 kg/m³) and BMB (52.491 kg/m³). As mentioned before, the differences between the used equipment to obtain the sugarcane juice should be considered when bagasse samples are compared, besides, the sugarcane variety must be taken into account. Due to the significant dissimilarity between straw and bagasse particles size and form, the bulk density of CSS is around 44% minor in relation to bagasse samples.

3.2. Chemical and thermal analysis

Immediately after the collection of chopped straw and both bagasse samples, the *in natura* moisture was determined, that is, the moisture content in which the samples are carried to the boiler in Alta Mogiana mill, through a drying oven at 60ºC up to stable weight, as is presented in table 2. The results shows that the CSS has a moisture content of 40.797% while the BMA and BMB have 44.650% and 48.207% as moisture content, respectively. The results are essential under the cogeneration view, since the samples supply the boiler for steam and electricity generation and the moisture content states the energy required to dry the solid fuel before its combustion. According Filippetto [20], up to 20% of the heating released during the combustion can be consumed from the biomass solid fuel itself.

From the proximate analysis is possible predict the biomass solid fuel behavior when undergone to thermochemical processes and in Table 2 is shown the results for contents of moisture, volatile matter fixed carbon, ash and higher heating value for different samples of sugarcane straw and bagasse obtained in this work and from literature.

The volatile matter found for the CSS sample was 77.279% in dry basis against 87.631 and 89.482% for bagasse from milling A and from milling B, respectively (see Table 2) . Thus, both straw and bagasse are composed mainly by volatile matter, which notices as easily combustible is a fuel, since this fractions refers to the first fraction released during the thermochemical process. The volatile matter results for both bagasse samples match with the reported literature, whereas the volatile matter for CSS is 6% minor on average when compared to the values found by Bizzo et al. [6].

About the fixed carbon content, it is important behold that the ASTM method was applied, which is based on coal as a fuel, however, the biomass does not present elemental carbon, since its carbon fixation relies on assimilation photosynthetic on carbohydrate molecules, and consequently, lipids and proteins. From this, the most suitable term to define the fixed carbon in biomass could be pyrolytic carbon, which refers to the last fraction of the fuel to combust. According Table 2, the fixed carbon from the chopped straw samples (11.535%) presented a slight difference between the fixed carbon content found for bagasse from milling A (10.291%) and the value found in literature (10,1%) reported by Bizzo et al. [6], in dry basis. The bagasse from milling B had a fixed carbon of

8.918% in dry basis and this value is about 31% minor than the content obtained by Protásio et al. [21].

In general, sugarcane straw shows higher ash content than bagasse, as can be seen in Table 2 by the found and reported values, that implies in some operational problems in boilers, such as fouling and corrosion as related by Babcock & Wilcox Company [8]. Samples of CSS presented 11.185% of ash in dry basis against 2.076 and 1.6% in dry basis for BMA and BMB, respectively. The minor ash content of bagasse from milling B is due to the straw removing process by the sugarcane dry cleaning system before the juice extraction on milling B.

Table 2. Contents of moisture, volatile matter fixed carbon, ash and higher heating value for different samples of sugarcane straw and bagasse obtained in this work and from literature.

Sample	Moisture *in natura* (wt% wet basis)	Volatile matter	Fixed carbon**	Ash	HHV (MJ/kg dry basis)
		(wt% of dry basis)			
CSS*	40.797(± 0.964)	77.279(± 0.505)	11.535(± 0.402)	11.185(± 0.207)	16.535(± 0.111)
BMA*	44.650(± 0.302)	87.631(± 0.036)	10.291(± 0.039)	2.076(± 0.043)	18.591(± 0.035)
BMB*	48.207(± 2.321)	89.482(± 1.272)	8.918(± 1.265)	1.600(± 0.021)	18.425(± 0.108)
Bagasse [21]	-	86,0	13,1	0,9	18,89
Straw [6]	-	82,5	10,1	7,5	17,1

*Results obtained in this work, **Obtained by content difference

The higher heating value found for chopped sugarcane straw was on average 16.535 MJ/kg, while for bagasse from milling A and B were 18.591 and 18.425 MJ/kg, respectively. Therefore, it is noticed that there were not influence on higher heating value due do the difference of milling used.

Considering the heterogeneous samples in this study, it is possible indicate that the values for higher heating value for chopped straw and bagasses samples match with the values found in literature, as is reported by Protásio et al. [21] and Bizzo et al. [6] and exposed in Table 2.

3.3. Ash analysis

As already mentioned, as important as ash content information, the ash composition is essential to predict some negative effects inside of the boiler on power plants by biofuels as slagging, fouling and corrosion.

The results obtained from EDS analysis for ash properties of straw bagasse samples from Alta Mogiana mill, as well some references values, are shown in Table 3. The EDS analysis is not a quantitative analysis, however, shows an analysis of abundance and then, a estimative of the inorganic matters in biomass ash.

From the results in Table 3, the inorganic properties found in the ash composition of sugarcane straw and bagasse samples match, according Van Loo & Koppejan [23], with the typical elements that composes the most of the biomasses, such as Si, Al, Fe, Ca, Mg, Na, K, P e S.

For the CSS ash composition, the majority elements are Fe, Si, Al, Ca and K with 33.13, 17.79, 16.46, 10.34 and 6.42% of ash mass on average, respectively.

For sugarcane bagasse sample from milling A, these elements also compose the majority inorganic matter in the ash content, however there is some different among the contents on average of Fe, Si, Al, Ca and K, being of 27.89, 18.15, 12.41, 7.09 and 14.42% of ash mass, respectively. On the other hand, for the bagasse from milling B, the ash content on average for Fe, Si, Al, Ca and K is 21.06, 24.76, 10.63, 12.25 and 12.17% of ash mass, respectively. About chlorine content, there is a slight difference among the values found in this work for straw and bagasse samples and they are not significatives compared to the other elements, however, the presence of chlorine along with high contents of potassium indicates operational losses in boiler during the combustion of the biofuel due to corrosion caused by these ash components.

Table 3. Inorganic properties of sugarcane bagasse and chopped straw samples (wt% of ash)

Sample/ Ash composition (%)	CSS	BMA	BMB	Bagasse [22]	Straw [6]
Na_2O	0.357	0.56	0.46	0.45	0.54
MgO	4.90	5.61	9.08	8	4.49
Al_2O_3	16.46	12.41	10.63	2.42	9.64
SiO_2	17.79	18.15	24.76	48.74	40.81
P_2O_5	1.43	1.48	4.13	6.91	1.77
Cl	0.25	0.28	0.24	-	-
K_2O	6.42	14.42	12.17	23.42	8.03
CaO	10.34	7.09	12.25	6.17	21.15
TiO_2	4.64	5.62	1.33	-	-
FeO	33.13	27.89	21.06	0.47	4.47
CuO	-	5.76	-	-	-

Beisdes corrosion, the presence of alkali elements, chlorine and silicon increases the fouling and slagging effects on biomass cogeneration plants, implying in losses along the heating exchange inside the boilers.

4. Conclusion

After some pretreatments processes, the sugarcane dry cleaning system residue (CSS) is burnt in a cogeneration boiler along with sugarcane bagasse from two different mill system of sugarcane juice extraction (BMA and BMB). From this, these residual biomasses supply, as a solid biofuel, the boiler at Alta Mogiana mill aiming at steam and electricity supplying.

The bulk density and mean particle size are important for boiler supplying system design and these properties were determined for CSS, BMA and BMB. CSS had 2.282 mm of mean particle size and bulk density of 29.971kg/m³, on average. BMA showed a mean particle size of 1.262 mm and bulk density of 53.267 kg/m³ on average, while BMB had 1.171 mm of mean particle size and bulk density of 52.491 kg/m³, on average. The difference between straw and bagasse bulk densities is done, mainly, by the distinct straw and bagasse particles size and form.

According to the presented results, the chopped straw is carried to the boiler with a moisture content around 40%, whereas *in natura* bagasse from milling A and from milling B shows a moisture content around 45 and 48%, respectively, which imply in a heating load during the combustion process. Besides, is it possible to say that both CSS as bagasse samples show fuel properties, since they are composed in majority by volatile matter and fixed carbon, fractions that will combust on air attendance. CSS is composed on average by 77.279% and 11.53% of volatile matter and fixed carbon, respectively. About the bagasse samples, BMA is composed by 87.631% of volatile matter on average and 10.291% of fixed carbon on average, both in dry basis, whereas BMB showed a volatile matter around 89.482% and a fixed carbon content of 10,1% on average in dry basis.

The larger difference between straw and bagasse samples is noticed in ash content, since samples of CSS presented 11.185% of ash in dry basis against 2.076 and 1.6% in dry basis for BMA and BMB, respectively. The minor ash content of bagasse from milling B is due to the straw removing process by the sugarcane dry cleaning system before the juice extraction on milling B. Therefore, the CSS attendance can increase the ash content in biomass boiler and, consequently, implies in a larger content of inorganic elements, such as Fe, Si, Al, Ca and K, which causes heating losses in boilers due to slagging, fouling, as well corrosion problems.

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Nomenclature

e_s	opening of the upper sieve, mm)
e_i	opening of the sieve in which the particles are retained
x	mass fraction inside the sieves interval
d_p	average particle size related to one sieve
$\overline{\boldsymbol{d_p}}$	average particle size of the sample
D	specific mass, $kg.m^{-3}$
M_2	beaker mass with sample, kg
M_1	beaker mass, kg
V	beaker volume, m^3
wt%	percentage by weight
HHV	higher heating value, MJ/kg
DCR	dry cleaning system residue
BEN	National Energy Balance
EDS	energy dispersive x-ray detector

References

[1] BRASIL. Ministério de Minas e Energia. **Balanço Energético Nacional 2013**: Ano base 2012. Ministério de Minas e Energia - Empresa de Pesquisa Energética. Brasília, 2013. Available in: < https://ben.epe.gov.br/downloads/Relatorio_Final_BEN_2013.pdf.> Last access in March, 2013.

[2] FAO – Food and Agriculture Organization of the United Nations. **FAOSTAT – Sugar cane production. 2014**. Available in: http://faostat3.fao.org/home/index.html#SEARCH_ DATA. Last access in March, 2014.

[3] HASSUANI, S.; REGIS, M.; CARVALHO, I. **Biomass power generation: sugar cane bagasse and trash**. (Série Caminhos para Sustentabilidade). Piracicaba: PNUD-CTC, 2005. 217 p.

[4] LEAL, M.R.L.V.; GALDOS, M.V.; SCARPARE, F.V.; SEABRA, J.E.A.; WALTER, A.; OLIVEIRA, C.O.F. Sugarcane straw availability, quality, recovery and energy use: A literature review. **Biomass and Bioenergy**, v. 53, p. 11-19, 2013.

[5] WERTHER, J.; SAENGER, M.; HARTGE, E.U.; OGADA, T.; SIAGI, T. Combustion of agricultural residues. **Progress in Energy and Combustion Science**. v. 26, p. 1–27, 2000.

[6] BIZZO, W.A.; LENÇO, P.C.; CARVALHO, D.J.; VEIGA, J.P.S. The generation of residual biomass during the production of bio-ethanol from sugarcane, its characterization and its use in energy production. **Renewable and Sustainable Energy Revie**ws, v.29, p.589-603. 2014.

[7] CHÁVEZ RODRÍGUEZ, M. F. **Uso de água na produção de etanol de cana de açúcar.** Campinas, SP. 2010. 198 p. Master Tesis in Mechanical Engineer. Faculdade de Engenharia Mecânica. Universidade Estadual de Campinas, Campinas.

[8] Smith, J. W. Supercritical (Once Through) Boiler Technology, Babcock & Wilcox Company, 1998. Available in : http://www.babcockwilcox.com/pgg/tt/pdf/BR-1658.pdf. access in January, 2014.

[9] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D4749-87**: Standard test method for performing the sieve analysis of coal and designating coal size. West Conshohocken, 1987. 10p.

[10] SOSA ARNAO, J. H. **Caldeiras aquatubulares de bagaço – estudo do sistema de recuperação e energia**. Campinas, SP. 2007. 257 p. Tese (Doutorado em Engenharia Mecânica). Faculdade de Engenharia Mecânica. Universidade Estadual de Campinas, Campinas.

[11] Chrisostomo, Walbert **. Estudo da compactação de resíduos lignocelulósicos para utilização como combustível sólido**. Dissertação (mestrado). Universidade Federal de São Carlos, Campus Sorocaba. 67p. 2011.

[12] PELAEZ SAMANIEGO, M.R. **Uso de biocombustível da pirólise rápida da palha de cana em um motor de ciclo Otto**. 2007. 100 p. Dissertação (Mestrado em Engenharia Mecânica) - Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, Campinas, 2007.

[13] FOUST, A.; WENZEL, L. A.; CLUMP, C. W.; MAUS, L.; ANDERSON, L. B. **Principios das Operações Unitárias**. 2^a ed. Rio de Janeiro: Editora Guanabara Dois, 1982. 670 p.

[14] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM E873-82**: Standard test method for bulk density of densified particulate biomass fuel. West Conshohocken, 1982. 2p.

[15] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM D2015-00**: Standard test method for gross calorific value of coal and coke by adiabatic bomb calorimeter. West Conshohocken, 2000. 9p.

[16] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM E1755-01**: Standard test method for ash in biomass. West Conshohocken, 2001. 3p.

[17] AMERICAN SOCIETY FOR TESTING AND MATERIALS. **ASTM E872-82**: Standard test method for volatile matter in the analysis of particulate wood fuels. West Conshohocken, 1982. 3p.

[18] DEDAVID, B.E.; GOMES, C.I.; MACHADO, G. **Microscopia eletrônica de varredura**: aplicações e preparação de amostras: materiais poliméricos, metálicos e semicondutores. Porto Alegre: EDIPUCRS, 2007. 60p. Disponível em: http://www.pucrs.br/ edipucrs/online/ microscopia.pdf Acesso em: 15 Maio 2014.

[19] REIN, P. **Cane Sugar Engineering**. Verlag Dr. Albert Bartens KG: Berlin, 2007.

[20] FILIPPETTO, D. **Briquetagem de resíduos vegetais: viabilidade técnico-econômica e potencial de mercado**. Campinas, 2008. 61p. Dissertação (Mestrado em Engenharia Mecânica). Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, Campinas

[21] PROTÁSIO, T.P.; BUFALINO, L.; TONOLI, G.H.D.; GUIMARÃES, M.; TRUGILHO, P.F.; MENDES, L.M. Brazilian lignocellulosic for bioenergy production: characterization and comparison with fossil fuels. **BioResources**, v.8, n.1, p. 1166-1185, 2013.

[22] VIRMOND, E.; SENA, R.F.de; ALBRECHT, W.; ALTHOFF, C.A.; MOREIRA, R.F.P.M.; JOSÉ, H.J. Characterization of agroindustrial solid residues as biofuels and potential application in thermochemical processes. **Waste Management**, v. 32, p. 1952-1961, 2012.

[23] VAN LOO, S.; KOPPEJAN, J. **The handbook of biomass combustion and co-firing**. London: Earthscan, 2008. 442 p.