Biomass in an industrial boiler: characterizing and reducing waste from the burning process

Biomassa em uma caldeira industrial: caracterizando e reduzindo os resíduos do processo de queima

Biomasa en una caldera industrial: caracterización y reducción de residuos del proceso de quema

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Abstract
Ashes constitute a waste produced in the heat generation process from bioenergy. This study aimed to improve the biomass energy efficiency used in an industrial boiler. The physicochemical analysis was used to perform improvement in the quality of the biomass for solid fuel. Four biomass types (eucalyptus bark, wood chips, sawdust, and recycled wood waste) were analyzed. The material (ash) was collected every two months over one year. All samples were characterized regarding proximate analysis, chemical composition (macro and micronutrients), morphological characterization (via scanning electron microscopy [SEM] coupled with dispersive energy spectroscopy [EDS]), and particle size distribution. The four biomass types presented significant differences in moisture content and proximate analysis. The bark showed a high percentage of impurities with an ash content of 26.99%. It was possible to reduce the ash content of the biomass inserted into the boiler in half, by separating the bark in the granulometric strata and excluding the smallest particle size (<0.84 mm). The results regarding the ashes showed that chemical composition and physical attributes were similar in all samples over the year. The chemical components were the same, although they varied in quantity. It is possible to improve the biomass energetic performance by excluding the smallest particles prior to the boiler insertion.
Keywords: Solid fuel; Ash; Biomass waste; Bark.

Resumo
As cinzas constituem um resíduo produzido no processo de geração de calor a partir da bioenergia. Este estudo teve como objetivo melhorar a eficiência energética da biomassa utilizada em uma caldeira industrial. A análise físico-química foi utilizada para realizar melhoria na qualidade da biomassa para combustível sólido. Quatro tipos de biomassa (casca de eucalipto, cavacos de madeira, serragem e resíduos de madeira reciclada) foram analisados. O material (cinzas) foi coletado a cada dois meses ao longo de um ano. Todas as amostras foram caracterizadas quanto à análise

imediata, composição química (macro e micronutrientes), caracterização morfológica (via microscopia eletrônica de varredura [MEV] acoplada à espectroscopia de energia dispersiva [EDS]) e distribuição granulométrica. Os quatro tipos de biomassa apresentaram diferenças significativas no teor de umidade e na análise imediata. A casca de eucalipto apresentou alto percentual de impurezas com teor de cinzas de 26,99%. Foi possível reduzir pela metade o teor de cinzas da biomassa inserida na caldeira, separando a casca nos estratos granulométricos e excluindo o menor tamanho de partícula (<0,84 mm). Os resultados referentes às cinzas mostraram que a composição química e os atributos físicos foram semelhantes em todas as amostras ao longo do ano. Os componentes químicos eram os mesmos, embora variassem em quantidade. É possível melhorar o desempenho energético da biomassa excluindo as menores partículas antes da inserção da caldeira.
Palavras-chave: Combustível sólido; Cinzas; Resíduos de biomassa; Casca.

Resumen

Las cenizas constituyen un residuo producido en el proceso de generación de calor a partir de bioenergía. Este estudio tuvo como objetivo mejorar la eficiencia energética de la biomasa utilizada en una caldera industrial. Se utilizó el análisis fisicoquímico para mejorar la calidad de la biomasa para combustible sólido. Se analizaron cuatro tipos de biomasa (corteza de eucalipto, astillas de madera, aserrín y residuos de madera reciclada). El material (cenizas) se recolectó cada dos meses durante un año. Todas las muestras se caracterizaron para su análisis inmediato, composición química (macro y micronutrientes), caracterización morfológica (mediante microscopía electrónica de barrido [SEM] acoplada con espectroscopia de energía dispersiva [EDS]) y distribución del tamaño de partículas. Los cuatro tipos de biomasa mostraron diferencias significativas en contenido de humedad y análisis inmediato. La corteza presentó un alto porcentaje de impurezas con un contenido de cenizas del 26,99%. Fue posible reducir a la mitad el contenido de cenizas de la biomasa insertada en la caldera, separando la corteza en los estratos granulométricos y excluyendo el tamaño de partícula más pequeño (<0,84 mm). Los resultados para la ceniza mostraron que la composición química y los atributos físicos fueron similares en todas las muestras durante todo el año. Los componentes químicos eran los mismos, aunque variaban en cantidad. Es posible mejorar el rendimiento energético de la biomasa excluyendo las partículas más pequeñas antes de la inserción de la caldera.
Palabras clave: Combustible sólido; Ceniza, residuos de biomassa; Corteza.

1. Introduction

Power generation from renewable sources is currently used in the forestry sector in Brazil such as in paper and pulp industries, and in wood panel plants using waste from the production process which can be exploited as feedstock. This renewable material considered “CO_2 neutral” is a widely available alternative for energy supply (Liu, et al., 2019; Magdziarz, et al., 2016; Maj, et al., 2021). It is estimated that over 60% of the waste in forestry field industries is destined for burning in boilers adapted for biomass. This practice reduces the use of fossil fuels, generating energy for industries in the form of steam, hot air, or electricity through cogeneration. In doing so, it is feasible to reduce energy dependence on external sources and reduce costs (IBA, 2019; Mayer, et al., 2022).

Lignocellulosic biomass which can be used for energy generation may be broadly classified into the following categories: woody, herbaceous, aquatic, agroforestry, and waste. The forestry waste may vary from sawdust, bark, or other material which is not used in the production process. Each of these categories has distinct physicochemical characteristics, which may result in different thermal behaviors. More than one category is frequently used at the same time, which hinders the predictability of the process (Biswas, et al., 2017; Fermanelli, et al., 2020; Madanayake, et al., 2017).

The biomass material is directly combusted in the burning process in boilers, reaching temperatures of approximately 900 °C. All inserted material should ideally be transformed into energy. However, efficiency may not reach its full potential because the initial waste conditions are uncontrolled in terms of moisture or impurities. Another difficulty that can be encountered in this system is the generation of ash (bottom ash and fly ash), which consists of mineral materials that do not burn and accumulate in the boilers (Hansted, et al., 2018).

Ash accumulation in the internal structure of the boiler can be detrimental because it leads to thickening of the inner parts and, consequently, results in loss of energy efficiency. Thus, it is important to reduce the impurities present in the biomass before insertion into the boiler. This “cleaning” can be accomplished by mechanically separating the biomass by particle size (García, et al., 2014; Hansted, et al., 2018). In addition, the presence of some specific oxides with silicon or aluminum may change the slagging tendencies. High percentages of these oxides may result in less severe slagging issues. This fact highlights the need to investigate the variation in the biomass composition, in order to choose the material that results in less maintenance in the burning process (Yao, et al., 2020).

Even though the biomass goes through a cleaning process to reduce the ash content, a certain percentage of ash remains in the boilers (International Paper, 2015). The elemental composition of ash is not constant and depends on the biomass origin. The most common elements in ash are Si, Ca, Mg, Al, Pb, Cu, S, Mn, and Fe, among others. Identifying and quantifying the components related to the biomass origin are of fundamental importance in defining the final destination of ash (De Arruda, et al., 2016; Hu, et al., 2019).

In this sense, there are already some commercial applications for boiler ashes, such as in cement/concrete production, or hot asphalt mix in paving (Tahami, et al., 2018; Tamanna, et al., 2020). The ashes can also function in correcting soil acidity because ashes have a basic pH, and as an agricultural fertilizer, depending upon the presence and amount of micro and macronutrients (Cacuro & Waldman, 2015; Osaki & Darolt, 1991; Shi, et al., 2017; Simioni, et al., 2018). It is also important to verify the presence of heavy metals content, and the limits for their concentration according to the local guideline. In Brazil, the resolution CONAMA 420/2009 (Brasil, 2009) must be followed, and not only heavy metals but elemental components must be identified and measured to verify if they are within acceptable limits (Lanzerstorfer, 2017; Shi, et al., 2017).

This study aimed to characterize the biomass used in an industrial boiler of a company in the wood sector, to identify possibilities for optimizing energy resources. At the same time, investigate the physicochemical characteristics of the residue (ash) from the energy generation process over a year.

2. Methodology

2.1 Biomass sampling

The biomasses were collected from a wood panel plant in the city of Salto/SP - Brazil. The materials inserted in the boiler were: bark, sawdust, woodchips (*Eucalyptus urophylla* x *Eucalyptus grandis* at seven years old); and recycled wood material. The proportion of each material inserted into the boiler varies according to the availability of stock throughout the year. The bark is the material with the highest utilization percentage (> 50% of the biomass inserted in the boiler).

2.2 Biomass characterization

2.2.1 Moisture content

The moisture content was determined according to ASTM D4442 – 20 (ASTM: D4442-07, 2019). The biomasses were weighed on a semi-analytical scale and placed in an oven at 105 ± 2ºC. The weighing was carried out until the materials had a constant mass. The moisture content was calculated on a dry basis according to equation (1):

$$MC = \frac{(Ww - DW)}{Dw} * 100 \qquad (1)$$

Where: MC: moisture content (%); Ww: wet weight (g); Dw: Dry weight (g)

2.2.2 Particle size distribution

The bark, the woodchips, and the recycled material were inserted into a tap sieve shaker for 5 min in order to obtain the particle size distribution. The following sieve sizes (opening) were used: 50.80 mm, 25.40 mm, 12.70 mm, and 6.35 mm. The granulometric classification was based on the NBR NM 248/2003 (ABNT NBR NM: 248:2003, 2003) standard.

2.2.3 Proximate analysis and HHV

The biomasses were crushed in a Wiley mill and the proximate analysis was carried out. The ash content was determined according to ASTM D1102-84 (*Standard Test Method for Ash in Wood*, 1984) and the volatile matter according to the ABNT NBR 8112/86 standard. The fixed carbon content was calculated according to equation (2):

$$FC = 100 - (AC + VM) \qquad (2)$$

Where: FC = fixed carbon content (%); AC = ash content (%); and VM = volatile matter content (%)

The higher heating value (HHV) was obtained by using the IKA C200 calorimetric pump based on the standards of ASTM D240-19. Three replicates were performed.

2.3 Biomass energetic improvement

The bark is the material with the highest amount (4000 tons/month) generated in the wood panel plant. The company's internal regulation establishes that it must be used to its full potential. However, the bark presents the undesirable characteristic of high ash content. The ash reduces the heating value and increases the cost of boiler maintenance. Thus, the bark was subjected to particle size separation in order to reduce the ash content, resulting in three treatments: E1 (particles > 2 mm), E2 (from 0.84 to 2 mm), and E3 (particles < 0.84 mm). The ash content and HHV were then calculated for each treatment.

2.4 Ash sampling

The ashes were collected from an aquatubular boiler operating at 900 °C. The average ash amount generated was 250 t/ month.

Ash was randomly collected from a container in the yard of a wood panel company in the city of Salto-SP, Brazil. The ash samples were collected every two months over one year. A total of six samples were collected: C1; C2; C3; C4; C5 and C6. The purpose was to observe the effect of different biomass proportions on the ash characteristics.

2.5 Ash characterization

2.5.1 Proximate analysis

The proximate analysis of the material (ash) was determined. Although the boiler reaches a temperature of 900 °C for power generation, it was possible to notice charcoal-like particles, demonstrating incomplete burning during the process.

The ash content was determined according to the ASTM D1102-84. Material with a moisture content of 0% was inserted into the oven at a temperature of 600 °C for six hours. The material was subsequently weighed, and the ash content was calculated according to Equation 3.

$$AC(\%) = \left(\frac{\mathrm{Fw}}{\mathrm{Dw}}\right)x100 \qquad (3)$$

Where: AC= ash content (%); Dw: Dry weight (g), and Fw= final weight (g).

2.5.2 Chemical components

The chemical components analysis of the ash was conducted at the Soil Laboratory of the Sao Paulo State University, Botucatu Campus. The previously established components for the analysis were N, P, K, Ca, Mg, S, Na, B, Cu, Fe, Mn, Zn, TOC - Total Organic Carbon (Brasil, 2014), and pH according to ASTM D4972−18 (ASTM-D4972-18, 2018). The evaluation was performed on all samples collected during the year.

In addition to this analysis, samples were subjected to SEM (scanning electron microscopy) coupled with EDS (dispersive energy spectroscopy) to detect the presence of heavy metals, components that may make the biomass impractical to use because of the risk of soil contamination (He, et al., 2019; Maeda, et al., 2007; Shi, et al., 2017).

The ash was evaluated according to its particle size distribution. A particle shaker and sieves with sieve sizes (opening) of 12.7 mm, 2.0 mm, 0.84 mm, and 0.42 mm were used, respectively.

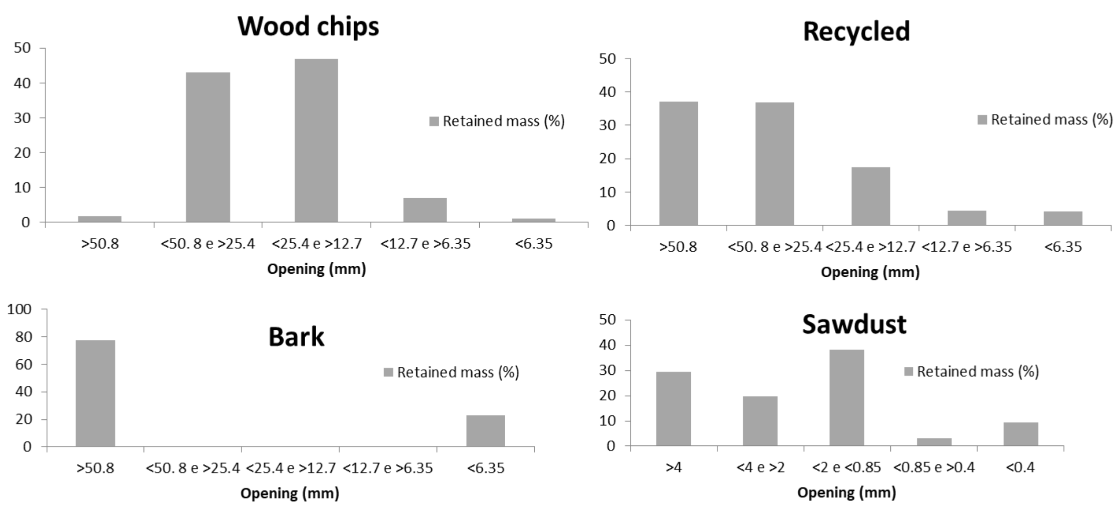
3. Results and Discussion

3.1 Biomass characterization

The bark in the studied company is dried in the open air, which is a slow drying process when compared to an artificial process, and there is no programmed wait for their use. The drying period varies according to biomass availability and use. This process occurs over the year. The other sources are not left in the open air for drying. The values found for moisture content on a dry basis were: 62% (chip), 73% (bark), 20% (recycled), and 4% (sawdust). However, a lower moisture content is indicated for better energy performance (Posom, et al., 2016). Several factors can decrease the heat production when the material is inserted for burning with significant moisture content (>25% d.b.). The need for biomass drying decreases energy efficiency because of heat loss in this process. The inversely proportional relationship between heat generation and moisture content is known (Furtado, et al., 2012; Lima, et al., 2008). Moist material can also generate overlapping combustion stages, which slows the combustion and induces a greater release of polluting gases (Maxwell, et al., 2020; Price-Allison, et al., 2019). Moisture also increases the impurity content adhering to the biomass, thus decreasing the organic material that participates in the burning (Hansted, et al., 2016; Rajput, et al., 2020).

Smaller dimensions regarding particle size can provide a higher rate of mass loss, which causes a decrease in the heat permanence in the system. On the other hand, the smallest particles heat up more evenly, increasing the thermal predictability of the process (Akhtar et al., 2012). Thus, it is necessary to define an intermediate size according to the behavior of the biomass in the place where it is used. The biomass distribution can be seen in Figure 1.

Figure. 1: Particle size distribution of the four types of biomasses inserted in the boiler.



Source: Authors.

In the case of the studied company, sawdust is used to regulate heat generation in the boilers, as it instantly increases the heating value. However, high amounts of this material can cause the heat to reflux into the equipment due to the presence of small particles, requiring correction in the dosage.

The differences regarding the proximate analysis of the biomasses can be observed in Table 1.

Table 1: Proximate analysis of the four types of biomasses inserted in the boiler.

	Contents (%)			
Material	Ashes	Volatile matters	Fixed carbon	HHV (J/g)
Chip	1.09 (±0.21)	81.56 (±0.36)	17.34 (±0.16)	11782 (±34)
Bark	26.99 (±0.24)	58.27 (±0.12)	14.73 (±0.25)	7964 (±94)
Recycled	2.24 (±0.10)	79.20 (±0.19)	18.55 (±0.28)	15984 (±133)
Sawdust	0.78 (±0.08)	80.32 (±0.64)	18.88 (±0.62)	18187 (±160)

Source: Authors.

For the ash content, there is a 34-fold increase in bark compared to sawdust. The ash content is the portion of the material formed by mineral materials such as aluminum, silica, and calcium which do not contribute to combustion (Thy, et al., 2009). When in high values (> 3%), the ash content may indicate contamination with dirt or sand. Vale (2002) studied several species and found differences of up to 18 times in the ash content between wood and bark of the same species. In this case, some kind of treatment is indicated, since the ashes can corrode structures and reduce the thermal capacity of equipment such as boilers (Pereira, et al., 2000). Even though the ashes of bark are high, the industry still burns this material to generate heat. This represents higher costs and maintenance steps in the production process.

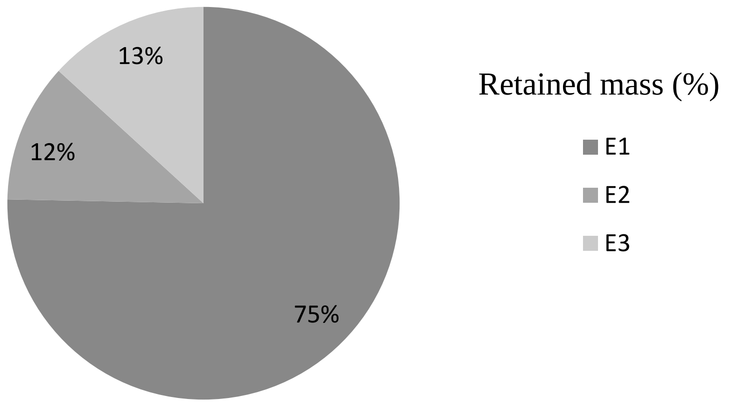
The volatile content indicates the portion of the material that should start combustion. It is the fraction released at the beginning of combustion and directly influences the thermal capacity of the material. Combustion can start at lower temperatures when volatile content is present in representative levels in biomass (Nogueira & Lora, 2003). The volatile content values for wood residues can vary depending on the origin of the material. Paula (2010) presented values of 78 to 83% for wood residues, while Souza (2012) presented values from 82 to 86%. Thus, it was possible to verify how the biomasses studied in this work are close to those described in the literature, highlighting the energetic potential of the analyzed materials. The residue formed by the bark showed relatively lower levels due to the high content of impurities, which increased the ash content.

The fixed carbon is the portion of the material that must remain on fire even after leaving all volatile, organic, and inorganic components. The fixed carbon is responsible for the slow-burning in the solid phase and maintains the heat for a longer period than the volatile content (Dashti, et al., 2019). It is expected that the value for forest residues will be between 10 and 30% for the fixed carbon content (Nogués, et al., 2010). The higher the fixed carbon content, the longer the material's combustion time, resulting in greater permanence in the firing devices (Dashti et al., 2019). All materials analyzed herein are in accordance with that described in the literature, however, the sawdust and the recycled material presented more suitable performance for energy purposes due to their different characteristics.

3.2 Biomass energy improvement

Granulometric separation was performed to establish in which part (stratum) the contaminants are predominant in the material (Fig. 2). It resulted in three classes E1 (particles > 2 mm), E2 (from 0.84 to 2 mm), and E3 (particles < 0.84 mm). It is possible to verify how the distribution of the material occurs according to the established granulometry. The *Eucalyptus* bark presents the highest percentage of material (75%) with particle sizes > 2 mm (Figure. 2).

Figure. 2: Distribution of *Eucalyptus* bark according to the selected sieves E1 (> 2 mm), E2 (<2 mm and> 0.84 mm) and E3 (<0.84 mm).



Source: Authors.

The calculation of the ash content for the strata showed that the smaller particle sizes (E3) retained the highest ash percentage (79.32%), and the HHV presented significant differences among the strata, as expected. (Table 2).

Table 2: Ash content and HHV for the established granulometric strata. Means followed by distinct letters differ significantly at 5% significance.

Strata	Ash content (%)	HHV (J/g)
E1	9.30 c (± 0.39)	16583 a (± 41.52)
E2	22.74 b (± 0.86)	14189 b (± 100.59)
E3	79.32 a (± 1.52)	3517 c (± 67.12)

Source: Authors.

It is possible to verify the possibility of excluding E3 by separating the mentioned granulometric strata so that the ash content of the material can be reduced. With the exclusion of this stratum, the previous ash content of 26.99% would be reduced to 9.48%. This difference represents a significant impact on the heat generation provided by the bark, previously 7964 J/g (Table 1), possibly doubling the heat generation according to Table 2. According to Chen et al. (Chen, et al., 2015), heat generation increases and the equipment abrasion decreases with a reduction in ash content, as verified in this study.

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3.3 Ash characterization

Analysis of ash content resulted in relatively homogeneous data. According to the Tukey test, a significant statistical difference between the C3 and C4 samples was verified with a 5% significance level (Table 3).

Table 3: Ash content (means) and chemical components of the boiler samples. Means followed by different letters differ statistically at a 5% significance level.

Components		Samples					
		C1	C2	C3	C4	C5	C6
Ash content		97.93 ab	95.37 ab	94.87 b	98.46 a	97.26 ab	96.09 ab
N	%	0.06	0.10	0.10	0.59	0.32	0.10
P_2O_5	%	0.42	0.52	0.35	0.56	0.51	0.27
K_2O	%	1.06	1.11	1.08	0.93	1.02	0.65
Ca	%	4.90	4.05	4.72	4.28	4.25	3.62
Mg	%	0.86	1.07	0.93	1.02	1.00	0.74
S	%	0.13	0.23	0.11	0.23	0.21	0.06
TOC*	mg.kg^{-1}	2	1	1	1	1	1
Na	mg.kg^{-1}	3900	4220	3218	3600	3750	4199
Cu	mg.kg^{-1}	66	82	70	72	70	120
Fe	mg.kg^{-1}	10750	15500	11445	18900	13550	13492
Mn	mg.kg^{-1}	1444	1656	1351	916	1100	757
Zn	mg.kg^{-1}	202	358	96	166	105	195
pH		12.4	12.5	12.0	12.3	12.0	12.2

*TOC: Total Organic Carbon. Source: Authors.

The difference in ash content between C3 (94.87%) and C4 (98.46%) may be explained by the fluctuation in the content of unburned material within the boiler. It can occur due to operational factors or because of the condition of the material inserted for combustion. Regarding operational issues, it was reported that the material did not always remain for the maximum period inside the boiler because of a decrease in boiler temperature and consequently in the heat supply. This occurs because of the reduction in the energy production rate; thus, it is necessary to insert more material into the boiler, preventing the total burning of the initially inserted biomass. Regarding the initial conditions of the material, it was reported and verified (item 3.1) that the biomass is inserted with high moisture content (>25% d.b.) and with significant impurities (26.99%).

The analysis of the chemical components of the ash enabled identifying metals and oxides already described in the literature. Caustic alkalis and oxides of Ca, Mg, K, and P are directly related to an increase in pH (Guo, et al., 2020; Wons, et al., 2018). Thus, the material with these components had several potential uses such as in changing low pH characteristics for acidic soil improvement (Shi, et al., 2016). Quantifying these components will enable adjusting calculations for the acidic soil.

Ash components are already allowed for use in some places to improve soil characteristics, either to neutralize or fertilize it. Legislation and guidelines may vary according to countries or regions. Some countries limit the amount it can be used each time the ash is applied, and some countries limit the total use for a specific area (CCME, 2021; Maresca, et al., 2018). The

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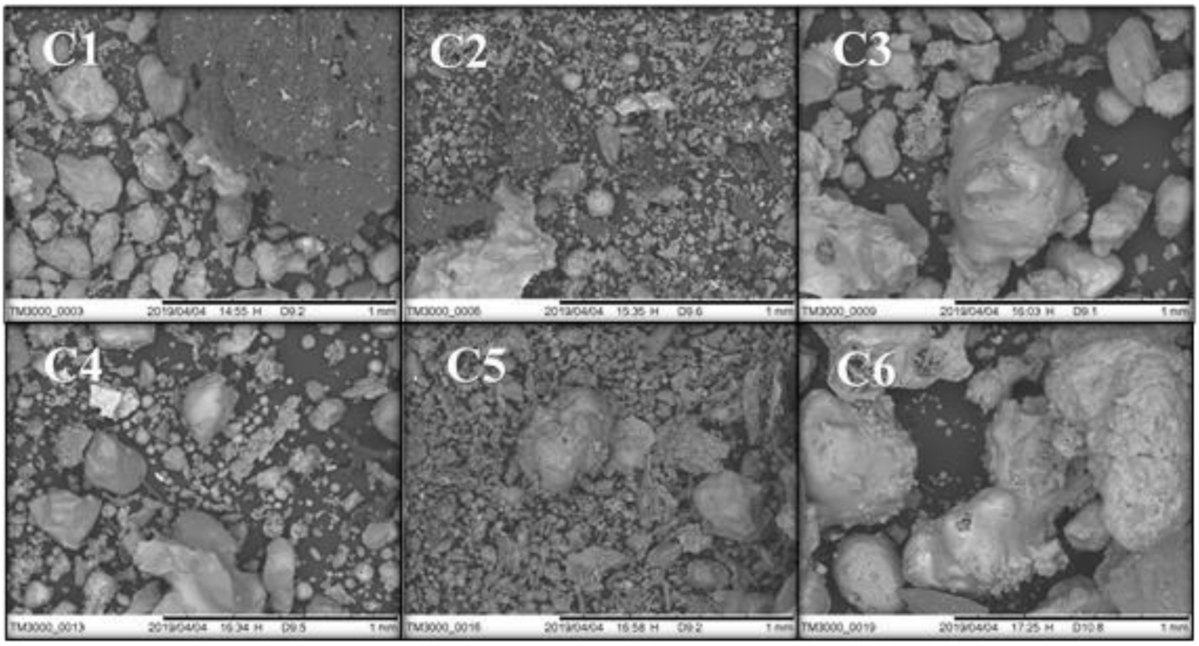
slow release of the nutrients into the soil is a common effect of ash application and constitutes a beneficial characteristic because it can improve organism and plant development (Kataki, et al., 2017; Liang, et al., 2020).

Another relevant factor in chemically evaluating ash regarding prior energy production is the relationship between components and melting characteristics. It is possible to predict how the boiler incrustation and corrosion will occur. Some elements have already been identified as problematic in this respect, such as alkali metals (e.g., Na, K). Their presence can result in significant corrosion at low combustion temperatures in the range of 500–550 °C (Fernández, et al., 2019; Nunes, et al., 2016; Pio, et al., 2020). This represents the lowest melting point temperatures and can result in boiler deposition processes, harming the energy performance of the process (Magdziarz, et al., 2018).

The results obtained in SEM and EDS can be considered complementary to the analysis of chemical components. Images obtained with 100x and 120x magnification are shown in Figures 3 and 4, respectively.

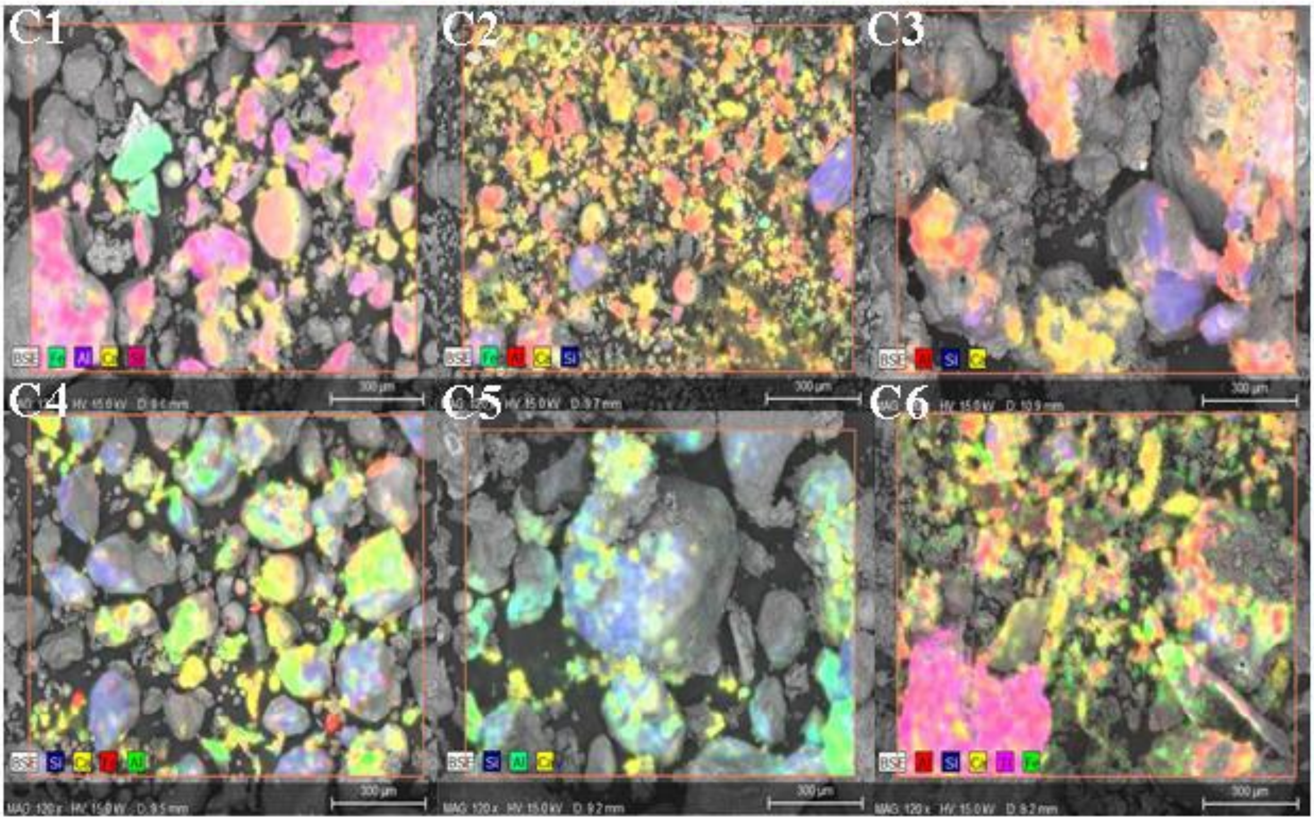
Figure. 3: Images of the structures of the six boiler ash samples were obtained from the scanning electron microscope (SEM) at 100x magnification.



Source: Authors.

The analysis performed in the SEM allowed the visualization of the heterogeneous structures of ash samples. It was possible to identify the different forms of the components. The structures found in the material were analyzed using dispersive energy spectroscopy (EDS) and the results were consistent with the results of chemical analysis. Fe, Ca, Si, and Al were identified in all samples, as shown in Figure 4.

Figure. 4: Images of particles in the boiler ash sample were obtained under 120x magnification during dispersive energy spectroscopy (EDS), and identification of the components by different colors.

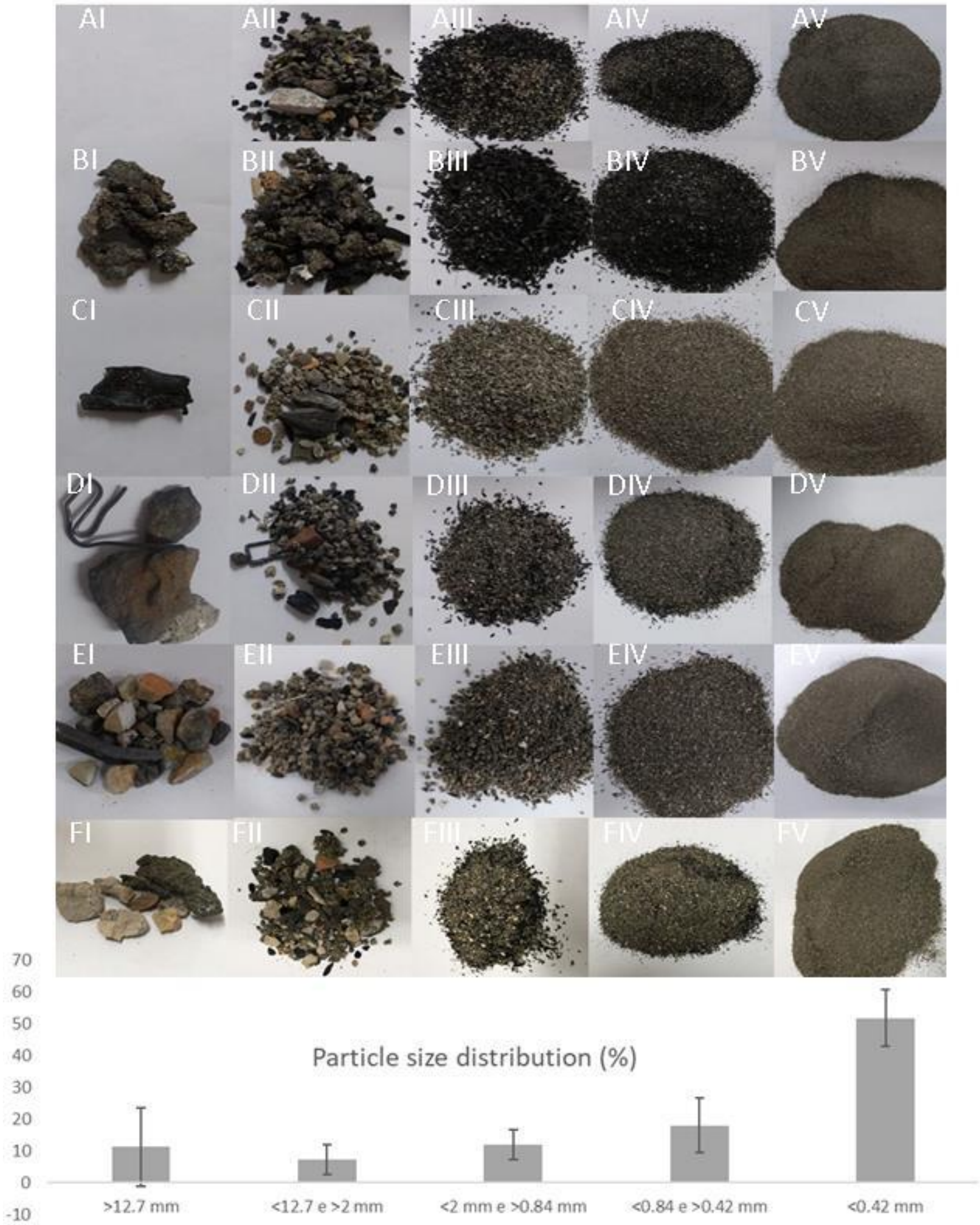


Source: Authors.

Although some metals were identified in the ash samples, there are no reference values for these components' application in Brazil since they are naturally found in tropical soils in high concentrations (SBCS, 2013).

The average particle size distribution for the ashes indicated a particle distribution pattern (Figure 5).

Figure. 5: Images of all samples after segregation based on particle size: (1) >12.7 mm; (2) >12.7 mm and <2 mm; (3) <2 mm and >0.84 mm; (4) <0.84 mm and >0.42 mm; (5) <0.42 mm. Where: A: C1, B: C2, C: C3, D: C4, E: C5, and F: C6.



Source: Authors.

The averages presented similar values among samples. The burning process influenced the size of the generated particles. Because all samples were residues from the same boiler (same temperature and burning time), it was expected there would be no distinct differences in this regard. Particle size is an important indicator depending on the end-use of the material. For example, it is necessary to analyze this aspect when analyzing soil because it influences the surface flow and water passage to the inner layers of the soil (He, et al., 2019; Kataki, et al., 2017). According to the current classification, soil texture should be the relative proportion of size classes: sand 0.05 to 2 mm; silt 0.002 to 0.05 mm, and clay <0.002 mm (EMBRAPA, 1979). The smaller the particle size, the greater the water retention in the soil. Ash was classified with 12.7 mm, 2 mm, 0.84 mm, and

0.4 mm sieves as a function of particle size. Based on these characteristics, it was possible to determine that the ash would allow soil water drainage.

It was possible to determine biomass that had not been completely burned (darker, charcoal-like particles) in some particle-size strata (AIII, AIV, BIII, BIV, FIII). Such components are explained by the ash content (below 100%) and by the TOC content in Table 3. Metal segments are exposed for the larger particle size strata (DI and EI), which are explained by the presence of Fe and Al (aluminum) in the samples, as determined by the chemical analysis of EDS in Figure 4. It was also possible to note the absence of any material for AI (>12.7 mm), and this can be explained by the cleaning process of the biomass prior to its use. This process should be conducted by the company to avoid bigger pieces in the boiler; however, maintenance was not provided to the extent needed. The greatest standard deviation in Figure 5 is explained by these unsuitable biomass sizes since the boilers were not frequently cleaned.

One way to avoid the use of ash made of differently-sized particles is to aggregate the material. Preparing granules or pellets may aid in the predictability of the effects. Even though this alternative appears to be a promising option, the manufacturing cost and machinery availability are limiting factors (Wang, et al., 2018; Zeng, et al., 2018). It is possible to determine a better use of this residue in developed countries because of the access to technologies and research incentives (Hall, 1997; Indiramma, et al., 2020).

4. Conclusion

The biomasses used in the boiler are heterogeneous. The bark, which constitutes the main biomass used by the company, showed low quality: high ash content (26.99%), and high moisture content (73%). The awareness of these parameters can assist in predicting the energy performance in the industry.

It was possible to verify that the bark inserted in the boiler had improvement potential. It was identified that the high ash content resulted in a lower HHV than the other materials, of 7964 J/g. With the separation into different particle sizes, it was identified that the smallest particle sizes (<0.84 mm) contain the highest ash content (79.32%). Excluding the smallest particle size, the ash content of the bark would be reduced to 9.48%.

The use of different sources and amounts of biomass in the boiler did not change the physicochemical characteristics of the ash. The ash particle size and chemical properties showed the possibility of its use in soil, due to the presence of elements that are typically present in tropical soils, with the advantage of the possibility to correct the soil acidity, as a result of its high pH and presence of Ca and Mg. Notably, heavy metals were not detected in any analysis performed, therefore constituting a factor that can expand the possible uses.

All these findings provide valuable information and promote the advancement of future research in this field. It is important to keep track and monitor potential ash suppliers and promote field trials to verify the efficiency of the material.

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