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ENERGY DENSIFICATION OF SUGARCANE BAGASSE BRIQUETTE THROUGH OXIDATIVE TORREFACTION IN MINERAL LAYER

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Abstract. *With the increase in energy demand, renewable energies have gained more recognition, among them biomass is one of the promising sources. In Brazil, the use of sugarcane bagasse is part of the country's energy supply, being used even in the production of electricity, however, like all biomasses, they present difficulties in their implementation, however, there are pre-treatment methods such as torrefaction that can help with these challenges. Torrefaction itself presents challenges in its implementation due to its cost and complexity, so a new form of torrefaction is proposed, which eliminates the use of inert gas and reduces the complexity of the process. As a result, it was possible to observe that the process improved the calorific power of the samples along with the hydrophobicity, which aims to use this residue in better conditions, in addition, the mass yield showed a behavior inversely proportional to the processing temperature. The results obtained were favorable, but larger studies are still needed.*

Keywords: *Oxidative torrefaction, mineral layer, silica sand, sugarcane bagasse.*

1. INTRODUCTION

Energy demand is constantly growing as population increases, development and quality of life improve, according to a report by the international energy agency (IEA, 2022) 80% of this energy demand is met by fossil fuels, but with the new indications and objectives proposed in the (COP, 2015), seek to reduce this percentage. Due to this, renewable energies have gained much more relevance, among them biomass, which in data from (IEA, 2022) contributes 10% of this energy demand.

According to data from (FAO, 2022), the most significant crop of 2021 in Brazil with a production of approximately 716 million tons was sugarcane, which has the particularity of producing certain residues in its production, among them the case of sugarcane bagasse (SB), work by Khalil, et al. (2021), estimates that the production of SB is 300kg/Ton which gives an estimate of 215 million tons of SB produced.

With this SB production, it is necessary to have a continuous improvement in its use, and since biomass presents challenges in its implementation due to its natural properties (Da Silva, et al. 2018), one of the mechanisms to improve its use is torrefaction, a pre-treatment process where the material is generally heated in a range of 200 to 300 °C. With this, it sought to obtain a hydrophobic biomass, with greater calorific power, a higher energy density, among other characteristics (Filho, et al. 2023). Torrefaction is usually done in an inert condition, in which carrier gases such as nitrogen are injected, which presents a cost and complexity in industrial implementation.

Currently, the literature presents a promising method of torrefaction in an inert mineral medium, in which a significant improvement in the properties of the biomass is seen without the need for a carrier gas stream, since the mineral medium has the function of limiting the access of oxygen in the air to the sample inside a reactor, it also has advantages such as better heat distribution and disadvantages such as that the material used must be of a considerable size to be able to separate between the medium and the sample (Leontiev et al. 2019a).

In the literature, one can find some works on oxidative torrefaction in inert mineral media in which different variables are considered, such as layer heights, different mineral media, use of combustion inhibitors, among others. Leontiev, (2018a) for example, studied the oxidative torrefaction of briquettes using bentonite as a mineral medium. The authors point out that the effect of the height of the mineral layer is linked to the operating temperature, being greater with its increase. In the following study Leontiev et al. (2018b) evaluated the oxidative torrefaction of pine pellets considering not one mineral medium but two, in this case bentonite and microcalcite. In this work it is confirmed that the mass yield increases proportionally with the increase in the height of the mineral layer, however the energy yield decreases. In the following study Leontiev et al. (2019b) increased the number of mineral media and evaluated the oxidative torrefaction of pine pellets. The results focused on the behavior of the mineral medium showed that the amount of oxygen that can be accessed inside the reactor depends on the effective density of the material. In the last study by Leontiev et al. (2019b) mixed the mineral medium with an oxidation inhibitor and studied the oxidative torrefaction behavior of pine pellets in a mineral medium mixed with the inhibitor. The results showed that the use of the inhibitor increases the mass yield due to its inhibition of partial oxidation, however it decreases the increase in calorific value. After studies by Leontiev et al. We have Korshunov et al. (2020) who evaluated the combustible characteristics of Eucalyptus chips roasted in a layer of bentonite. According to the authors, fuel reactivity decreases with increasing torrefaction duration. Islamova et al. (2022) evaluated the torrefaction of sunflower seed coat in kaolin mineral medium. In the notes of the work, it is observed that the kaolin works as a mineral medium and that with the increase of the layer the mass yield increases.

Considering the drawbacks presented by the dry torrefaction process and the few biomasses analyzed, in this work, the torrefaction of SB briquettes was studied in this new type of torrefaction proposed in the literature, also, due to the lack of studies on the evaluation of mineral layer, silica sand was chosen to analyze its behavior. The studies were carried out under the following conditions, temperatures of 200 – 300 °C, with a residence time of 30 min and a height of 3 cm.

2. MATERIALS AND METHODS

2.1 Materials

At work, the biomass used was SB in briquettes (Figure 1a) and silica sand (Figure 1b)

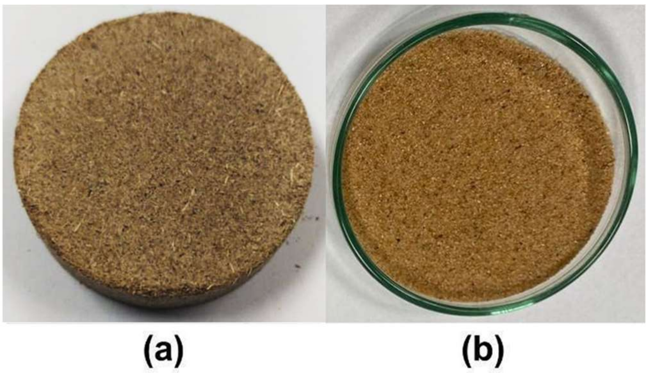

Figure 1. (a) SB briquettes; (b) Silica sand.

The SB underwent grinding, using a knife mill (Figure 2a) and finally sieving, which was carried out in an electromagnetic sieve shaker (Figure 2b). Then the briquetting process was carried out adopting a standard geometry (Ø 35 mm x 20 mm) approximate to homogenize the samples. Before torrefaction, the briquettes were dried in an oven at 105°C for 24 hours. Silica sand was selected as the inert material, which was sieved to uniform size between 250 and 500 μm. The silica sand residue was previously calcined in a muffle furnace at 600 °C for 4 h to reduce its impurities.

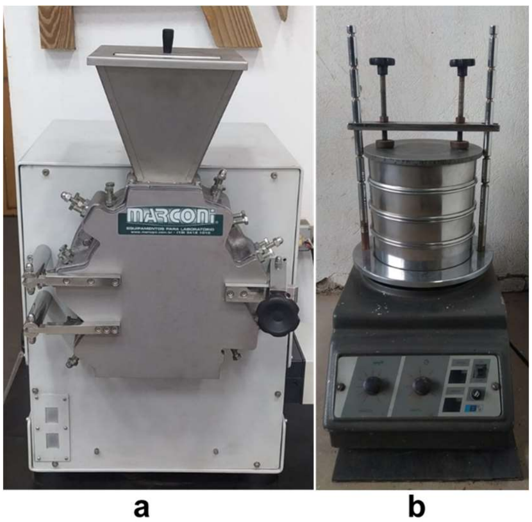

Figure 2. (a) Knife mill; (b) Vibrating sieve.

2.2 Experimental setup

Figure 3 shows the experimental bench used in this study, which is based on the work by Leontiev et al. (2018a). The experiments were carried out in a 3.72 kW muffle furnace connected to the environment through a tube. As a reactor, a 600ml Beaker was used, as shown in figure 3. Initially, the biomass sample was placed at the bottom of the Beaker. In the experimental tests, the effect of temperature was evaluated, varying from 200, 250 and 300°C, keeping the layer height fixed at 3 cm and the experiment time at 30 min. At the end of the oxidative torrefaction process, the reactor was cooled to a temperature below 150°C to remove the torrefied biomass, preventing its self-ignition.

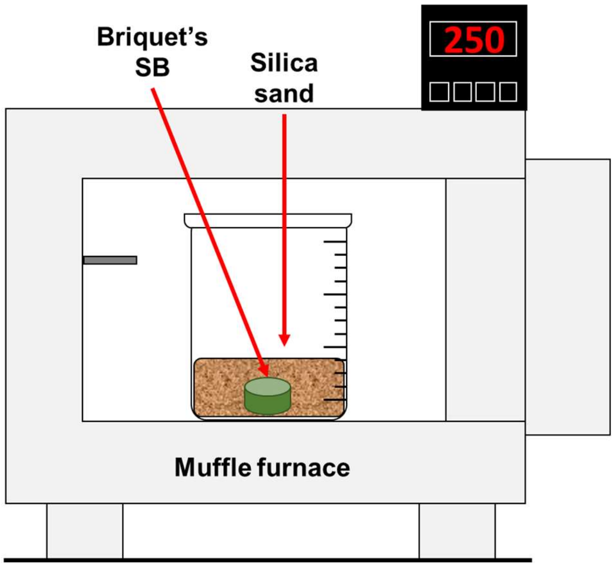

Figure 3. Experimental setup.

2.3 Characterization techniques

2.3.1. Proximate analysis – Volatile material (MV) and fixed carbon (FC) are two important indicators in solid fuels. The high MV content in a material provides a more reactive fuel along with a lower calorific value. At the same time, high FC material means the fuel is less reactive, but its calorific value is higher. (Kourshnov et al. 2020a).

2.3.2. Higher Heating Value - The higher heating value (HHV) was defined as the amount of heat released by the unit mass of the fuel once burned and the products returned to the initial temperature. (Leontiev, 2019b). The calorific value was calculated using the calorimeter IKA C5300.

2.4 Parameters of torrefaction

2.4.1 Mass yield - The solid product of the roast was analyzed. The mass yield of the biomass was determined and defined as the ratio between the final mass of the roasted product and the initial mass of the in natura biomass.

$$\%MY = \frac{final\ mass}{initial\ mass} * 100 \quad (1)$$

2.4.2 Energy yield - The energy yield is a relationship between the calorific value and the mass yield to determine the energy improvement of the material by the amount of mass:

$$\%EY = \frac{HHV\ torrefied * final\ mass}{HHV\ nature * initial\ mass} * 100 \quad (2)$$

2.4.3 Enhancement factor - One of the main motivations for carrying out a thermal pre-treatment of biomass is to improve its energy properties. The enhancement factor is a ratio between the calorific value of the roasted biomass and the in natura biomass:

$$\%EF = \frac{HHV\ torrefied}{HHV\ nature} * 100 \quad (3)$$

3. RESULTS AND DISCUSSION

The tests were carried out as indicated, with repetitions in duplicate and working as an arithmetic mean of the values obtained. In the evidenced results, one can see the difference in physical characteristics of the sugar cane bagasse briquettes, such as their color and texture (Figure 4).

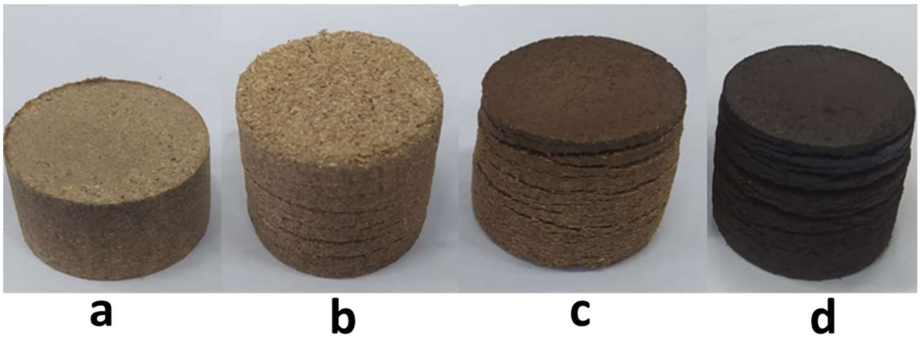

Figure 4. Briquettes before and after torrefaction: (a) In nature; (b) 200 °C; (c) 250 °C; (d) 300 °C.

After torrefaction, an increase in the size of the briquette and cracks in the outer texture can be observed, this is due in part to the release of volatile material during the torrefaction process, as well as a change in color, which indicates a higher concentration of carbon the higher the temperature.

Figure 5 presents the mass yield as a function of temperature, considering stable conditions of layer height and time. In the Figure 5 the highest temperature the mass yield decreases markedly, unlike the first section, this may be due to what Basu, 2018 pointed out, where it says that after 270 °C the torrefaction reaction becomes exothermic, making the decomposition of the SB greater.

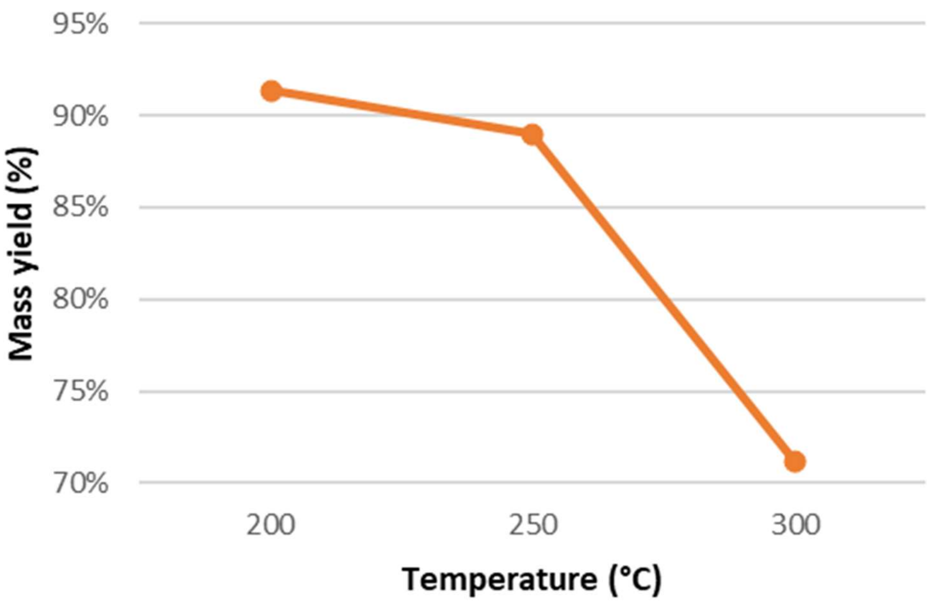

Figure 5. Mass yield vs Temperature.

Figure 6 shows the behavior of the enhancement factor as a function of temperature. In the Figure, it can be seen that the increase in temperature leads to an increase in the enhancement factor, the higher the temperature, the greater the increase, this is a behavior similar to that presented by Leontiev et al (2018b), where a greater release of volatiles leads to a higher concentration of carbon, which increases the calorific value.

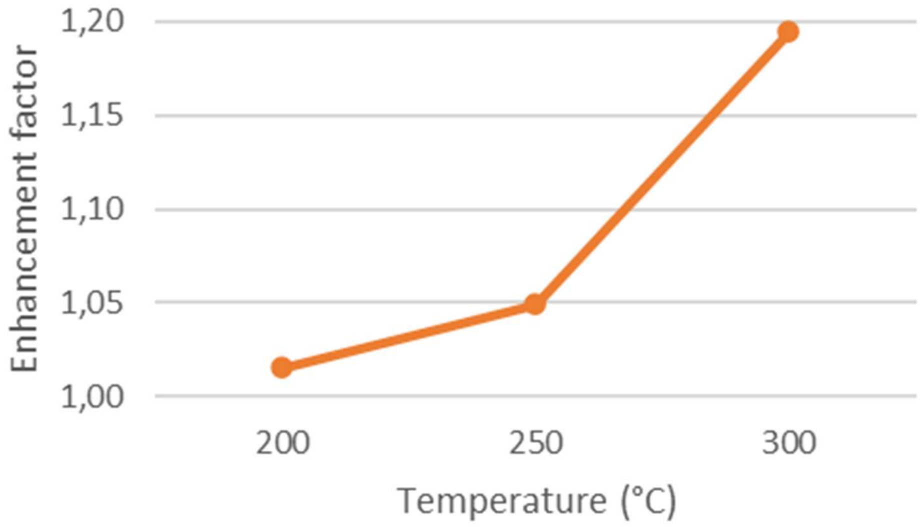

Figure 6. Enhancement factor vs Temperature.

Figure 7 shows the behavior of energy yield as a function of temperature. It can be seen that in the first section between 200 and 250 °C the energy yield increased, this shows that the increase in the enhancement factor compensated for the lost mass, however with a greater increase in temperature the mass loss is much more noticeable, making the increase in the enhancement factor not enough to continue increasing the energy yield, if not that it decreases noticeably.

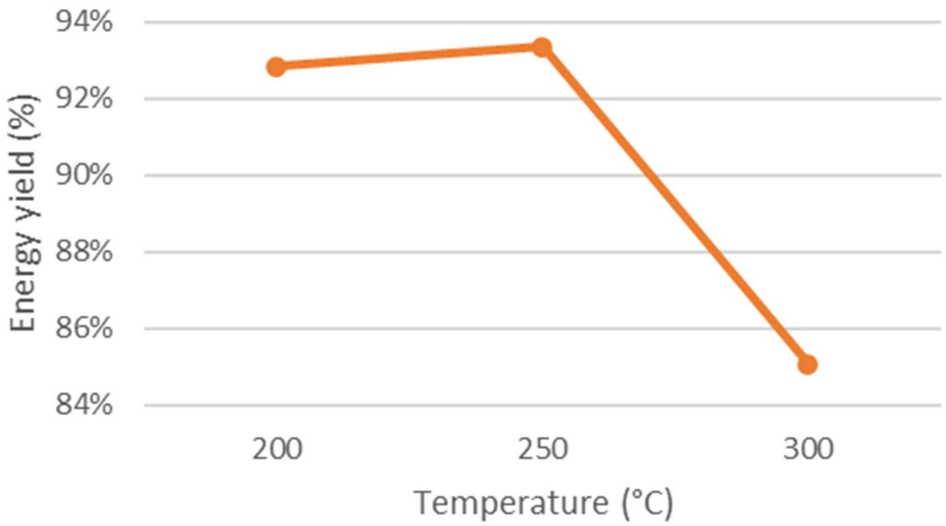

Figure 7. Energy yield vs Temperature.

GENT *et al.* 2017 proposes energetically sustainable limits for torrefaction parameters, minimum 70 for mass yield and 80 for energy yield, in the case of mineral layer torrefaction, these limits were not exceeded, which aims to ensure energy viability.

4. CONCLUSIONS

The results show a considerable mass and energy yield, which guarantees a good yield of the indicated method, since the literature recommends a mass yield above 70% and energy yield above 80%, however, further studies are needed to assess the sustainable behavior of this type of roasting, however, the starting point is favorable. In addition, it was confirmed that the sand works as an inert mineral medium and that the briquettes did not collapse and improved their energy properties.

It can be pointed out that the use of sand as an inert mineral medium has the potential to be used, since its behavior adapts to the yields that are expected in the process of oxidative torrefaction in inert mineral medium, in addition to being able to easily separate the briquette from the medium mineral. In the end, the use of torrefaction in a mineral layer with silica sand showed good behavior and can be applied as a biomass pre-treatment method.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Basu, P. Biomass gasification, pyrolysis and torrefaction: practical design and theory. 3. ed. Academic press, 2018.

Da Silva, C., Carneiro, A., Vital, B., Figueiró, C., Fialho, L., Magalhães, M., Carvalho, A., Cândido, W., 2018, Biomass torrefaction for energy purposes – Definitions and an overview of challenges and opportunities in Brazil. Renewable and Sustainable Energy Reviews, Vol. 82, pp. 2426–2432.

Dovichi, F.B., Lora, E.E., Palacio, J.C., Venturini, O.J., Jaén, R.L., 2023, An approach to technology selection in bioelectricity technical potential assessment: A Brazilian case study. Energy, Vol. 272, pp. 126995.

FOOD AND AGRICULTURE ORGANIZATIONS (FAO), 2020. Disponível em: https://www.fao.org/faostat/en/#data/QCL/visualize. Accessed 14 July 2023.

Gent, S., Twedt, M., Gerometta, C., Almberg, E., 2017, Torrefaction of Wood in a Quiescent Layer of Talc, Energy Fuels, Vol. 34, pp. 4660−4669.

IBA, 2021. “Relatório anual IBÁ” Instituto Brasileiro da Arvore. 7 Dec. 2021 https://iba.org/datafiles/publicacoes/relatorios/relatorioiba2021-compactado.pdf.

IEA, 2022, *World Energy Outlook 2022*, *Final Report*, https://iea.blob.core.windows.net/assets/830fe099-5530-48f2-a7c1-11f35d510983/WorldEnergyOutlook2022.pdf. Accessed 14 July 2023

Islamova, S.I., Ermolaev, D.V., Bulygina, K.S., 2021, Oxidative torrefaction of sunflower husk pellets in the kaolin layer. BioEnergy Research, pp. 1-10.

Khalil, M.J., Aslam, M., Ahmad, S., 2021, Utilization of sugarcane bagasse ash as cement replacement for the production of sustainable concrete–A review. Construction and Building Materials, Vol. 270, pp. 121371.

Korshunov, A., Kichatov, B., Sudakov, V., Kolobov, A., Gubernov, V., Kiverin, A., 2020b, Torrefaction of Wood in a Quiescent Layer of Talc, Energy Fuels, Vol. 34, pp. 4660−4669.

Leontiev, A., Kichatov, B., Korshunov, A., Gubernov, V., Kiverin, A., Medvetskaya, N., Melnikova, K., 2019a, The effect of an inhibitor on the torrefaction of pellets inside a quiescent layer of bentonite clay. Biomass and Bioenergy, Vol. 130, pp. 105381.

Leontiev, A., Kichatov, B., Korshunov, A., Kiverin, A., Medvetskaya, N., Melnikova, K., 2018a, Oxidative torrefaction of briquetted birch shavings in the bentonite. Energy, Vol. 165, pp. 303–313.

Leontiev, A., Kichatov, B., Korshunov, A., Kiverin, A., Zaichenko, V., Sytchev, G., Melnikova, K., 2018b, Oxidative torrefaction of pine pellets in the quiescent layer of mineral filler. Fuel Processing Technology, Vol. 182, pp. 113–122.

Leontiev, A., Kichatov, B., Korshunov, A., Melnikova, K., Yakovenko, I., Gubernov, V., 2019b, Torrefaction of biomass in a quiescent mineral layer: Influence of mineral filler type. Fuel, Vol. 255, pp. 115740.

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