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# EXPERIMENTAL STUDY OF OXIDATIVE TORREFACTION OF EUCALYPTUS WOOD CHIP USING A MINERAL LAYER OF SILICA SAND

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### **Abstract.**

*Due to the increase in energy demand in recent years, renewable energy sources have gained greater prominence, with biomass considered as the fourth source of renewable energy. In Brazil, a biomass of great importance is the wood chips generated by the industrial production of eucalyptus. Eucalyptus chips are mainly used as fuel in several industries, however, like other biomasses, they have some disadvantages such as low calorific value and high humidity. These disadvantages can be minimized by the torrefaction process. The literature has presented several options, one of which is oxidative dry torrefaction. Within oxidative torrefaction, there is a form where the biomass is immersed in a bed of inert material, however this form of torrefaction is still under study. In this work, sand-assisted oxidative torrefaction of eucalyptus chips is studied. The torrefaction temperature range was varied, in addition, variables such as time and height of the sand bed will be evaluated. The results obtained indicate that the yield of torrefied biomass is inversely proportional to temperature and time. Furthermore, the height of the sand bed has an influence on the yield and properties of the torrefied biomass. Sand-assisted oxidative torrefaction improves calorific value, reduces moisture content and increases hydrophobicity.*

**Keywords:** Oxidative torrefaction, mineral layer, silica sand, eucalyptus spp.

## 1. INTRODUCTION

Energy is one of the most important basic needs, currently most of this energy is supplied by the use of fossil fuels (coal, oil and natural gas), which are being depleted and their burning for energy production is one of the sources emissions of Greenhouse Gases (GHG). In order to satisfy the energy demand and reduce the impact of GHGs, it was decided to use biomass, which can be cultivated for energy purposes or can be residual biomass resulting from some industrial process, which can be considered almost carbon neutral sources for generating electricity. energy (Liu et al., 2021).

In Brazil, in 2020, the total area of trees planted totaled 9.55 million hectares. Among the tree species, 78% of the area is composed of eucalyptus cultivation, with 7.47 million hectares (IBÁ, 2021). From the production of wooden boards, 26% become chip, this significant amount of material is destined mainly for the generation of thermal energy (Vieira, 2003). But eucalyptus chips, like other biomasses, have difficulties in their use due to the inherent properties of the material, such as low specific mass, high moisture content, low calorific value, among others (Da Silva, et al. 2018). To improve these properties, an alternative could be the application of torrefaction as a pretreatment method in biomass.

Torrefaction is a thermochemical pre-treatment process, in which the biomass is heated in an inert environment, caused by the continuous injection of a carrier gas such as nitrogen, to ensure that the oxygen in the air does not react with the sample, preventing its oxidation. However, to promote an inert environment demands a consumption of carrier gas, which has a cost and directly influences the cost of the process. Recently, a new type of torrefaction is being studied, called oxidative torrefaction in inert mineral medium, which is of special interest due to its characteristics such as not needing a carrier gas and the heat generation in the process, resulting from the burning of the volatile material released during torrefaction (Leontiev et al. 2019a). The results obtained showed a good mass yield confirming the potential of this type of torrefaction.

The literature presents some works on oxidative torrefaction assisted by inert mineral medium, evaluating different materials and different process conditions. Leontiev, et al. (2018a) studied the oxidative torrefaction of birch briquettes considering a bentonite mineral medium. The authors point out that at temperatures below 260 °C the effect of the height of the mineral layer is not very significant, but above this value the increase in mass yield is remarkable. Leontiev et al. (2018b) evaluated the oxidative torrefaction of pine pellets considering bentonite and microcalcite as mineral medium. It is confirmed that the mass yield increases proportionally with the increase in the height of the mineral layer, however, the energy yield decreases. Leontiev et al. (2019b) evaluated the oxidative torrefaction of pine pellets considering different types of materials such as mineral medium (bentonite, calcite, talc and ash). The results showed that the amount of oxygen that can be accessed inside the reactor depends on the effective density of the type of material. Leontiev et al. (2019b) studied the behavior of oxidative torrefaction of pine pellets in a mineral medium mixed with sodium hydrocarbonate, which is an oxidation inhibitor. The results showed that the use of soda increases the mass yield, but greatly decreases the calorific value when compared to torrefaction without soda. Korshunov et al. (2019a) evaluated the pyrolysis characteristics of roasted pine pellets in a mineral layer with different variables. According to the authors, fuel reactivity decreases with increasing torrefaction duration.

The works reported in the literature use several types of inert materials, however, to our knowledge, no articles were found using silica sand. In addition, there are very few works on eucalyptus chip torrefaction and no article was found addressing its silica sand-assisted oxidative torrefaction. Thus, the objective of this work is to study the behavior of the oxidative torrefaction process assisted by silica sand from eucalyptus chips, aiming at its application in energy generation.

## 2. MATERIALS AND METHODS

### 2.1 Materials

In the study, the biomass used was eucalyptus spp. An approximate standard geometry (46 mm x 46 mm x 14 mm) was adopted to homogenize the samples (Figure 1a). Before torrefaction, the wood was dried in an oven at 105°C for 24 hours. Silica sand (Figure 1b) was selected as the inert material, which was sieved to uniform size between 250 – 500 µm. The silica sand was previously calcined residue in a muffle furnace at 600°C for 4h to reduce its impurities.

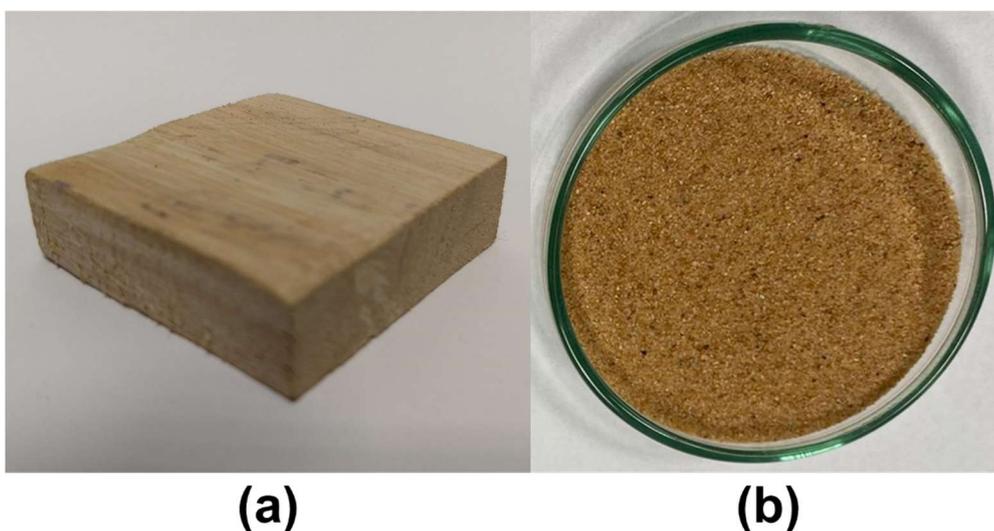


Figure 1. (a) Eucalyptus wood chip; (b) Silica sand.

### 2.2 Experimental setup

Figure 2 presents the experimental bench used in this study, which is based on the work of Leontiev et al. (2018a). The experiments were carried out in a 3.72 kW muffle furnace connected to the environment through a tube. A 600ml beaker was used as a reactor as shown in Figure 2. Initially, a 10mm layer of sand was set up, where the biomass sample was placed. In the experimental tests, the effect of the height of the sand layer with the beaker at 50 and 100% of its volume, at a temperature of 200 and 300°C and the torrefaction time of 30 and 60 min, were evaluated. At the end of the oxidative torrefaction process, the reactor was cooled to a temperature below 150°C to remove the torrefied biomass.

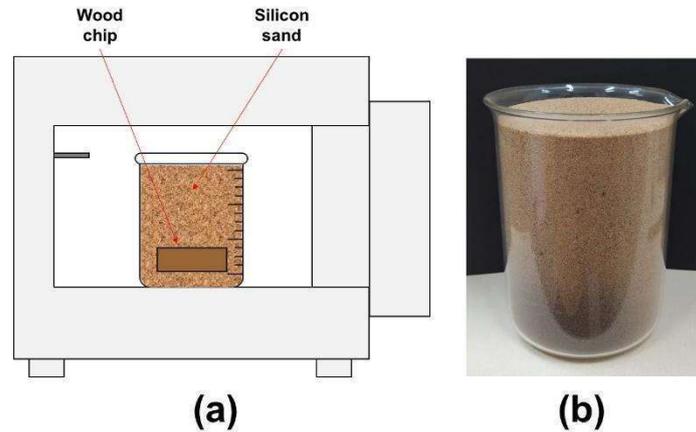


Figure 2. (a) Experimental setup; (b) Torrefaction's reactor.

### 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.

$$\%RM = \frac{\text{final mass}}{\text{initial mass}} * 100 \quad (\text{Ec. 1})$$

**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:

$$\%RE = \frac{HHV \text{ torrefied} * \text{final mass}}{HHV \text{ natura} * \text{initial mass}} * 100 \quad (\text{Ec. 2})$$

**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 improvement factor is a ratio between the calorific value of the roasted biomass and the in natura biomass:

$$\%FM = \frac{HHV \text{ torrefied}}{HHV \text{ natura}} * 100 \quad (\text{Ec. 3})$$

## 3 RESULTS AND DISCUSSION

The tests were carried out as indicated, with repetitions in duplicate and the arithmetic mean of the values obtained was used. In the evidenced results, one can look at the difference in physical characteristics of the chips, such as their color and texture (Figure 3), in addition, a close analysis test was carried out to determine the values of fixed, volatile carbon and water contained in the torrefied material.

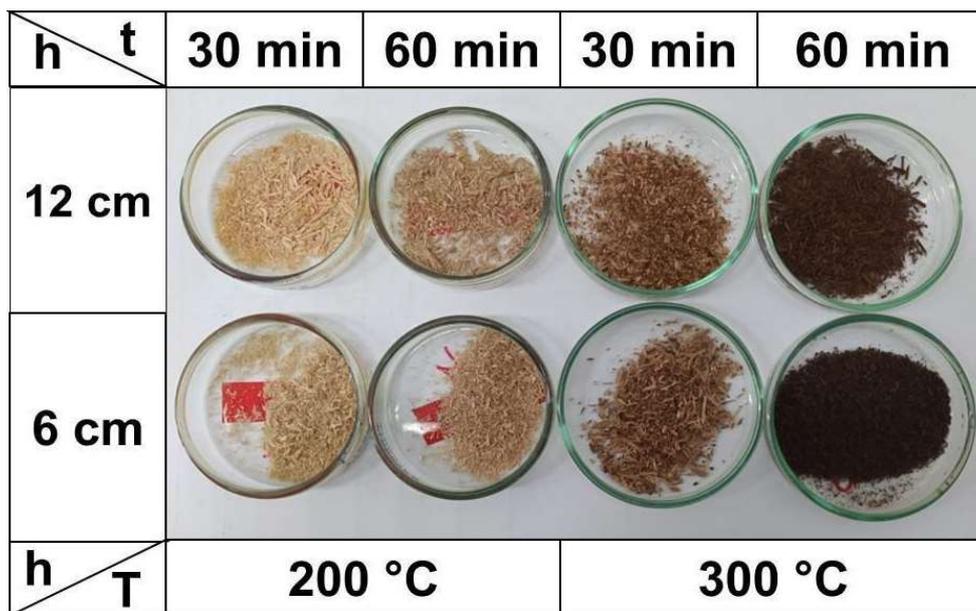


Figure 3. Torrefied eucalyptus wood chips in different conditions.

Figure 4 shows the mass yield as a function of the height of inert material, considering two torrefaction temperatures. The blue line and orange line represent torrefaction at 200 and 300°C. In the Figure it can be seen that at the highest torrefaction temperature (300°C) the height of the silica sand mineral layer has a greater influence, resulting in an increase in mass yield. However, at the lowest torrefaction temperature (200°C), the height of the mineral layer does not have a significant influence. This behavior is possibly related to the effective diffusion of air in the mineral layer as pointed out by Leontiev et al. (2019a), where the height of the mineral layer makes it difficult for air to flow into the environment to reach the sample, at low temperatures the reactivity of oxygen is not very high, but as the temperature increases, the reactivity of oxygen increases, making it easier for the gas to diffuse into the sample. mineral medium. It is also observed that with increasing temperature the mass yield decreases.

This is a common behavior in the process, whether oxidative or not, since temperature is one of the variables with the greatest influence on torrefaction due to the thermal decomposition of the biomass structure. Furthermore, it appears that as the residence time increases, the mass yield decreases. This may be due to the fact that, as the residence time increases, the time that heat is transported through the mineral medium to reach the temperature differential between the outside and inside of the reactor increases.

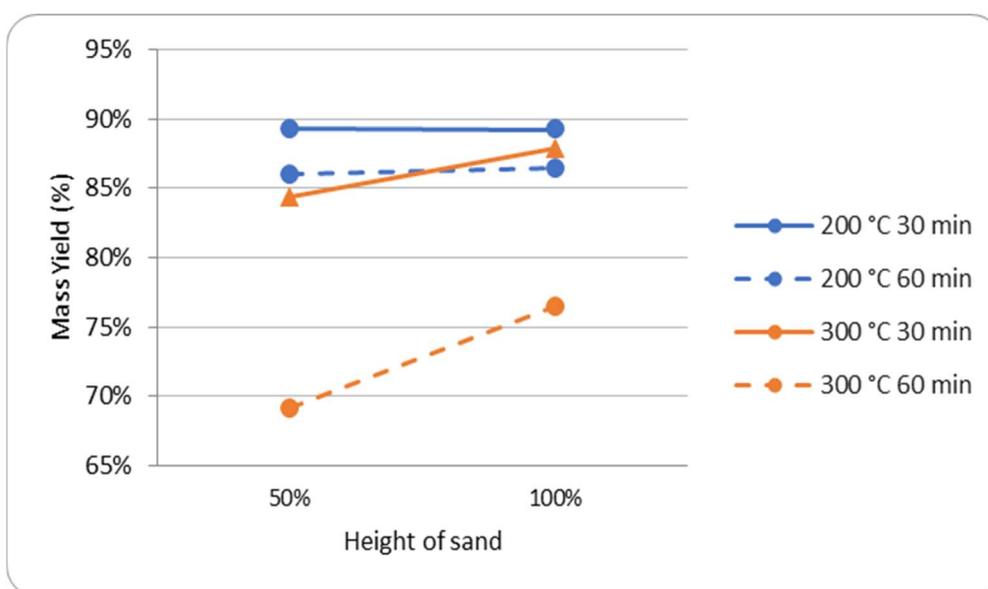


Figure 4. Mass yield vs Height of sand.

Figure 5 shows the behavior of energy efficiency as a function of the height of inert material. The blue line and orange line represent torrefaction at 200 and 300°C. In the Figure it can be seen that the increase in the height of the mineral layer results in an increase in energy efficiency, this can be shown by Leontiev et al. (2019b). Where it shows that with the increase of the effective density, the energy efficiency increases, in addition, it says that the increase of time favors the decrease of the energy efficiency since this is associated with the amount of mass lost.

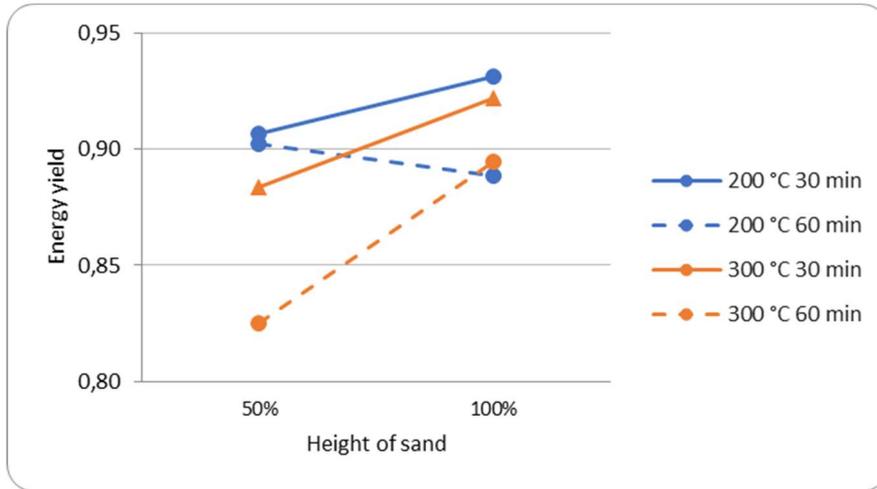


Figure 5. Energy yield vs Height of sand.

Figure 6 shows the behavior of the improvement factor as a function of the height of inert material. The blue line and orange line represent torrefaction at 200 and 300°C. The results obtained a value similar to the work presented by Leontiev et al. (2018b) where  $\text{CaCO}_3$  was used under the same conditions. In the Figure, it can be seen that the increase in the height of the mineral layer results in a decrease in the improvement factor, a behavior that follows that pointed out by Leontiev et al. (2019a). Since, with the increase in inert material, both heat transfer and oxygen access to the sample were difficult, making decomposition more difficult. On the other hand, with increasing temperature, a greater improvement factor is observed when compared to low temperatures.

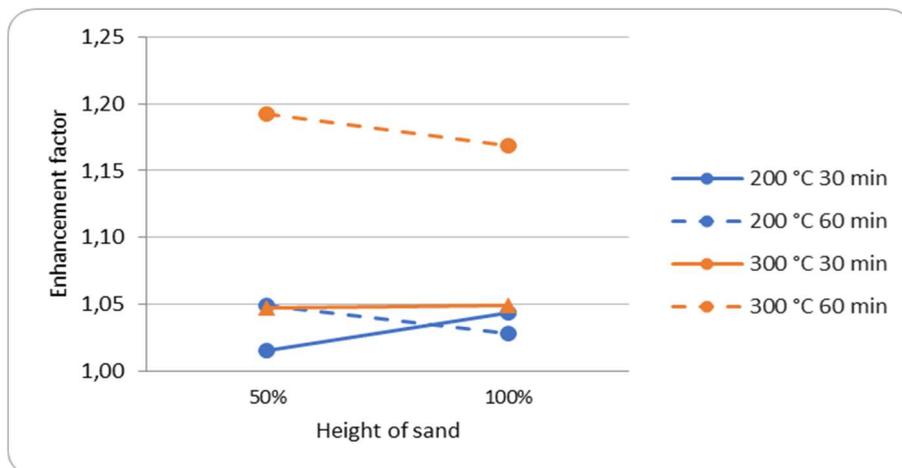


Figure 6. Enhancement Factor vs Height of sand.

#### 4 CONCLUSIONS

The results show a considerable mass yield which guarantees a good yield of the indicated method; however, it was observed that the mineral layer can help in the process to improve the yields at high temperatures optimizing the torrefaction. In addition, it was confirmed that the sand maintains the behavior registered by the method presented in the literature, such as that with increasing temperature or time, the mass yield decreases and the calorific value increases, that the influence of the mineral layer has a greater effect the greater is the temperature. 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 expected yields in the oxidative torrefaction process in an inert mineral medium.

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