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EXPERIMENTAL STUDY ON TORREFACTION OF *Eucalyptus* spp. SAWDUST

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Abstract. *The world's energy demand is constantly increasing, with almost 85% of energy demand being supplied by the combustion of fossil fuels such as coal, oil and natural gas. The constant use of these fossil fuels has led to the emission of large quantities of greenhouse gases (GHG) to the atmosphere. Biomass is the fourth energy source in the world, its use through the combustion process for power generation presents several challenges due to its irregular geometry, high moisture content and volatile material, low calorific power and high alkaline composition, in addition, their availability and the problems of operation (transportation and storage). In this sense, torrefaction appears as a biomass pretreatment technology. Torrefaction causes a significant increase in calorific power, expressive reduction of moisture content and increase of the apparent density. Among the biomass that has the potential for energy generation are agroindustrial and forest residues. Brazil residues derived from the production of eucalyptus have potential for energy generation. Despite the work involving the use of residues derived from eucalyptus production, there are scarce studies on torrefaction of *Eucalyptus* spp. sawdust. The results show an increase in energy yield of torrefied eucalyptus spp. sawdust.*

Keywords: *Energy, Torrefaction, Eucalyptus spp., sawdust.*

1. INTRODUCTION

The world's energy demand is constantly increasing, with almost 85% of energy demand being supplied by the combustion of fossil fuels such as coal, oil and natural gas, but, the constant use of these fuels leads to the emission of large quantities of greenhouse gases (GHG) to the atmosphere (Abbasi and Yozgatilgil 2014; Saidur et al., 2011). Of the total GHG emitted, 3/4 corresponds to carbon dioxide (CO₂), which is the main anthropogenic emission responsible for global warming (Huaman and Jun 2014; Lin et al., 2011). According to the Intergovernmental Panel on Climate Change (IPCC, 2013), there is a significant correlation between rising GHGs and global warming.

To meet the high energy demand aiming at reducing GHG emissions, especially CO₂, several alternatives were proposed, among them the use of biomass. Biomass is the fourth energy source in the world, its use through the combustion process for power generation presents several challenges due to its irregular geometry, high moisture content and volatile material, low calorific power and high alkaline composition, in addition, their availability and the problems of operation (transportation and storage) (Tran et al., 2015; Riiza et al., 2014; Saidur et al., 2011).

In this sense, torrefaction appears as a biomass pretreatment technology. Torrefaction is the thermal process where the biomass is heated in an inert atmosphere in a temperature range between 200°C and 300°C. Torrefaction causes a significant increase in calorific power, expressive reduction of moisture content and increase of the apparent density (Bonassa et al., 2018; Da Silva et al., 2018; Gent et al., 2017; Proskurina et al., 2017; Chen et al., 2015). Thus, the generation of energy from wood biomass is relevant due to the better utilization of biomass.

Among the biomass that has the potential for energy generation are agroindustrial and forest residues. According to Oliveira et al., (2013), in Brazil residues derived from the production of *eucalyptus* have potential for energy generation. In 2010, Brazilian production of legalized wood increased by 8.26% in relation to 2009, reaching a production of over 115 million m³, with most of the production concentrated in the South and Southeast. Residues derived from *eucalyptus* production in Brazil have an energy potential of approximately 140 PJ (1015 Joules). With the South and Southeast of Brazil being able to produce 60.5 and 50.2 respectively. The literature presents a significant amount on torrefaction of several biomasses, however, there are still few works related to torrefaction of *eucalyptus* residues.

Arteaga-Perez et al., (2015) performed analyzes to identify the most appropriate temperature for the torrefaction of two eucalyptus species (*globulus* and *nitens*), based on the chemical composition of the volatile material released during the process. Araujo et al. (2016) investigated the characteristics of briquettes made from eucalyptus (*eucalyptus grandis* and *eucalyptus* spp) after undergoing a torrefaction process using different temperatures and compaction pressures to produce briquettes. Doddapaneni et al., (2016) studied the effect of torrefaction on the kinetics, reaction mechanism and heat flux during the pyrolysis of biomass making a comparative analysis between the pyrolysis of dry and torrid eucalyptus. Pereira et al. (2016) developed a study to evaluate the effect of torrefaction temperature on the properties of eucalyptus chips. Pinto et al. (2017) studied the effect torrefied eucalyptus *globulus* stumps on the performance of gasification, productivity, and quality of synthesis gas.

Despite the work involving the use of residues derived from eucalyptus production, there are scarce studies on torrefaction of *Eucalyptus* spp. sawdust.

2. MATERIALS AND METHODS

2.1 Materials

Figure 1 shows a sample of *Eucalyptus* spp. sawdust. For the experimental test a particle size of range 250 - 500µm was used. The compositional analysis was realized in order to determine the composition of hemicellulose, cellulose, and lignin based on TAPPI standard.



Figure 1. *Eucalyptus* spp. sawdust.

2.2 Experimental setup

Figure 2 shows the experimental setup used for the test. The energy required for torrefaction is provided by a muffle oven. A stream of nitrogen gas was used to create an inert atmosphere inside the reactor and promote the output of the volatile material. A condenser with cold water was used to condense part of the volatile material. Mass (MY) and Energy (EY) yield were calculated according to the expressions (Eqs. (1) and (2), all terms in dry basis):

$$MY = \frac{\text{Weight of torrefied biomass}}{\text{Weight of raw biomass}} * 100 \quad (1)$$

$$EY = MY * \frac{HHV \text{ torrefied biomass}}{HHV \text{ raw biomass}} \quad (2)$$

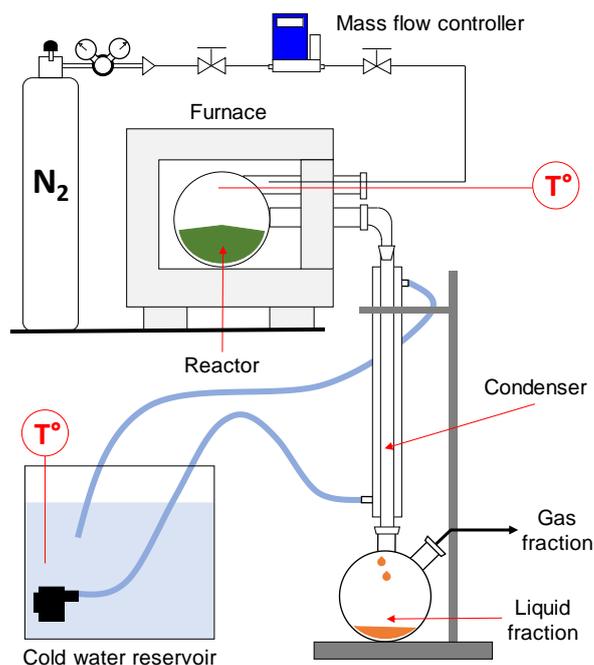


Figure 2. Experimental setup of torrefaction.

2.3 Characterization techniques

In this section is showed the techniques used for characterization. TGA analysis was performed by TA Instruments (SDT Q600) in order to determine the proximal analysis. HHV was determined using a Calorimeter IKA C500. All tests are performed in duplicate using a mass of (0.5 ± 0.05) g.

3. RESULTS AND DISCUSSION

3.1 Chemical characterization of *Eucalyptus* spp.

Table 1 shows the chemical composition of *Eucalyptus* spp. The present study sought to use eucalyptus sawdust from small and medium-size sawmills in the Itapeva region, south of the state of São Paulo, as it is a region with large volume of wood and one of the forest poles of the state. To use sawdust is a big challenge, as this type of company usually does not have quality control for the raw material that enters the industry, so the chemical analysis of eucalyptus to be used in the study is vitally important to try to predict what the thermal degradation will be like during the torrefaction process.

It can be seen from the results on Table 1, eucalyptus has a high lignin content, typical hardwood indexes, which is desired when it comes to energy, because its amorphous macromolecule is composed of aromatic compounds, with phenyl propane units, and because it is produced in the middle lamella and secondary wall during the maturation process, it incorporates into the last wall component, interpenetrating the fibrils, stiffening the cell wall. According to Pereira et al. (2016) torrefaction process changes the concentration of chemical constituents of wood, where hemicellulose and cellulose degradation occurs before lignin, although it starts first, its macromolecule undergoes a slower thermal degradation due to of its constitution.

Table 1: Chemical composition of *Eucalyptus* spp.

Parameter	% mass
Holocellulose	63,55
Klason Lignin	27,66
Soluble lignin	4,78
Total lignin	32,44
Total extractives	2,97

3.2 Thermal analysis of *Eucalyptus* spp.

Figure 3 shows the thermal analysis of *Eucalyptus* spp. In the first and second event corresponding to the decomposition of hemicellulose (at 293 °C) and cellulose (362 °C) respectively, even though a decomposition of lignin also occurs at this temperature. The third event (at 400 °C) lignin begins to dominate the mass loss rate, continuing to decompose above 400 °C. From the TG curve, it can be seen values above 75 % of volatile material.

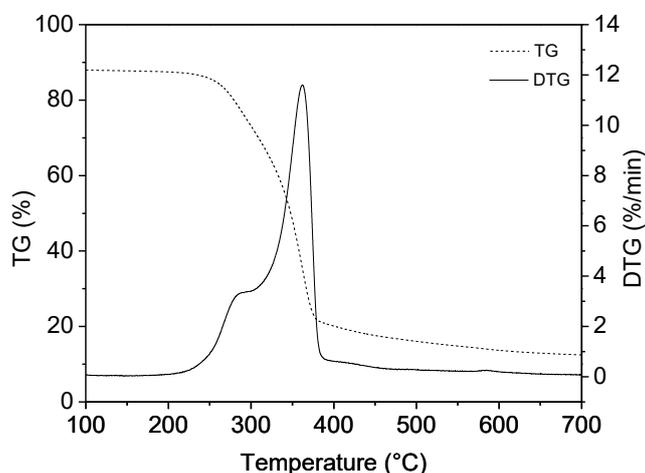


Figure 3. TG and DTG curves for eucalyptus spp. sawdust.

3.3 Torrefaction results

Figure 4 shows samples of eucalyptus in natura and torrefied at each temperature. It can be seen in Fig. 4 above, the color of the *Eucalyptus* spp. sawdust became darker as the temperature increased, that is, with a more carbonized appearance due to the temperature increase. During torrefaction, the gas and liquid fractions are separated and can be studied for use as fuel. In continuous torrefaction plants, these fractions of the raw material are harnessed to generate energy for torrefaction, reducing the amount of energy required for the process.



Figure 4. Raw material on the torrefaction steps.

Figure 5 below shows the results obtained for proximate analysis, demonstrating the values for ash, fixed carbon, and volatile materials. Ash content increased as torrefaction temperature increased along with fixed carbon content, however, there was a decrease in the concentration of volatile materials. The ashes come from mineral components in the wood, being undesirable in beneficiation and burning processes, as its components accelerate the wear of the cutting tools, as well as depreciate over time, causing erosion and rust in burning equipment, but their values are too low in the inner areas of the wood, most of which comes from the bark, Pereira et al (2016), who studied the torrefaction in eucalyptus sp chips found values below those found in the present study, but with high variation among the results, due to the too low value of these compounds in wood. Araujo et al. (2018) worked with several eucalyptus species also found values below those found in the present study, however, all values increased after the torrefaction process.

There is an increase in fixed carbon content during the torrefaction process, the fixed carbon value increased to 56.83 %. The increase in fixed carbon levels is due to the thermal degradation of hemicelluloses and celluloses, maintaining part of the lignin macromolecules, constituent with higher carbon concentration. This increase in fixed carbon content is positively related to the increase in the calorific value of the material (PEREIRA et al, 2016; ARAUJO et al, 2018; CARDONA et al, 2019).

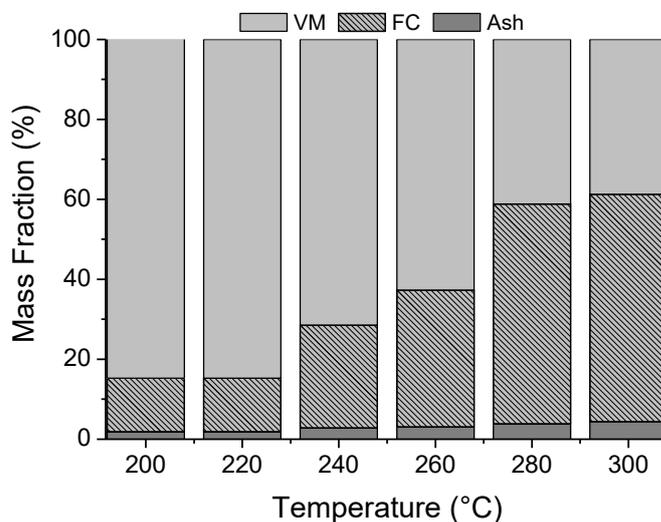


Figure 5. Proximate analysis of *Eucalyptus* spp. torrefied.

The content of volatile materials is one of the most important when dealing with biomass for energy generation, since the activation energy, that is, what gives ignition to the burning of the material depends on this concentration in the raw material. During the torrefaction process, part of the gas fraction and the liquid fraction of the material is removed, according to Cardona et al. (2019), who worked with a composite of leaves, bark and eucalyptus wood tailings, found values of 63.34 % (wet basis) for fresh biomass, a concentration that decreased as the torrefaction temperature increased, but at 300 °C the value for volatile materials was 53.35 % higher than 38.74 % (dry basis) found, which can be explained by the fact that the calculation base is different (wet versus dry base) and the uniformity of the raw material, since only eucalyptus sawdust separated in 250 mesh was used.

3.4 Correlation between mass yield and high heating value

The mass yield of a process is important for the industry as it indicates the feasibility of performing a biomass pretreatment or not. A large difference was observed between the analyzed extremes, with yields of 93.45 % and 35.55 % for the temperatures of 200 °C and 300 °C respectively, which is explained by the degradation of the cellulose and hemicellulose chains during the torrefaction process. Of the wood constituents, hemicellulose is the first to have a complete thermal degradation, which starts at temperatures around 220 °C and goes up to 315 °C, the cellulose comes after, its chains begin to thermally decompose in the side groups, at temperatures for around 315 °C going up to 400 °C, and lastly, lignin, which begins to decompose before the other components, at 160 °C, however, lignin is a macromolecule and has a high molar mass, making its thermal degradation more demanding, going to 900 °C. However, the degradation of these constituents is not desired because they are the main constituents of wood that directly influence the high heating value of the material and consequently the energy density. (PINTO et al, 2017; PEREIRA et al, 2016; DA SILVA et al, 2018)

According to Arteaga Perez et al. (2015) who studied species of *Eucalyptus globulus* and *Pinus radiata*, the difference between hardwoods and softwoods leads to different cell formations, directly affecting how each constituent will degrade during a torrefaction process, for the eucalyptus species studied by the authors, at 30 minutes, at 250 °C the mass yield was 79.0 % and at 280 °C was 56.0 %, higher than those found in the present study, which was 64.89 % at 240 °C, 51.88 % at 260 °C and 37.26% at 280 °C, however, the average particle size used in the studies performed by Arteaga-Perez et al. (2015) was 2 to 4 mm, while the sawdust used in the present study averaged 0.058 mm. With smaller particles, the contact surface of the material is larger, being one of the possible causes of the material mass yield decrease.

During torrefaction, the hygroscopic equilibrium moisture is evaporated, considerably increasing the high heating value as less thermal energy is used. According to Pereira et al. (2016) hemicelluloses, which are the first constituents to be degraded, are the most hydrophilic compounds in wood constitution, so when subjected to temperatures above 200 °C, the torrefied biomass becomes more hydrophobic.

As the torrefaction temperature increases, the high heating value increases reaching a maximum of 27.7 MJ/kg at 280 °C, then declining to 26.74 MJ/kg at 300 °C, where what may have happened. It is a degradation of lignin, causing a loss in high heating value. Silveira et al (2019) worked with *Eucalyptus grandis* macroparticles, reports linear growth with a positive correlation ($R^2 = 0.98$) between the decrease in mass yield and the increase in energy yield, a relationship also seen when compared the increase of HHV with the increase of the fixed carbon content of the material (while there is a decrease in the volatile material content).

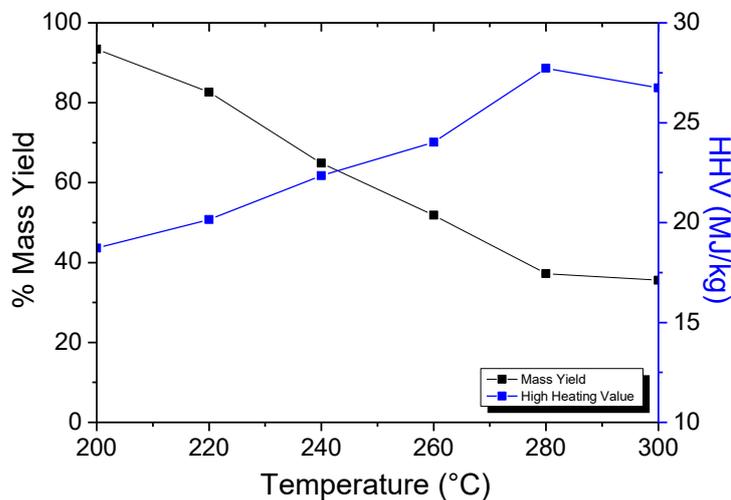


Figure 6. Mass yield and HHV.

4. CONCLUSIONS

The torrefaction of eucalyptus spp. sawdust increases high heating value. Increasing the torrefaction temperature causes thermal degradation making the mass yield lower. The fixed carbon content increases as the torrefaction temperature increases as well as the ash content, while volatile materials content has decreased. The fixed carbon content directly influences the high heating value, so torrefaction proved to be consistent as a process of improvement of the raw material improving energy production, something also demonstrated in the HHV and mass yield. However, at temperatures above 280 °C, there is a loss of material and high heating value start to decrease, this can be explained by the pyrolysis zone of the material, with more degradation of the constituents.

5. ACKNOWLEDGEMENTS

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