REVISTA BRASILEIRA DE ENERGIAS RENOVÁVEIS

WOOD THERMAL PROFILE DURING THE PYROLYSIS PROCESS[1]

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Abstract

The objective of this project was to obtain the temperature profile formed in the wood during the slow pyrolysis process. For this, small holes were opened into the wood using a drill, three thermocouples were inserted in the radial portion along the length of the wood and on the surface - center direction. Three Eucalyptus wood logs, 35 cm long, 30% moisture and 8, 9 and 12 cm diameters, were used. The final pyrolysis temperature was 400 °C. The gravimetric yield of the products was calculated after the pyrolysis process. The formation of thermal gradients was observed in the wood throughout the process. The temperature difference between the surface and the center can reach up 200 °C, in the pyrolysis of the largest diameter wood. Thermal heights formed in the wood at 100 °C were detected, being more evident in the central portion. The thermal variation perceived in the wood can be explained by the presence of water, which demands energy for its evaporation and changes the temperature gradients, and the heat conductivity is poor due to the wood being a porous material, mainly in the carbonized zone.

These phenomena influence the heat transfer during the pyrolysis process. On the surface - to - center direction, the formation of temperature gradients generates transient thermal threshold due to the drying process. Thus, a temperature gradient was formed between the surface and the center of the wood during the pyrolysis and the total time of the process will be higher in the largest diameter wood.

Keywords: Slow pyrolysis, Biomass, Charcoal.

PERFIL TÉRMICO DA MADEIRA DURANTE O PROCESSO DE PIRÓLISE

Resumo

O objetivo do trabalho foi obter o perfil de temperatura formado na madeira durante a pirólise lenta. Para isso foram abertos pequenos orifícios na madeira com o auxílio de uma furadeira e inseridos quatro termopares na porção radial ao longo do comprimento da madeira e no sentido superfície – centro. Foram utilizados dois toretes de madeira de *Eucalyptus,* de 35 cm de comprimento, 30% de umidade e diâmetros de 8 e 9 cm. A temperatura final de pirólise foi de 400 ^{o}C. Ao final, foi calculado o rendimento gravimétrico dos produtos. Foi observado que há a formação de gradientes térmicos na madeira durante todo o processo. A diferença de temperatura entre a superfície e o centro pode atingir até 200 ^{o}C. Foi observado patamares térmicos formados na madeira aos 100 ^{o}C, sendo mais evidente na porção central. A variação térmica observada na madeira pode ser explicada devido à presença de água, que demanda energia para evaporá-la e altera os gradientes de temperatura e a má condução de calor por ser um material poroso, principalmente na zona carbonizada. Isso influencia a transferência de calor durante a pirólise. No sentido superfície - centro a formação de gradientes de temperatura, gera patamar térmico transitório devido o processo de secagem. Dessa forma foi verificado que há formação de um gradiente de temperatura entre a superfície e o centro da madeira durante a pirólise e o tempo total do processo será maior na madeira de maior diâmetro.

Palavras-chave: Pirólise lenta, Biomassa, Carvão vegetal.

INTRODUCTION

Changes in the climate due to the increase of temperature caused by the greenhouse effect are considered one of the main challenges of the present time. Emissions of greenhouse gases (GHGs) from anthropogenic activities such as burning fossil fuels for power generation are the main contributors to climate change. This requires replacing conventional non-renewable sources for renewable energy ones, especially with a larger scale insertion of biomass into production processes.

According to the *International Energy Agency* (2018), energy from woody biomass can be considered one of the main alternatives for energy use, particularly when applying sustainable forest management practices and using efficient conversion techniques and equipment, combined heat, power and even biorefineries sources.

Currently, one of the main thermochemical conversion process for biomass is pyrolysis, which consists of thermal decomposition of the feedstock. Pyrolysis is an important process in the obtaining of renewable energy; it transforms the biomass into three states of fuel: solid, liquid and gases (WILLIAMS et al., 2012; WIT; FAAIJ, 2010).

In the slow pyrolysis of wood, decomposition of the structural chemical components, such as hemicellulose, cellulose and lignin, occurs in the controlled presence of oxygen, three products (i) charcoal, (ii) bio-oil and (iii) non-condensable gases are produced, the yields of them may be variable, because they depend mainly on the operating conditions and the raw material. According to Tripathi et al. (2016) there is no other conversion method that produces as many products as pyrolysis does. However, it is necessary to develop efficient tools that can provide a high understanding of the thermal phenomena that occurs during the process. According to Hasan et al. (2017), resistance to heat transfer and mass are the major obstacles in developing efficient conversion technology. These phenomena are directly related to the temperature gradient formed in the wood (PARK et al., 2010). Nowadays some researchers use small specimens as experimental samples. Thus, it becomes interesting and necessary to understand the thermal behavior of the wood during the pyrolysis. Therefore, the objective of this work was to obtain the temperature profile formed in the wood during the slow pyrolysis.

MATERIALS AND METHODS

Three stems of 35 cm long of *Eucalyptus sp.* wood were used. The diameter was measured on each stem and the moisture content was determined (Table 1).

Table 1 - Diameter and moisture of *eucalyptus sp.* wood samples

Sample	Diameter (cm)	Moisture (%)
A	8	30
B	9	30
C	12	30

Three type J thermocouples with iron rod and *constantan* were inserted into the stems, with a braided mesh fiber coating. These were inserted along the length of the sample on the surface - center portion (heartwood). Thus, it was possible to obtain the temperature variation and the thermal profile of the radial and longitudinal direction of the wood. The thermocouples were connected to a temperature reader model *Gulterm 700-10S*, which was measured at 10-minute intervals. The thermocouples were positioned in the radius of the stem, one of them in 2 cm from the outer surface of the wood and the other one between the radius and surface, along the length of the sample.

The carbonizations were carried out in an electric muffle model GP Scientific-2000, which has a stainless steel box with nominal dimensions of 0.465 x 0.195 x 0.195, sealed with a thermal blanket. In this muffle, a condensate gas recovery system was connected, using a water-cooled tubular condenser coupled to a collection vessel (Figure 1).

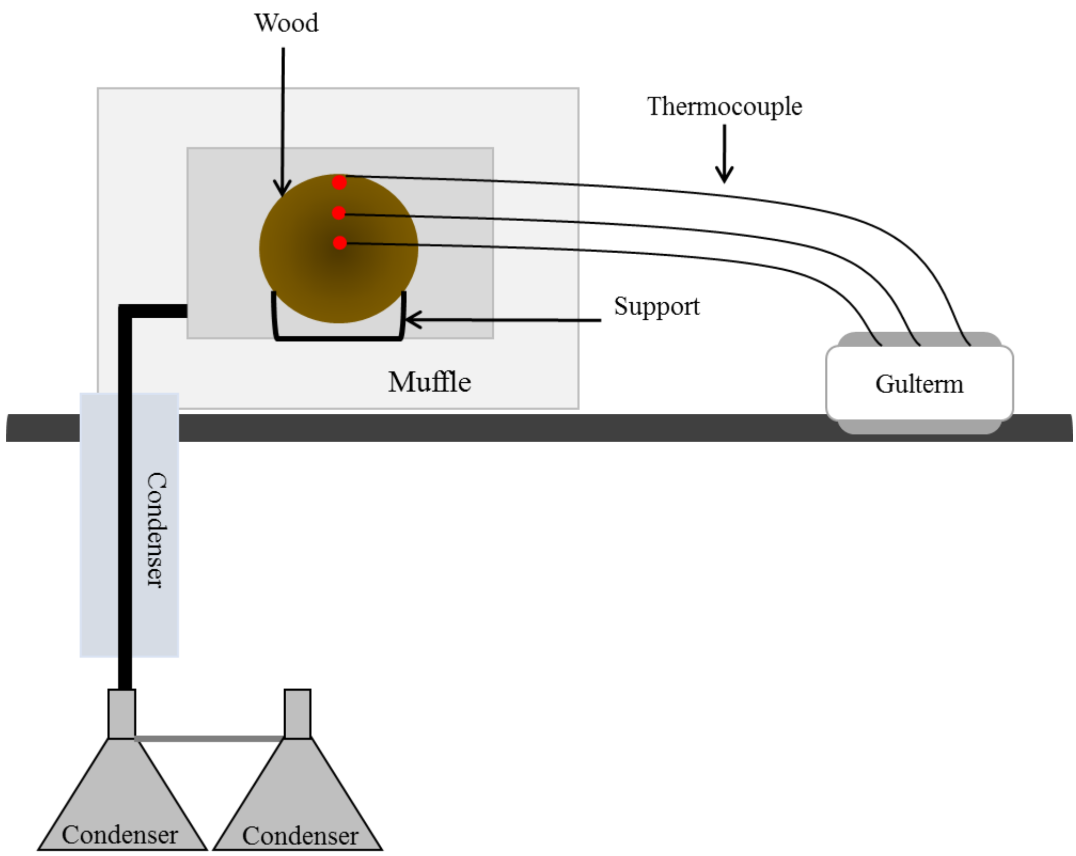

Figure 1 - Layout of the carbonization system used in the experiments.

The experimental conditions of the slow pyrolysis process were: (i) initial temperature of 50 °C, (ii) final temperature of 400 °C, and (iii) heating rate of 1.10 °C min^{-1}.

After the carbonizations the gravimetric yields were obtained in (i) coal, (ii) condensable gases (pyroligneous liquor) and by difference, (iii) non condensable gases.

RESULTS AND DISCUSSION

Figure 2 shows the temperature values and process times in the wood in different positions for each carbonization. As the heat flux by radiation (muffle) increased, a significant temperature gradient between the surface and the center was created, it revealed non-linear heating rates in the wood. In the three samples, higher temperatures near the surface of the wood were observed, different from the central portion. The results show that the external surface of the wood presents heating rates different from the center (PARK et al., 2010).

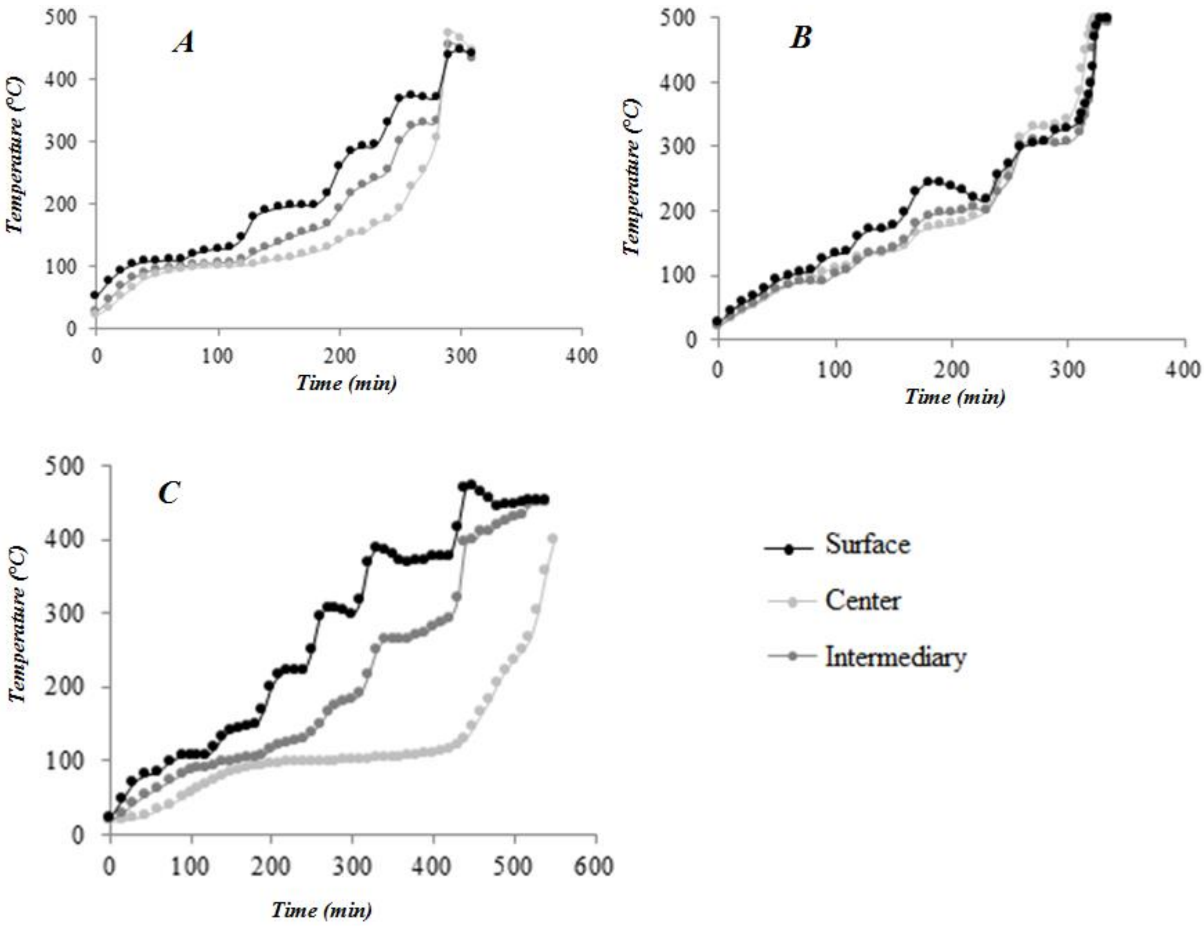

Figure 2 - Graphical representation of the thermal gradient formed in wood A, B and C samples during slow pyrolysis.

The thermal difference between the surface and the center was even more evident in the carbonization of the largest sample (Fig. 2C). The temperature and pressure gradients tend to be more significant in pieces with larger diameters, and the center of the samples used to be the position where the lowest temperatures are recorded (HASAN et al., 2017). It was possible to observe that in the sample of the largest diameter (12 cm), in the central thermocouple, the formation of a high threshold occurred when reaching 100 °C, caused by the presence of water in the wood. Experimental studies by Bryden et al. (2002) also demonstrated that the presence of water in the wood favors the formation of thermal thresholds at this temperature. Drying and pyrolysis occur non-uniformly in the wood, but sequentially, this also contributes to the thermal gradient formation. According to Jesus (2016), after the water is eliminated in the form of vapor, the temperature in the center of the material increases rapidly, fact also found in this work.

The total carbonization time varied among the samples, which was found to be 310, 355 and 540 minutes respectively for carbonization of the samples A, B and C (Fig. 2). The larger the diameter the greater the carbonization time, for the same percentage of moisture content (30%). The diameter has a strong influence on the carbonization time of the wood (RAAD, 2004; BABU, CHAURASIA, 2004; JESUS et al., 2015).

In the pyrolysis, the thickest samples have greater resistance to heat transfer, so the formation of temperature gradients are evident. In this work, it was verified that when the samples reached 300 °C on the surface of the largest diameter wood, in the center was still observed 100 °C, revealing a difference of 200 °C. This is a factor that can also influence the yield of the products in the process.

Table 2 shows the yield values of charcoal, pyroligneous liquor and non-condensable gases. The yield in charcoal was 33.4%, 31.7% and 30.5% for samples A, B and C, respectively. Considering that all the samples have the same moisture content, the difference in carbon yield was influenced by the diameter, since it was exposed to the final process temperature by a longer time interval.

Table 2 – Wood carbonization products yields.

Sample	Diameter	Average charcoal yield (*wt* %)	Average pyroligneous liquor yield (*wt* %)	Average non-condensable gases yield (*wt* %)
A	8	33.4	33.0	33.6
B	9	31.7	30.7	37.6
C	12	30.5	23.9	45.5

CONCLUSION

The understanding of the biomass thermal behavior represents an important factor for the development of renewable energy applications. The research confirmed the dominant role of the process temperature in the decomposition reactions and heat transfer. From this study of temperature profiles during the wood pyrolysis, it is confirmed that there is a formation of threshold occurred when the process reached 100 °C, caused by the presence of water in the wood. This contributes to the thermal gradient formation of the wood.

The wood thermal behavior confirms the increase in resistance to heat transfer when the distance between center and surface increases. The temperature gradients behavior in the stem C was more visible than in the stem A and B, due to the resistance to the conduction of heat between the wood pores, knowing that the distance center-surface of this sample is higher .

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