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THERMAL AND ENERGETIC ANALYSIS OF *EUCALYPTUS UROSEMENTE*

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Abstract. *The aim of this study was to evaluate the energy of Eucalyptus Urosemente used to produce steam in boilers and which has an average age of 9.5 years. The wood studied is used as fuel for the steam production used for food and raw materials preparation. The firewood available is larger than the company consumption, therefore is essential to know the thermal and energy characteristics for their consumption and future surplus biomass commercialization. In this study the samples were categorized by diameter and days after cutting. Were performed tests of moisture content and calorific value for firewood samples taken between May and July 2014, all conducted following Brazilian standards. In addition, was determined the relationship between the calorific value and moisture content. The results confirmed the high energy potential of Eucalyptus Urosemente. Based on the values obtained for the lower calorific value on dry basis was defined that both, fine and mixed firewood, should be consumed within the range of 90 to 120 days after cutting.*

Keywords: *Energy evaluation, eucalyptus, steam generation, moisture content, calorific value.*

1. INTRODUCTION

When comparing wood to fossil fuels, in relation to its use as an energy source, it presents less pollution problems because it has a low sulfur content (Cunha *et al.*, 1989). Furthermore, the planting of a new biomass offers a favorable environmental aspect, since the emission of CO_2 in the atmosphere from burning can be amortized or even absorbed (Ingham, 1999). It also stands out for the facilities of storage, conversion, transportation and the possibility of increasing its energy density (Lippel, 2014). These advantages make the use of wood interesting for energy production, however, requiring an appropriate characterization.

Firewood is probably the oldest energy product used by man and still has a great importance in the Brazilian Energy Matrix. The steel industry is the largest consumer of firewood produced in Brazil, which has already been transformed into coal. The second is the residential sector, where it is mainly used for cooking and heating environments (Brito and Cintra, 2004). In Brazil, *eucalyptus*, which is of Australian origin, is the main source of firewood obtained from reforestation.

An analysis by Silva and Morais (2008) studied the sugarcane bagasse used in the energy supply in an industrial park. An energetic increase of 92% was obtained reducing moisture content of *in natura* product from 50% to 0%. 60% of this increase is achieved by reducing the humidity to approximately 20%. Therefore, the most viable and advantageous is its use with a moisture content of around 20%, because the energy consumption to obtain a drier bagasse makes the process unfeasible. This result demonstrates the importance and necessity of material characterization for its use as energy source.

The calorific value and moisture content are considered some of the most important properties to analyze and define the best wood conditions for use as fuel (Brito and Barrichelo, 1978). Therefore, this work had as objective to define which is the best condition of *Eucalyptus Urosemente* firewood to be used in boilers, based on calorific value and moisture content tests and considering the following parameters: log diameter and the number of days after cutting.

2. FUNDAMENTALS

For fuels characterization there are several tests that can be performed, for example: calorific value, moisture content, density and proximate analysis. They are considered the most important properties to analyze and define the best wood conditions to use it as fuel.

In this study, were performed tests of moisture content and calorific value following the ABNT NBR 8112/1986 and 8633/1984.

The equipment required to carry out the tests, according to the norms, were: scale with a capacity of 1.0 kg and precision of 1% and a drying oven capable of reaching 110^{o}C and a bomb colorimeter.

2.1 Samples

Firewood samples were collected according to the combination of two parameters: number of days after cutting (1, 30, 60, 90, 120 and 150 days) and the diameter of the logs. That second parameter was divided into: fine (diameters from 50 mm to 120 mm) and mixed (diameters from 130 mm to 260 mm). If the log presented diameter greater than 260 mm it was split in half. Therefore, 12 samples were collected.

2.2 Moisture Content

The moisture content determines the water proportion present in the wood, which has the behavior of an impurity, reducing the thermal energy released by that source, because part of this energy is spent in water heating and vaporization. Therefore, the humidity influences negatively the amount of heat released, being inversely proportional to the calorific value (Farinhaque, 1981). In addition, this moisture content also influences the company's expenses with firewood transportation (Cunha *et al.*, 1989).

ABNT NBR 8112/1986 in order to define the moisture content of firewood sample determines the following procedures: using a precision scale, measure the container mass and then place the firewood sample with a particle size of less than 19 mm in the container and measure the total mass (sample + container). The steps described above are shown in Fig. 1.

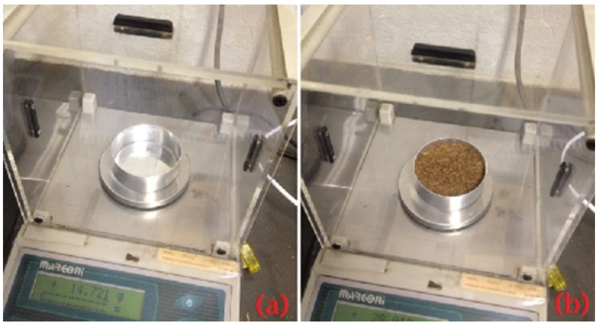

Figure 1: **Weighing the container (a) and the container with firewood of particle size less than 19 mm (b).**

Then, the container with firewood is placed in a drying oven preheated at 105^{o}C. Daily, during the drying step, it is removed from the drying oven, placed in the desiccator and then weighed. This procedure is repeated until the sample mass remains constant. Finally, with the sample final mass defined, the moisture content is calculated using Eq.(1).

$$MC = \frac{m_0 - m_1}{m_2} * 100 \tag{1}$$

where, MC is the moisture content [%], m_0 is the assembly initial mass [g], m_1 the final [g] and m_2 is the initial assembly mass subtracted container mass.

2.3 Calorific Value

The heat released in the combustion of a wood mass unit is defined as calorific value (Jara, 1989). It is the most important property for the fuel energy evaluation and is expressed in the International System in joules per gram or kilojoules per kilogram, but is can also be presented in kilocalories per kilogram.

Two values of calorific value are highlighted: the higher calorific value (HCV) and the lower calorific value (LCV). The HCV corresponds to the energy released by the complete combustion of fuel mass unit. For this, the water formed during the combustion is condensed and the heat that is spent in its evaporation is recovered.

To obtain the LCV, the complete combustion of fuel mass unit is also realized, however the losses with the water evaporation must be deduced. Thus, the LCV is obtained when the water is considered in the vapor state at the end of combustion (Quirino *et al.*, 2004).

The HCV establishes the theoretical energy potential contained in the fuel, but it can not be taken as the energy released in a real combustion process, because the water remains in the vapor state and is released with the gases formed in the combustion (Filho, 2013). In practice the LCV is adopted because it gives a more accurate idea of the heat released by the fuel. For a dry fuel, the LCV on dry basis can be deduced from the HCV as shown in Eq.(2). The removed energy is required to evaporate the water from the hydrogen combustion contained in the fuel (Ciampi, 1992).

$$LCV_{DB} = HCV_{DB} - h_{lv} * m \tag{2}$$

where, LCV_{DB} is the Lower Calorific Value on dry basis [kcal/kg], HCV_{DB} is the Higher Calorific Value on a dry basis [kcal/kg], h_{lv} is the enthalpy of water vaporization at 20^{o}C [kcal/kg] and *m* is the percentage of water vapor mass present in the combustion gases [%]. When analyzing the chemical reaction of fuel combustion, it is seen that the mass of water formed is equal to 9 times the hydrogen mass. Therefore, for a dry fuel, we obtain: *m = 9 H*, where *H* is the mass percentage of hydrogen contained in the fuel. Replacing is obtained Eq.(3).

$$LCV_{DB} = HCV_{DB} - \frac{h_{lv} * 9 * H}{100} \tag{3}$$

Brand (2010) found for woods an average of 6% hydrogen in their constitution. In your study Protásio *et al.* (2011) found 6.36% for the hydrogen content for *eucalyptus*. The percentage adopted in this study was 6%.

Equation (3) was applied only for fuels with a moisture content equal to 0%. To determine the real energy that will be released by the fuel, it must also remove the amount of energy required to evaporate the moisture in the wood, as shown in Eq.(4). This calorific value is called lower calorific value on wet basis (LCV_{WB}) .

$$LCV_{WB} = LCV_{DB} * \left(1 - \frac{MC}{100}\right) - h_{lv} * \frac{MC}{100} \tag{4}$$

where, LCV_{WB} is the Lower Calorific Value on wet basis [kcal/kg] and MC is the sample moisture content [%].

IKA-WERNER C2000 Bomb Calorimeter, shown in Fig. 2, was used to determine the Higher Calorific Value (HCV). The others calorific values was obtained using the Eqs. (3) and (4).

Figure 2: **IKA-WERNER C2000 Bomb Calorimeter.**

3. RESULTS

3.1 Moisture Content

Initially was proposed to identify and analyze the evolution of moisture content, present in the firewood, as a function of days after cutting. This analysis is fundamental, because the LCV on dry basis, which is the real energy supplied to the system, is strongly influenced by the water amount present in the firewood, and they are inversely proportional.

Figure3 shows the evolution found for the moisture content as a function of the number of days after the cutting, for fine and mixed firewood. It is observed that the wood moisture has an inverse relationship with the number of days after cutting, because with the increase of the first one there is a reduction in the moisture content, as obtained by Gatto *et al.* (2003).

Brand *et al.* (2004) quantified and qualified the waste generated in the lumber industry in the region of Lages, Santa Catarina. They were stored for six months and during this period the moisture content of the various wood species was analyzed. The waste moisture content varied from 29.5 to 67.3% when they arrived. The residues with the greatest reduction were the *Pinus* and *Eucalyptus*. The author relates the greatest loss of moisture by *Pinus*, because it presents a larger surface area. The ideal storage of these woods occurs with four months, because with one the material has not lost the moisture amount required for the use as fuel and with six months the wood is in the biodegradation process and,

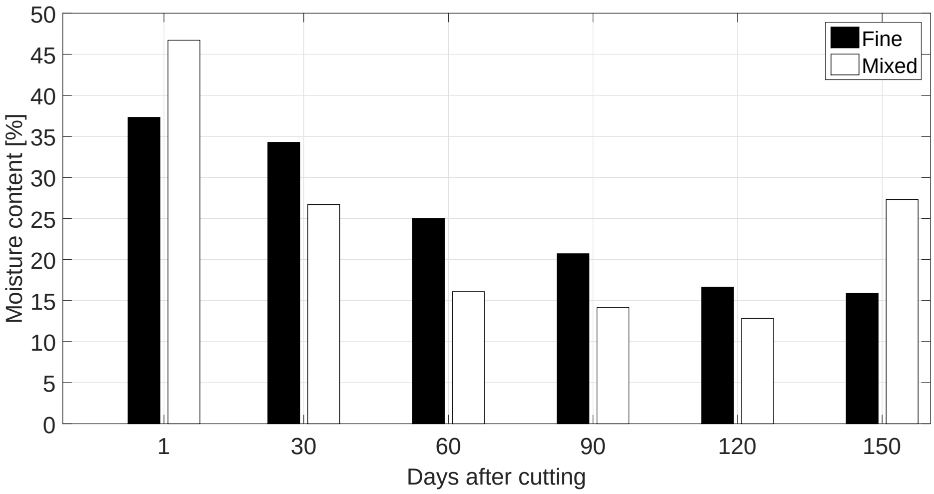

Figure 3: **Moisture content as a function of days after cutting.**

therefore, becoming more permeable. Another important result is that shelled eucalyptus had a reduction in the moisture content faster than with bark.

The results obtained in this work are also in agreement with Brand *et al.* (2004), because the firewood of *Eucalyptus Urosemente* presented the greatest moisture content reduction for the mixed firewood, because it presents the largest surface area, and the mixed firewood of 150 days after cutting began to show moisture gain by a biodegradation process, making it more porous and as a result, more permeable.

3.2 Calorific Value

The calorific value is defined as the fuel energy amount per mass unit. The value obtained in the tests performed in the calorimeter corresponds to the Higher Calorific Value (HCV). However, it is necessary to determine the Lower Calorific Value on dry basis (LCV_{DB}), because it represents the real energy supplied to the system. We considered 586.16 kcal/kg as the value for the enthalpy of water vaporization at 20^{o}C and 6% to the average percentage of hydrogen present in *Eucalyptus Urosemente* (Brand, 2010; Protásio *et al.*, 2011). The LCV_{DB} was calculated using Eq.(4).

Table 1 lists the values found for the calorific value of *Eucalyptus Urosemente* firewood, depending on the number of days after cutting and the log diameter, the second criterion being separated into fine and mixed.

Table 1: **Higher calorific value (HCV) and lower calorific value on wet basis (LCV_{WB}) for all types of firewood analyzed.**

Days after cut.	Type	HCV				LCV_{WB} (kcal/kg)
		Avg. (kcal/kg)	Stand. Devia. (kcal/kg)	Variat. Coeff.	Number of rep.	
1	Fine	4506.67	22.28	0.49	3	2407.63
	Mixed	4089.00	55.65	1.36	3	1736.56
30	Fine	4324.00	61.02	1.41	3	2432.78
	Mixed	4602.33	38.76	0.84	3	2985.48
60	Fine	4418.67	63.97	1.45	3	2930.07
	Mixed	4583.33	34.53	0.75	3	3485.96
90	Fine	4421.33	28.15	0.64	3	3133.31
	Mixed	4476.00	35.79	0.80	3	3487.97
120	Fine	4420.67	28.89	0.65	3	3323.21
	Mixed	4597.00	30.18	0.67	3	3568.91
150	Fine	4473.67	34.02	0.76	3	3403.90
	Mixed	4560.00	55.97	1.23	3	2924.50

Analyzing the results of the Higher Calorific Value (HCV) obtained in this study, it is noted that they range from 4089 ± 55 kcal/kg (mixed with 1 day after cutting) to 4602.33 ± 38.76 kcal/kg (mixed with 30 days after cutting). Still analyzing the HCV, the results are all close to those found by Silva (2012), which obtained a range between 4625.34

kcal/kg (*E. Citriodora*) and 4687.61 kcal/kg (*E. Grandis*), and most of the values are included in the range obtained for the 26 *eucalyptus* species through the bibliographic survey carried out by Quirino *et al.* (2004). It is also verified that practically all HCV values were close to 4500 kcal/kg. In this way the LCV_{WB} is practically only dependent on the variation of the firewood moisture content, which are inversely proportional.

4. CONCLUSION

The samples showed a moisture content reduction with the passage of days after cutting, up to 120 days. In relation to the higher calorific value (HCV), it was observed that it does not depend on the number of days after the cutting and it was a little higher for the mixed firewood. The definition of the best condition to use the firewood was based on lower calorific value on dry basis (LCV_{DB}), because it already takes into account the energy spent with the evaporation of moisture present in the firewood, and thus represents the real energy supplied to the system. Therefore, all types of firewood should be consumed within the range of 90 to 120 days after cutting, because they already have low moisture contents and after that there is a risk that firewood reabsorb moisture by the biodegradation process.

5. ACKNOWLEDGEMENTS

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