EUCALYPTUS LOGS DRYING AT HIGH TEMPERATURES[1]

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ABSTRACT – The objective of this work was to evaluate the drying speed of *Eucalyptus urophylla* logs in high temperatures and the influence of the presence or absence of bark and also the diameter of the log in the drying rate. *Eucalyptus* logs 60 cm long were divided into three diameter classes: 8-12 cm; 12,1-16 cm and 16,1-20 cm. The logs were dried in a heater with forced air circulation, in the presence or absence of bark in five temperatures: 50, 75, 100, 125 and 150ºC. The mass and the initial moisture were determined from each log and the water loss was kept up with periodic weightings, closing the drying process when the logs reached 20% moisture. The drying rate of the logs was calculated using the ratio between the total loss of moisture and the time in hours in order to reach the established moisture. It was concluded that the increase in temperature promotes the raise of the drying ratio, as being higher for smaller logs in relation to bigger ones and in addition to this, the bark effect was not significant in the drying of eucalyptus logs above 100°C. It was also concluded that the best conditions for the operation of artificial dryers for *Eucalyptus* logs containing bark and separated in diameter classes would be at 125°C.

Keywords: Drying rate; Moisture content; Artificial dryers.

SECAGEM DA MADEIRA DE EUCALIPTO EM TORAS A ALTAS TEMPERATURAS

RESUMO – O objetivo deste trabalho foi avaliar a velocidade de secagem de toras de ***Eucalyptus urophylla*** *a altas temperaturas e a influência da presença ou ausência de casca e do diâmetro da madeira na taxa de secagem. Utilizaram-se toretes de* ***Eucalyptus urophylla*** *com 60 cm de comprimento, em três classes diamétricas: 8-12 cm; 12,1-16cm e 16,1-20 cm. Os toretes foram submetidos à secagem em estufa com circulação forçada de ar, na presença ou ausência de casca em cinco temperaturas: 50, 75, 100, 125 e 150ºC. Determinou-se a massa e a umidade inicial de cada torete e com pesagens periódicas acompanhou-se a perda de água, encerrando o processo de secagem quando os toretes de madeira atingiam a umidade de 20%. A taxa de secagem foi calculada por meio da relação entre a perda total de umidade e o tempo total em horas para que as toras atingissem a umidade estabelecida. Conclui-se que o aumento da temperatura promove o aumento da taxa de secagem, sendo maior para as toras de menor diâmetro em relação às toras de maior diâmetro e na secagem das toras de eucalipto em temperaturas superiores a 100ºC, o efeito da casca não foi significativo. Conclui-se, também, que a melhor condição de operação de secadores artificiais para a madeira de eucalipto em tora seria em temperatura de 125ºC, com presença de casca e separadas em classes diamétricas.*

Palavras-chave: Taxa de Secagem; Teor de Umidade; Secadores Artificiais.

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1. INTRODUCTION

The domestic charcoal producers, looking for production increase and better product quality, are adopting the best available and accessible technologies in the market, like large dimensions rectangular kilns with mechanized loading and unloading activities (Guimarães Neto et al., 2007; Arruda et al., 2011); carbonization control based on the kiln's internal temperature (Carvalho et al., 2012; Oliveira et al., 2013); and furnaces for the carbonization gases combustion that minimizes the polluting gases emissions to the environment (Cardoso et al., 2010; Costa, 2012).

According to Yang et al. (2007), during the wood's carbonization several carbon and hydrogen-rich gaseous compounds are generated, mainly CO, CO_2, H_2 and CH_4. At adequate temperature conditions, those gases could undergo chemical reaction at the presence of oxygen, with the emissions constituted of CO_2 and water steam only and liberating energy in heat form (Cardoso et al., 2010). The temperature of the gases liberated to the environment through the chimney, after the combustion at the furnace interior, could reach temperatures from 200 to 500ºC (Oliveira et al., 2013).

One way to take advantage of the heat generated by the furnaces in the productive process of the charcoal could be its redirection to the wood logs drying through industrial dryers. Since the outdoors wood drying, nowadays the main used method according to Zanuncio et al. (2013) demands a longer period of time for reducing the wood moisture to satisfactory levels for carbonization, between 30 and 40%, also presenting great heterogeneity of the moisture scent related to the log dimensions and pile position.

In both drying methods, the wood characteristics plus the temperature, relative humidity and air circulation of the environment conditions influence the water outlet speed. However, in the outdoor drying the environment conditions will be the ones verified in the place where the wood is exposed, while in the artificial drying it's possible to change the environment by using fans for air circulation and renovation, heating systems to elevate the temperature and also the relative humidity control.

According to Galvão and Jankowsky (1985), higher temperatures favors the drying process of the wood, providing more energy for water evaporation and elevating the air potential to receive more water steam. Thus, the use of industrial dryers that employs as a heat source the combusted gases of carbonization allows the moisture homogenization in great volumes of wood, reduction of drying time and getting lower moisture scent than the usually verified levels at outdoor drying.

In the literature, several studies about some wood products can be found: particles, sheets and mainly lumber (Albuquerque, 2000; Jankowsky, 2000; Santini and Haselein, 2002). However, there are no studies about the application of this drying method in logs destined to carbonization.

Thus, the objective of this works was to evaluated the wood drying speed of *Eucalyptus urophylla* logs at higher temperatures, as a subsidy to future projects of industrial dryers. It was also aimed to evaluate the influence of the presence or absence of the bark and the wood diameter in the drying speed at different temperatures.

2. MATERIAL AND METHODS

The wood logs used in this study came from a 7-year old *Eucalyptus urophylla* plantation, cultivated with a 3 x 2 m spacing, in the city of Viçosa/MG. This town has a 650 m average altitude, the weather – according to the Köppen classification – is a Cwb type, mesothermic, with a dry winter and rainy summer. The average annual precipitation is 1200 mm and the average annual temperature is 20,5ºC, with a minimum of 14,6ºC and maximum of 26,3ºC (Zucoloto et al., 2011).

2.1. Sample preparation

Seven eucalyptus trees, with diameter at breast height (DBH) of 18 cm and average height of 25 m were collected. Each tree was sectioned in logs with 1,3 m of length until the minimum diameter of 8 cm.

The logs were taken to the Laboratório de Painéis e Energia da Madeira – LAPEM of the Universidade Federal de Viçosa - UFV, where the circumferences of the base and topo of the logs were determined for calculating the average diameter. Later, they were separated in three diameter classes.

The Class 1 was composed by the logs obtained in the superior part of the trees with 8 to 12 cm diameters; the Class 1 composed by logs obtained in the intermediated height region of the tree, with 12,1 to 16 cm diameters and the Class 3 by logs with 16,1 a 20 cm, obtained closer to the tree bases.

After the diameter separation, the logs were sectioned in logs of 60 cm, with central circle of 10 cm of thickness being extracted from each log to determine the initial moisture from each log by the gravimetric method. Then, half of the logs of each diameter class keep their barks and the other half was manually peeled.

The logs were later put in elevated structure at 0,5 m of the ground in order to have a better air circulation between them in covered shed for natural drying until the average moisture level corresponds to 60% (±10%). The initial mass of each log was determined, in which the initial moisture was estimated in accord to the verified moisture in the correspondent discos. Then, periodical weightins of the logs were made until the corresponding mass to the established moisture. At that moment, the natural drying was finished and the logs were put in plastic bags with decahydrated sodium tetraborate to reduce the loss of water and the attack of wood decomposing organisms until all the logs reached 60±10% moisture, for the later oven drying.

The moisture of 60% (±10%) was established as the initial one for the logs at oven drying because the freshly harvested tree shows an elevated level of water filling its empty space, corresponding to free water, which output presents a low energetic expense, with an elevated water loss rate even with the field conditions drying. Lower than 60% moisture, even with free water in the wood log, the drying tax is reduced around five times, elevating the drying time.

With the initial drying happening in the field, the weight of the wood to be transported and the amount of water to be taken of the wood are reduced, lowering the energetic consume and the time of permanence in the artificial dryer.

2.2. Wood oven drying

After all the logs reach the 60% moisture level and put in plastic bags, a fraction of sawdust of all radial region (bark-marrow direction) was taken from each log using an electric drilling machine, according to the methodology described by Donato et al (2014). To estimate the initial moisture of each log, the sawdust moisture was determined in a OHAUS MB35 Halogen determining scale with an halogen lamp.

Then, the initial mass of each log was determined and, before the oven drying was made, the far ends of the logs were waterproofed with metallic paint in order to minimize the loss of water in the longitudinal direction of the wood for the drying to happen preferably in the radial direction of the wood to evaluated the diameter effect and the bark presence or absence.

Later, the logs were taken to oven drying, evaluating the effect of the diameter, presence of absence of bark and different drying temperatures, 50, 75, 100, 125 and 150ºC, in the drying speed of the eucalyptus wood.

A Marconi lab oven drying with forced air circulation in the horizontal direction, with temperature control until 200ºC and 480 liters of capacity was used. The internal structure of the oven drying is made of AISI430 stainless steel with a double chamber for air circulation and the external structure a 1020 steel sheet with an anticorrosive treatment, with the following internal dimensions: 800mm width; 600mm deep and 1000mm height, with a 5 steel shelves support where the logs were disposed. The temperature sensor was a PT100 type.

To achieve the drying speed, the logs were individually weighted at regular time intervals that varied in accordance to the evaluated treatment, finishing the drying at the oven drying when the logs reached a mass corresponding to 20% (±2%) of moisture. The wood moisture through time was calculated from the estimated wet mass and dry mass from each log.

From the average moisture levels of the logs over time and the real time needed for the logs achieve 20% moisture, the making of the drying curves in terms of diametric class, bark presence or absence and drying temperature at the oven drying followed. Using the CurveExpert 1.4 software, models that could explain the moisture reduction over time or the drying curves, selecting the best among them based in the determination coefficient (R^2), standard residual error and residue distribution, could be defined.

Through the existing relation between the total loss of moisture and the total necessary time, in hours, for the logs to reach the final moisture closer to 20% after the oven drying, the reduced moisture per hour drying rate %, in function of the treatments, could be calculated in accord to the Equation 1.

$$\text{Drying rate (\%/hour)} = \frac{\text{Ui - Uf}}{\text{t}} \text{ x } 100 \qquad (1)$$

In which,

Ui = Initial wood log moisture (%);

Uf = Final wood log moisture (%);

T = Necessary time to reach 20% of moisture (hours).

3. RESULTS

The mathematic model that better describes the reduction in the moisture scent of the logs in the different treatments (bark presence or absence, log diameter and drying temperature, except for 150ºC, Classes 1 and 2) over time was an exponential model of two parameters:

$$y = a * \exp(-bx) \quad (2)$$

In which:

y = estimated moisture value for eucalyptus logs (%)

x = drying time (days)

a,b = model parameters

For the 150ºC temperature with presence or absence of bark for logs with diameter varying between 8 and 12 cm (Class 1) and between 12,1 and 16 cm (Class 2), the model that was better suited to the moisture reduction values over time was a liner one with two parameters:

$$y = ax + b \quad (3)$$

In which:

y = estimated moisture value for eucalyptus logs (%)

x = drying time (days)

a, b = model parameters

Probably, the linear model for drying at 150ºC for the 1 and 2 Classes is due to the higher water evaporation water and log drying speed because of the higher temperature.

The adjusted equations to the eucalyptus wood log average moisture scent estimate over time presented determination coefficients (R^2) higher than 99%, thus showing that the model was satisfactory in modeling the wood log drying. The estimates of the parameters *a* and *b* for the drying curves in the different conditions for temperature, diameter and bark are presented in the Table 1.

In the figures 1 and 2 are presented the average estimated values of moisture in the eucalyptus logs over time, in the different temperatures of oven drying for each diametric class, in the presence and absence of bark.

In Table 2 are presented the drying rates, reduction of moisture scent per hour, for the eucalyptus logs, in the different temperatures of oven drying for each diametric class, in the presence and absence of bark.

It can be verified in the figures 1 and 2 that the logs with smaller diameter, of the Class 1, show the lower drying times, except for the drying made at 50ºC. In average, for the Class 2 logs to reach 20% of moisture, the necessary time was 50% superior to the one verified to Class 1. For the larger diameter logs of the Class 3, the drying time was 2 and 3 times superior, respectively, that the ones of the Classes 1 and 2.

The differences in the drying times (Figures 1 and 2) are caused by the verified differences between the diametric classes in the drying rates, that lower with the increase of the diameter of the logs (Table 2). In general, higher drying rates can be observed for the logs of Class 1, thus the lower drying times. For Class 2, there was an average reduction of 40% in the drying rate, resulting in the average drying times, while the Class 3 logs showed the longer drying times because of the drying rates, in average 20% lower than Class 2 and 50% than Class 1.

4. DISCUSSION

According to Vital et al. (1985), the log diameter is related to the distance to be traveled by the water inside the wood to the surface, where it will evaporate. Thus, the longest time of drying and the lower drying rate of the larger diameter logs in relation of the other classes, evidencing the effect of the wood dimension on the water outlet. So, it is verified that even with the drying happening in natural conditions, the diameter of the logs affects the speed of the water escape of the wood's interior, thus influencing the drying time, so it's recommended the separation of the logs in diametric classes before the oven drying for a better operation and better homogeneity of the moisture scent of the wood.

It can be seen that the eucalyptus logs drying period is reduced with the raise of the oven drying temperature, for the different diameters and in the

Table 1 – Parameters set of templates to moisture content reduce of the logs over time for Class 1, 2 and 3 at different temperatures and in bark presence and absence.
Tabela 1 *– Parâmetros dos modelos ajustados para redução do teor de umidade das toras ao longo do tempo para as Classes 1, 2 e 3, nas diferentes temperaturas e na presença e ausência de casca.*

Diametric Class	Temperature	Bark	*a*	*b*	R^2
Class 1 (Ø8-12 cm)	50ºC	Present	71,75	0,07	0,9955
		Absent	65,462	0,059	0,9991
	75ºC	Present	58,253	0,325	0,9963
		Absent	55,576	0,355	0,9961
	100ºC	Present	55,258	0,666	0,9965
		Absent	57,502	0,87	0,9929
	125ºC	Present	51,932	1,931	0,9675
		Absent	50,879	1,889	0,9987
	150ºC*	Present	- 55,007	44,666	0,9973
		Absent	- 49,957	47,071	0,9992
Class 2(Ø 12,1 -16 cm)	50ºC	Present	50,127	0,044	0,9958
		Absent	46,148	0,068	0,9889
	75ºC	Present	55,668	0,151	0,9951
		Absent	53,464	0,192	0,9949
	100ºC	Present	48,964	0,474	0,9940
		Absent	50,673	0,551	0,9908
	125ºC	Present	45,005	0,907	0,9774
		Absent	55,615	0,908	0,9871
	150ºC*	Present	-40,144	53,597	0,9865
		Absent	-37,963	48,947	0,9942
Class 3(Ø 16,1 - 20 cm)	50ºC	Present	54,693	0,040	0,9963
		Absent	50,128	0,059	0,9959
	75ºC	Present	79,600	0,086	0,9978
		Absent	78,455	0,095	0,9981
	100ºC	Present	68,930	0,420	0,9957
		Absent	59,546	0,420	0,9984
	125ºC	Present	67,466	0,674	0,9894
		Absent	74,060	0,739	0,9903
	150ºC	Present	71,451	0,618	0,9823
		Absent	69,161	0,607	0,9922

*Linear model

presence or absence of bark. Thus, the distances between the drying curves and the different drying periods verified in the Figures 1 and 2 are a result of the differences that exist between the drying rates in each temperature (Table 2).

The lower average drying rate, 0,08%/hour, happened at the 50ºC temperature; when the log drying was made at 75ºC, the drying rate was elevated at around 4 times, presenting a value equal to 0,30%/hour, while that for 100ºC, which the average drying rate value was 0,82%/hour, the rate was 2,7 times higher than the one verified at the 75ºC temperature and 10 times higher than at 50ºC. For the 125ºC temperature, it can be observed that the 2 times increase in the drying rate which average value was 1,68%/hour; there was no alteration in the average value of the drying rate observed at the 150ºC temperature in relation to the 125ºC one. Thus, the 5 time increase in the drying temperature made a 20 time increase in the drying rate of the wood log. As verified in this work, Santini and Haselein (2002) observed a higher drying rate for *Pinus* sawed wood in more elevated temperatures, in this case 110ºC in relation to 50ºC.

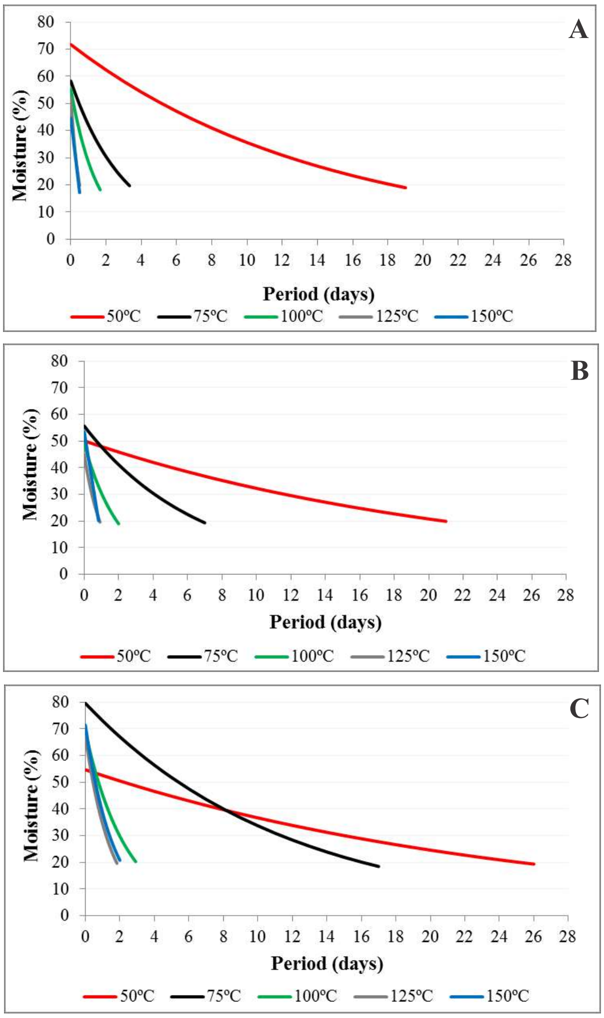

Figure 1 – Average estimated values of moisture from the Eucalyptus logs with bark, in drying temperature function. (**A**) Class 1 (Ø 8-12 cm); (**B**) Class 2 (Ø 12,1-16 cm); (**C**) Class 3 (Ø 16,1-20 cm).

Figura 1 – *Valores médios estimados de umidade das toras de eucalipto com casca em função da temperatura de secagem. (**A**) Classe 1 (Ø 8-12 cm); (**B**) Classe 2 (Ø 12,1-16 cm); (**C**) Classe 3 (Ø 16,1-20 cm).*

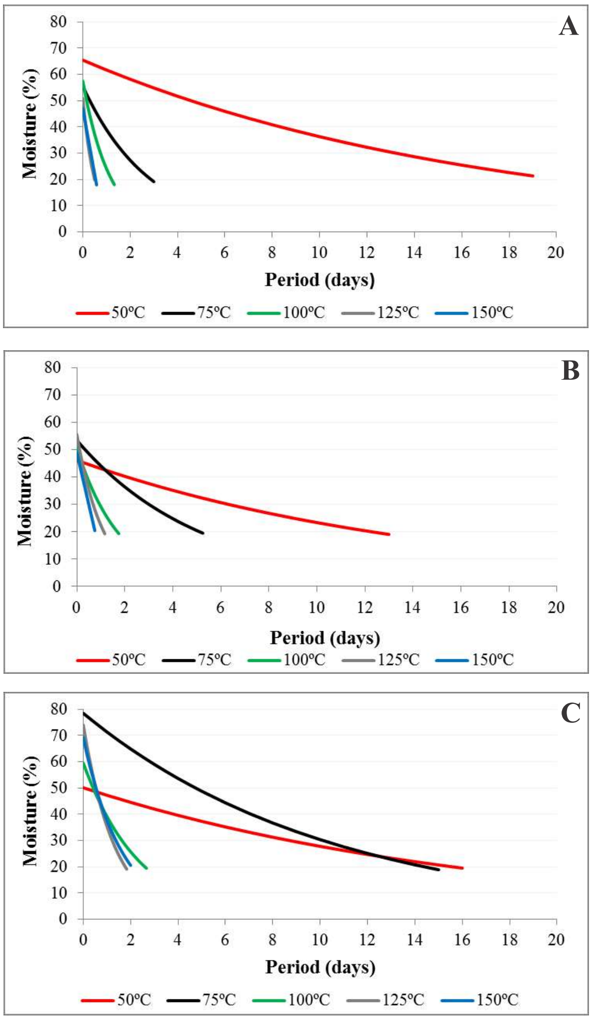

Figure 2 – Average estimated values of moisture from the Eucalyptus logs without bark, in drying temperature function. (A) Class 1 (Ø 8-12 cm); (B) Class 2 (Ø 12,1-16 cm); (C) Class 3 (Ø 16,1-20 cm).

Figura 2 – *Valores médios estimados de umidade das toras de eucalipto sem casca em função da temperatura de secagem. (**A**) Classe 1 (Ø 8-12 cm); (**B**) Classe 2 (Ø 12,1-16 cm); (**C**) Classe 3 (Ø 16,1-20 cm).*

Raad (1997), when evaluating the *Eucalyptus* spp. wood drying between 75 to 225ºC, has verified a 30% decrease in the the drying period for each 25°C temperature increase until 150ºC, higher than this temperature there were no alterations in the drying curve and in the total drying time. This work verified that until the temperature of 125ºC, variable reductions of 2 to 3 times in the drying period and, from 125ºC, the increase of the drying temperature to 150ºC promoted a reduction of 10% in the period of time, or no alteration, as verified for the Class 1 logs.

The lower drying time at high temperatures is due to the increase of heating supply rate to the wood, resulting in a increase of the speed in the migration speed of the internal moisture to the surface, elevating the drying speed (Santos et al, 2010; Coelho, 2013). Another reason for the higher drying efficiency is the

Table 2 – Average drying rate values, %/hour, Eucalyptus logs depending on the drying temperature, diameter class, and bark presence or absence.

Tabela 2 – *Valores médios da taxa de secagem, %/hora, das toras de eucalipto em função da temperatura de secagem, classe diamétrica e presença ou ausência de casca.*

Diametric Class	Bark	Drying rate (%/hour)				
		50ºC	75ºC	100ºC	125ºC	150ºC
Class 1(Ø 8-12 cm)	Present	0,12	0,48	0,93	2,68	2,29
	Absent	0,09	0,51	1,31	2,59	2,43
Class 2(Ø 12,1 -16 cm)	Present	0,06	0,22	0,64	1,15	1,67
	Absent	0,09	0,27	0,75	1,30	1,58
Class 3(Ø 16,1 - 20 cm)	Present	0,06	0,15	0,70	1,09	1,06
	Absent	0,08	0,17	0,63	1,25	1,01

higher drying speed of the wood's surface, elevating the moisture gradient between the surface and interior, also elevating the air capacity to receive a higher amount of water steam.

Several studies evaluating the natural drying of eucalyptus logs report that the minimum drying period is around 60 days for lesser diameter logs reach a 30% average moisture (Rezende et al., 2010; Pinheiro, 2013). Thus, the use of oven dryings with elevated temperatures is an option for reducing the wood log drying time and obtaining lower moisture scents, because for reaching a 20% moisture were necessary an average period of 20 days of drying at 50ºC; 8 days at 75ºC; 2 days for 100ºC and 1 day to 150ºC, with longer times for the larger diameters logs being verified.

In artificial dryers projects that aim to use the carbonization combusted gases as heat source, it is necessary the mix of the gases with the ambient air for fitting the fluid temperature to the more secure drying condition, since according to Oliveira et al., (2013), the liberated gases from the furnace reach temperatures that varies from 200 to 500ºC. Thus, aiming to the wood log drying, the more elevated temperatures would be the more indicated ones to the dryer operation because of the necessity of lower temperature reduction of the furnace gases and the higher drying speed resulting in a lower occupation time of the drying chamber, allowing the wood drying for several carbonization cycles.

However, because of how the differences among the drying time and rates between the 125º and 150ºC temperatures (Table 2) were not expressive, it is recommended that the wood log drying operation in metallic industrial dryers to be made at 125ºC, aiming for less damage to the structure of the dryer and fire risk, mainly when the wood presents a low moisture scent.

Generally, higher drying rates can be verified for the barkless logs, reflecting at lower drying times at the oven drying. For the 50ºC temperature, the average difference between the rates was 25%; at 75 and 100ºC, there was a reduction in this difference, which varied between 15 and 20%, with a significant difference in these temperatures for the drying periods until the stablished moisture scent being noticed. For the temperatures higher than 100ºC, difference of less than 10% between the drying rates for bark and barkless logs were observed, resulting in drying times equal or closer, differences of 2 to 4 hours, for drying conducted at 125 and 150ºC in the different diametric classes.

Vital et al. (1985); Rezende et al. (2010) and Pinheiro (2013) evaluating the natural drying of eucalyptus wood logs noticed that the bark presence influences in the drying period, becoming less effective with the moisture scent reduction. For the drying at superior than 100ºC temperatures, like the evaluation at this work, there was no significant effect of the bark presence on the drying time of eucalyptus logs, regardless of the diameter. Thus, the artificial dryers for wood log should operate at the 100 to 150ºC temperature rate for the debarking to be unnecessary, because it elevates the costs and activities involved in the production of wood made for carbonization.

5. CONCLUSION

The wood log drying at oven dryings at higher temperatures promoted the moisture reduction to values next to 20% for all the diametric classes, with the presence or absence of bark, in periods of less than 30 days.

The rise in the temperature promoted the increase of the drying rate and thus reducing the drying time, without alteration from 125ºC. The bark presence *Eucalyptus urophylla* wood log was insignificant in the drying at temperatures higher than 100ºC, so the debarking is not recommended.

The drying rate of the smaller diameter logs were superior to the verified rates of the larger ones at the same temperature conditions, resulting in differences in the drying period, with the recommendation for the logs to be separated in diametric classes before the oven drying.

The best condition for operation artificial dryers for eucalyptus wood logs would be with the presence of the bark, separated in diametric classes and at 125ºC.

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