QUALITY OF *Eucalyptus urograndis* CHARCOAL PRODUCED IN THE SOUTHERN REGION OF TOCANTINS

Raquel Marchesan[1*], Daniela Mendonça[2], Ana Carolina Caixeta Dias[3], Renata Carvalho da Silva[2], José Fernando Pereira[1], Vanessa Coelho Almeida[1]

[1]Federal University of Tocantins - UFT, Forest Engineering Departament, Gurupi, TO, Brazil - raqmarchesan@gmail.com*;
vanessacoelhoalmeida@uft.edu.br; josé.pereira@uft.edu.br;
[2]Forest Eng., Gurupi, TO, Brazil - renatacsilva@uft.edu.br;
[3]Forest Eng., M.Sc. in Forest and Environmental Sciences, UFT, Gurupi, TO, Brazil - vania.wcaixeta@gmail.com.com.

Recebido para publicação: 02/02/2018 – Aceito para publicação: 27/02/2019

Resumo

Qualidade do carvão vegetal de Eucalyptus urograndis produzido na região sul do Tocantins.O objetivo do trabalho foi determinar a qualidade do carvão vegetal do clone de *Eucalyptus urophilla* x *Eucalyptus grandis* definindo a densidade básica e retratibilidade da madeira, densidade aparente, índice de quebra, rendimento do carvão vegetal, rendimento em gases condensáveis e não condensáveis, AQI e poder calorífico, comparando os resultados de diferentes posições do tronco e em duas diferentes Rampas de carbonização, Rampa 1 (M1) com taxa de aquecimento de 1,25 ºC/min, temperatura final de 450ºC e tempo total de 6 horas, e Rampa 2 (M2) com taxa de aquecimento de 1,19 ºC/min, temperatura final de 500ºC e tempo total de 7 horas. As seis árvores avaliadas foram provenientes de um plantio clonal de seis anos de idade localizado no município de Gurupi, sul do estado do Tocantins. Os corpos de prova para as caracterizações foram confeccionados a partir de discos de madeira retirados das três posições do tronco (base, DAP, topo). A madeira de *Eucalyptus* urograndis apresentou densidade básica considerada média (0,47 g/cm³) e boa estabilidade dimensional. O carvão apresentou rendimento dentro do esperado, alto poder calorífico, influenciado pela temperatura final das Rampas de carbonização, alto teor de carbono fixo, teor de cinzas aceitáveis, além de baixo índice de quebra. Os resultados foram satisfatórios e identificaram a espécie como uma boa fonte energética.

Palavras-chave: retratibilidade, densidade básica da madeira, características energéticas, carvão vegetal.

Abstract

The objective of this work was to determine the quality of the *Eucalyptus urophilla* x *Eucalyptus grandis* clone charcoal, defining the basic density and wood retractability, apparent density, breaking index, charcoal yield, condensable and non-condensable gas yield, AQI and calorific values, comparing the results of different trunk positions and in two different heating ramps, ramp 1 (R1) with a heating rate of 1.25 ºC/min, final temperature of 450ºC and total of 6 hours, and ramp 2 (R2) with a heating rate of 1.19 ºC/min, final temperature of 500ºC and total time of 7 hours. The six evaluated trees were from a six-year-old cloned tree plantation located in the municipality of Gurupi, in the south of Tocantins state. The specimens for the characterizations were made from wooden discs removed from three trunk positions (base, DBH, top). The *Eucalyptus urograndis* wood presented basic density considered average (0.47 g/cm³) and good dimensional stability. The charcoal presented an expected yield and high calorific value influenced by the final temperature of the heating ramps, high fixed carbon content, acceptable ash content, as well as a low breaking rate. The results were satisfactory and identified the species as a good energy source.

Keywords: Retractability, basic wood density, energetic characteristics, charcoal.

INTRODUCTION

Wood is used for a variety of purposes, including energy uses. Data from the Food and Agriculture Organization (FAO) of the United Nations (2017) point to wood as the most important source of renewable energy, accounting for about 6% of the global supply of primary energy. Biomass in Brazil is largely made up of wood and when energy production is evaluated, it can be said that its use is divided into charcoal production (carbonization) and direct consumption of firewood (combustion) (Vale *et al*., 2002).

Charcoal is only a fraction of the products that can be obtained in the carbonization process. If appropriate collection systems are used, condensable and non-condensable gases can be obtained. Pyroligneous liquor, which is a condensable gas, can be used for energy as well as for several different purposes such as fertilizer, disinfectant, sterilizer, and as a food additive, among others.

Brazil is the largest producer and consumer of charcoal globally, and the only country to produce it commercially on a large scale. The charcoal consumer market is basically made up of the pig iron and ferroalloy industries (82% of the coal produced). The use of charcoal has advantages over coke as a reducing agent in the steel industry, for example lower ash, lower sulfur and phosphorus, and is more reactive. Moreover, and especially being more environmentally friendly because it is renewable and less polluting (OLIVEIRA *et al*., 2010).

Most energy forests plantations consist of the *Eucalyptus* genus, with characteristics such as rapid growth and considerable wood density, which guarantee easily renewable and good quality charcoal. The most used species in Brazil for these purposes are *E. grandis*, *E. saligna*, *E. camaldulensis* and *E. urophylla*, as well as their hybrids (SANTOS *et al*., 2010). *E. urograndis* is a hybrid developed by crossbreeding *E. urophylla* and *E. grandis*.

The first *Eucalyptus* plantations in Tocantins state appeared in the year 1990 and its main purpose was for farm sustainability. The region had an area of 13,900 hectares planted with eucalyptus until 2006, while plantations had an area of 109,000 hectares in 2012 (ABRAF, 2013). The main purpose of these plantations at the beginning was to supply the demand for wood for pulp production, mainly in Maranhão state, but as this demand was not fulfilled, the wood was directed to producing charcoal for use in steel industries in Tocantins, Goiás and Minas Gerais states.

The growth of this type of plantation in this region can be explained by the concentration of plantations in the south and southeast of Brazil, which caused the price of land to inflate, encouraging producers to migrate to the northern region; in addition, the characteristics of this region are favorable for good forest development, and despite the particularities such as high temperature and prolonged drought, some species are able to adapt and produce satisfactory results.

In this context, the objective of this work was to evaluate the quality of *Eucalyptus urograndis* charcoal aiming at energy production in the southern region of Tocantins state.

MATERIAL AND METHODS

The material for this study was obtained from six six-year-old trees in an experimental *Eucalyptus urophilla* x *Eucalyptus grandis* plantation from the Federal University of Tocantins, in Gurupi - TO University Campus, located in the south of the state, at 11º74'S and 49º04'W, at 280 meters of altitude. The study was conducted at the Forest Products Technology and Utilization laboratory at the Federal University of Tocantins.

Short logs were cut to 50 cm length at three trunk positions (Base, Diameter at Breast High, Top) of the felled trees for research. They were sent to a carpentry industry to manufacture specimens to determine shrinkage, basic wood density and to produce charcoal. All specimens were cut to approximately 5.0 x 2.5 x 2.5 cm (length x width x thickness) and identified with their original position.

Wood Characterization

Retractability

Wood retractability was obtained by selecting 10 specimens from each position (Base, DBH and top) with well-oriented radial, tangential and transverse planes. They were immersed in water until complete saturation, and after each of which was measured with an analog caliper to determine the saturated dimensions of each plane. They were subsequently put to dry at 0% humidity in a kiln at a temperature of 103 ± 2 ºC to constant mass, which were then measured after drying to determine the dry dimensions. The following were then calculated from the resulting data: radial, tangential, longitudinal, volumetric shrinkage and anisotropic factor based on COPANT 462 (1972).

Basic Density

Basic wood density was determined by the hydrostatic balance method for 20 specimens from each trunk position (Base, DBH and Top), totaling 60 specimens, and calculated based on ASTM D-2395 (ASTM, 2005).

Charcoal Production and Energy Characterization

For the charcoal production, the same 20 specimens obtained from each trunk position were used to determine the basic density, totaling 60 specimens. The specimens were charred in a muffle kiln adapted to capture pyroligneous liquor and programmed with two different carbonization increases (Table 1). Two ramped increases were then performed for each trunk position (base, DBH and top) using 10 specimens for each Ramp, totaling six pyrolysis groups. The first Ramp had a heating rate of 1.25°C/min, final temperature of 450°C and total time of 6 hours. The second Ramp had a heating rate of 1.19°C/min, final temperature of 500°C and total time of 7 hours. The specimens were brought to a dry chamber at 103 ± 2°C for 24 hours prior to carbonization to remove moisture from the wood.

Table 1. Temperature and carbonization time as a function of the carbonization run.
Tabela 1. Temperatura e tempo de carbonização em função da Rampa de carbonização.

Ramp	Temperature °C						Heating Rate °C/min	Total
	150	200	250	350	450	500		Time
1	1 hour	1 hour	1h30	1h30	1 hour	-	1.25	6 hours
2	1 hour	1 hour	1h30	1h30	1 hour	1hour	1.19	7 hours

The following were calculated after carbonization: charcoal yield, condensable and non-condensable gases, bulk density, gravimetric yield, breaking index, immediate chemical analysis (ICA) and calorific value.

Charcoal Yield, Condensable and Non-Condensable Gases

The adaptation to collect pyroligneous liquor made it possible to define the yield in charcoal, condensable and non-condensable gases. The reactor was first weighed with the wood prior to carbonization, as well as all parts of the pyrolysis system. After carbonization, all parts of the system containing liquor as well as the reactor with charcoal were weighed again to determine the yields (Equations 1, 2 and 3).

$$Yc = \frac{Mc}{Mw} * 100 \qquad (1)$$

Where: Yc = charcoal yield (%); Mc = mass of charcoal (g); Mw = wood mass (g).

$$Ycg = \frac{Ml}{PmMw} * 100 \qquad (2)$$

Where: Ycg = condensable gas yield (%); Ml = mass of pyroligneous liquor (g); Mw = wood mass(g).

$$Yncg = 100 - Yc - Ycg \qquad (3)$$

Where: Yncg = non-condensable gas yield (%); Yc = charcoal yield (%); Ycg = condensable gas yield (%).

Apparently density

Charcoal apparent density was defined as the ratio between the mass of charcoal weighed on an analytical scale and its volume, which was calculated by measuring its dimensions (length, width and thickness) with an analog caliper, as presented in Equations 4 and 5.

$$Dap = \frac{M}{V} \qquad (4)$$

Where: Dap = apparent density (g/cm³); M = mass of charcoal (g); V = volume of charcoal (cm³).

$$V = l * w * t \qquad (5)$$

Where: V = volume of charcoal (cm³); l = length, w = width and t = thickness (cm).

Breaking Index

The coal strength test was determined according to its breaking index based on ABNT NBR 7416/84 (ABNT, 1984), in which each charcoal was subjected to a free fall of 1830 mm and this fall test was repeated up to 3 times. The charcoal was weighed before and after testing, and the largest fragment resulting after the fall was weighed. The breaking index was determined using Equation 6.

$$Bi = \left(1 - \frac{f}{F}\right) * 100 \qquad (6)$$

Where: Bi = Breaking Index (%); f = largest fragment after testing (g); F = coal sample before testing (g).

Immediate Chemical Analysis (ICA)

An analysis of the immediate chemical composition of the charcoal was performed based on ASTM D 1762/84 (ASTM, 2007). The produced charcoals were ground separately producing 10 samples sorted by position origin and carbonization Ramp, totaling 60 samples. They were placed in porcelain crucibles, weighing the moist samples first, then placed in a drying kiln at approximately 100°C for 30 min. to obtain the dry mass. Finally, the crucibles with the charcoal samples were sent to a muffle kiln, where they remained first for 7 minutes at 900°C to determine the volatile materials, and then for another 7 hours at 700°C to determine the fixed carbon and ash contents.

Calorific Power

The calorific power of charcoal was determined based on the methodology of Do Vale *et al.* (2002), according to Equation 7:

$$CP = 4934{,}43 + 33{,}27 * FC \tag{7}$$

Where: CP = calorific power (kcal.kg^{-1}) and FC = fixed carbon percentage (%)

Statistical analysis

The experimental design was completely randomized with a 3x2 factorial arrangement considering the origin position factors of the samples and the two different carbonization Ramps. Statistical analysis was performed by the Assistat and Excel programs. The Tukey test was used for immediate chemical analysis and calorific value wood quality parameters. The Kruskal-Wallis test was used for other parameters.

RESULTS

Wood Characterization

Table 2 presents the analysis of variance for the physical properties of wood parameters.

Table 2. ANOVA of the basic density and retractability of *E. urograndis* wood.
Tabela 2. ANOVA da densidade básica e retratibilidade da madeira de *E.* urograndis.

Parameters	**F**
Basic wood density (g/cm³)	33.76 **
Tangential shrinkage (%)	9.19 **
Radial shrinkage (%)	0.04 ns
Longitudinal shrinkage (%)	0.21 ns
Volumetric shrinkage (%)	3.46 *
Anisotropic factor	1.82 ns

* significant at 5% probability level (.01 =<p <.05); ** significant at 1% probability level (p <.01); ns - not significant (p>= .05)

In Table 2, the analysis of variance of basic density and tangential shrinkage were significant at 1% probability level, while the volumetric shrinkage was significant at a 5% probability level. Radial and longitudinal retraction and anisotropic factor were not significant.

Table 3 shows the average values for the physical properties of wood parameters.

Table 3. Basic density and retractability of *E. urograndis* wood.
Tabela 3. Médias de densidade básica e retratibilidade da madeira de *E*. urograndis.

Parameters	**Positions**	
Basic Wood Density (g/cm^3)	Base	0.50 a (0.01 ; 2.86)
	DBH	0.46 b (0.01 ; 2.47)
	Top	0.44 c (0.02 ; 3.73)
Tangential shrinkage (%)	Base	7.13 a (0.75 ; 10.58)
	DBH	6.31 b (0.51 ; 8.04)
	Top	6.12 b (0.33 ; 5.37)
Radial retraction (%)	Base	4.35 a (0.80 ; 18.50)
	DBH	4.27 a (0.67 ; 15.66)
	Top	4.28 a (0.41 ; 9.59)
Longitudinal shrinkage (%)	Base	0.16 a (0.21 ; 131.15)
	DBH	0.23 a (0.31 ; 137.91)
	Top	0.18 a (0.11 ; 63.65)
Volumetric shrinkage (%)	Base	11.64 a (1.21 ; 10.38)
	DBH	10.81 ab (0.93 ; 8.61)
	Top	10.58 b (0.59 ; 5.53)
Anisotropic factor	Base	1.66 a (0.35 ; 21.12)
	DBH	1.53 a (0.24 ; 15.75)
	Top	1.44 a (0.15 ; 10.47)

The average followed by the same letter in the column do not differ statistically from each other by the Tukey test (5%). The values in parentheses respectively correspond to standard deviation and coefficient of variation (%).

Characterization of Charcoal

Table 4 presents the average yield values in charcoal, condensable and non-condensable gases of *E. urograndis* wood.

Table 4. Averages of charcoal yield in condensable and non-condensable gases of *E*. urograndis wood.
Tabela 4. Médias de rendimento em carvão, em gases condensáveis e não condensáveis de *E*. urograndis.

		Carbonization Rises	
Parameters	**Positions**	**450°C**	**500°C**
Charcoal yield (%)	Base	33.33	32.93
	DBH	31.17	31.17
	Top	30.49	30.12
Condensable gas yield (%)	Base	47.62	44.51
	DBH	45.45	46.10
	Top	50.00	48.19
Non-condensable gas yield (%)	Base	19.05	22.56
	DBH	23.38	22.73
	Top	19.51	21.69

Table 5 presents average values of apparent density and breaking index of *E. urograndis* charcoal.

Table 5. Average values of apparent density, gravimetric yield and breaking rate of *E.* urograndis charcoal.
Tabela 5. Médias de densidade aparente, rendimento gravimétrico e índice de quebra do carvão de *E.* urograndis.

		Carbonization Ramps	
Parameters	**Positions**	**450°C**	**500°C**
Apparent density (g/cm³)	Base	0.35 B	0.35 B
		(0.02 ; 5.47)	(0.02 ; 5.59)
	DBH	0.26 AB	0.23 A
		(0.02 ; 6.61)	(0.02 ; 7.18)
	Top	0.23 A	0.26 AB
		(0.04 ; 15.84)	(0.01 ; 4.98)
Breaking index (%)	Base	0.74 B	0.38 AB
		(0.17 ; 22.42)	(0.28 ; 73.55)
	DBH	0.19 A	0.15 A
		(0.16 ; 83.70)	(0.15 ; 99.05)
	Top	0.15 A	0.32 AB
		(0.10 ; 66.15)	(0.15 ; 47.17)

The average rate followed by the same letter in the row and column do not differ statistically from each other by the Kruskal-Wallis test (5%). The values in parentheses correspond respectively to standard deviation and coefficient of variation (%).

Table 6 presents the statistical analyzes of variance and significance of the ICA parameters and calorific power of *E. urograndis* charcoal between position interaction and carbonization ramp.

Table 6. ANOVA of volatile materials, fixed carbon, ash and calorific value of *E. urograndis* charcoal.
Tabela 6. ANOVA dos materiais voláteis, carbono fixo, cinzas e poder calorífico do carvão de *E.* urograndis.

Parameters	*Positions*	*Ramps*	*P x M*
Volatile Materials (%)	ns	**	**
Fixed Carbon (%)	*	**	**
Ashes (%)	**	**	**
Calorific power (%)	*	**	**

** significant at 1% probability level; * significant at 5% probability level; ns - not significant

The analysis of variance of the Immediate Chemical Analysis in Table 6 shows no significant difference for volatile materials between positions, and significant differences at the 1% probability level between the two different Carbonization Ramps and between the Ramp-Position interaction. There was a significant difference at 5% probability between positions for fixed carbon, and significant differences at 1% probability level between the two different Carbonization Ramps and between the Ramp-position interaction. There was also a significant difference at the 1% probability level for ashes between positions, Ramps and Ramp-Position interaction. Lastly, the calorific power presented significant positions at 5% probability, the Ramp and a significant Ramp-position interaction at 1% probability.

Table 7 shows the average test values for the parameters of the immediate chemical analysis and the calorific power of *E. urograndis* charcoal.

Table 7. Average values of volatile materials, fixed carbon, ash and calorific power of *E. urograndis* charcoal.
Tabele7. Averages of volatile materials, fixed carbon, ash and calorific value of *E.* urograndis charcoal.

		Carbonization Ramps	
Parameters	**Positions**	**450°C**	**500°C**
Volatile Materials (%)	Base	25.47 abA	21.24 aB
		(1.50 ; 5.88)	(0.98 ; 4.61)
	DBH	26.10 aA	18.60 bB
		(1.72 ; 6.58)	(1.00 ; 5.38)
	Top	24.52 bA	21.74 aB
		(1.11 ; 4.54)	(1.56 ; 7.17)
Fixed Carbon (%)	Base	73.87 abB	78.17 bA
		(1.49 ; 2.01)	(0.98 ; 1.26)
	DBH	73.46 bB	80.96 aA
		(1.72 ; 2.35)	(1.00 ; 1.23)

	Top	75.02 aB (1.11 ; 1.48)	77.81 bA (1.55 ; 1.99)
Ashes (%)	Base	0.66 aA (0.04 ; 6.14)	0.59 aB (0.04 ; 6.35)
	DBH	0.44 bA (0.02 ; 4.21)	0.43 bA (0.02 ; 5.65)
	Top	0.46 bA (0.02 ; 4.08)	0.45 bA (0.03 ; 6.40)
Calorific power (%)	Base	7392.09 abB (49.50 ; 0.67)	7535.16 bA (32.66 ; 0.43)
	DBH	7378.57 bB (57.32 ; 0.78)	7628.13 aA (33.21 ; 0.44)
	Top	7430.2 aB (36.85 ; 0.50)	7523.28 bA (51.54 ; 0.69)

The average followed by the same uppercase letter in the row and the same lowercase letter in the column do not differ statistically from each other by the Tukey test (5%). The values in parentheses respectively correspond to standard deviation and coefficient of variation (%).

DISCUSSION

Wood Characterization

Table 3 shows that the average for the basic wood density parameter decreased in the base-top direction due to the fact that the fibers have a thicker cell wall at the base and are less thick at the top for fact that the top has more youthful wood and the base is adult wood. The average result from the base was 0.50 g/cm³ and from the top 0.44 g/cm³, so all positions presented significant differences at the 5% probability level. The average values of *E. urograndis* wood sample density from this study were similar but lower than those found by Gonçalez *et al.* (2014) of 0.51 g/cm³ for 8-year-old *E. urograndis*, and of 0.54 g/cm³ by Santos *et al.* (2011) for *Eucalyptus* clones at seven years of age.

Basic wood density is considered an index for wood quality assessment, being one of the most relevant indicators to be evaluated among the various physical properties, as it can affect the others, especially the energy properties since wood density directly interferes with the charcoal density, its yield and quality. According to Coradin *et al.* (2010) and Silveira *et al.* (2013), woods are classified as light or low density (<0.550 g/cm^3), medium density (between 0.550 and 0.720 g/cm^3) and heavy or high density (> 0.730 g/cm^3). The higher the density, the more fixed carbon, the higher the calorific value, and the greater the energy potential. *E. urograndis* wood presented average basic density values which are considered low (0.46 g/cm³), mainly in the top position, which classifies it as low density wood. This factor may be linked to the tree age and environmental conditions.

Regarding the retractability (presented in Table 2), there was also a decrease of the average value in the base-top direction for the tangential shrinkage parameter, with a maximum average of 7.13% and a minimum of 6.12%, in which the position from the base differed statistically from the others at the 5% probability level. The averages were lower than that found by Batista *et al.* (2010), which was 9.25% for *E. grandis*.

There was a small variation in the averages for the radial shrinkage and longitudinal shrinkage parameters (Table 3), with the positions being statistically equal. The radial retraction average was 4.35% maximum and 4.27% minimum, which is close to that found by Batista *et al.* (2010) which was 4.60% for *E. grandis*. The average for longitudinal retraction was insignificant.

There was a decrease in the average for the volumetric shrinkage parameter in the base-top direction, with a maximum average of 11.64% and a minimum of 10.58%, thus resulting in a significant difference between the base and top at the 5% probability level, and meaning that the wood from the top has greater dimensional stability. The average volumetric retraction rate found by Batista *et al.* (2010) for *E. grandis* was higher, 14.10%, which means that the *E.* urograndis species studied in the present work has lower retractability, and therefore greater dimensional stability.

The anisotropic factor (still in Table 3), showed little variability of averages, where there was no statistical difference between one position from another. The average values of this factor ranged from 1.44 to 1.66, consequently lower than the average found by Batista *et al.* (2010) for *E. grandis* which was 2.05. The anisotropic factor is a paramount parameter for assessing the dimensional stability of wood. Following classification criteria, the wood of the species in this study is classified as normal at the base and excellent at the top for its dimensional stability.

Charcoal Characterization

Table 4 compares the charcoal yield in condensable and non-condensable gases between the different trunk positions and the different carbonization Ramps, in which the highest charcoal yield was based on the 450°C carbonization Ramp with a value of 33.33%, and the smallest was from the top in the 500°C Carbonization Ramp with a value of 30.12%. These values are similar to those of Oliveira *et al.* (2010), in which the *E. pellita* species for the same 450°C Ramp obtained 32.11% in charcoal yield, and a value of 31.09% for the same 500°C Carbonization Ramp. Vieira *et al.* (2013) found an average of 34% for *Eucalyptus micocorys* at the final temperature of 500°C. Soares *et al.* (2015) produced charcoal with yields of 33.06% with *Eucalyptus* at seven years of age at the final temperature of 450°C. It can be observed that higher temperature carbonization ramps tend to produce lower charcoal yields. Vilas Boas (2010) reports that this occurs due to the decomposition of the chemical constituents of wood, causing mass loss and consequently a loss in charcoal yield. It was also observed that the base tends to have higher yield because it has higher density compared to the top. Higher densities result in higher charcoal yield.

The yield for condensable gases (Table 4) was higher at the top for the 450°C Carbonization Ramp with a value of 50.00% and lower at the base for the 500°C Carbonization Ramp with a value of 44.51%. These values are slightly lower than those of Oliveira *et al*. (2010), in which the E. pellita species obtained 58.95% in condensable gas yield for the same 450°C Ramp, and 58.98% for the same 500°C Ramp. In a study with the *Corymbia citriodora* species and species of the *Eucalyptus* genus, Zanuncio *et al*. (2015) showed a lower average value of 31.05% for the *Corymbia citriodora* species at the final temperature of 450°C. The carbonization ramps in the present work significantly interfered in the pyroligneous liquor yield, with the lowest temperature increase being the most efficient for this parameter.

The non-condensable gas yield (Table 4) was higher in the DBH for the 450°C Carbonization Ramp with a value of 23.38%, and lower for the same Carbonization Ramp with a value of 19.05%. These values are much higher than those found by Oliveira *et al*. (2010), in which the *E. pellita* species obtained a non-condensable gas yield of 8.93% for the same Ramp of 450°C. Assis *et al*. (2012) studied the quality and yield of charcoal from a hybrid *Eucalyptus grandis* x *Eucalyptus urophylla* crossover clone and found higher average values for non-condensable gases of 28.89% at the final temperature of 450°C. Non-condensable gases as well as condensable gases have achieved high yields, and these can be harnessed in the energy industry as a source of energy through the dry distillation process that can be implanted from retorts rather than conventional ovens. The present work presented considerable yields, and thus the *E. urograndis* species can be considered as a good energy source.

The apparent density (Table 5) decreased in the base-top direction, as seen in the basic density, as they are similar parameters. The density of charcoal and the density of its source wood are correlated, and therefore there is a correlation between them, which indicates that the type of wood is determinant in the final density of charcoal. The highest apparent density was from the base with a value of 0.35 g/cm³ in the two different carbonization ramps. The lowest apparent density was 0.23 g/cm³, with this same value at the top and DBH of the 450°C and 500°C carbonization ramps, respectively. The average apparent density values of *E. urograndis* in the present study were similar to those found by Santos *et al*. (2011), of 0.27 to 0.35 g/cm³ in a study conducted with *Eucalyptus* clones by Oliveira *et al*. (2010), and in a study with *Eucalyptus pellita* F. Muell in which the authors found averages ranging from 0.353 to 0.368g/cm³.

The base and top had a significant statistical difference in the carbonization Ramp of 450°C. In contrast, the positions which had a significant difference were in the base and in DBH in the carbonization Ramp of 500°C. In general, the base stood out with higher densities, with this being an important feature for the load composition in the kiln, as the higher the charcoal density, the smaller the volume occupied by it and the higher the yield.

The breaking index (Table 5) also tended to be higher at the base, coinciding with the density and retractability which were higher at the base, and can be explained by the fact that the denser the specimen, the greater the impact on the fall which influenced the breaking, in addition to greater retractability in the base, meaning lower dimensional stability, thus influencing the index by possible cracks in the carbonization process of charcoal, which decreases its resistance. However, the species of the present work generally presented significantly low data average, meaning that the species is resistant to breakage. The highest value was 0.74% of base in the 450°C Carbonization Ramp and the lowest was 0.15% of the top and DBH for the 450°C and 500°C Carbonization Ramps, respectively. The base had a statistically significant difference from the other positions in the Carbonization Ramp of 450°C, while there were no significant differences in the Carbonization Ramp of 500°C.

Table 7 presents the ICA and calorific value data. The highest values for volatile materials were for the 450°C Carbonization Ramp with the largest DBH value (26.10%), and the lowest values of the 500°C Ramp was the lowest DBH value (18.60%), constituting higher values than those found by Oliveira *et al*. (2010) for the *E. pellita* species of 12.04% and 11.15% in the 450°C and 500°C Ramps, respectively. In studying *Eucalyptus* clones, Reis *et al*. (2013) also found average values close to this study of 26.04% for the final temperature of 450°C. In their study with *Eucalyptus* clones, Chaves *et al*. (2013) found close averages ranging from 24.63% to 19.59%. Furthermore, in a study with *Eucalyptus benthamii*, Nones *et al*. (2015) observed a high average content of 30.41%. Volatile materials are responsible for ignition of the material, and it is interesting to have a value less or equal to 25.00%, which constitutes the value resulting from the data of resolution SAA - 40 (2015), and defines values for fixed carbon and ash. The values of the present work for the volatile materials parameter were approximately 25.00%, which is ideal. The carbonization ramps were statistically different from each other, the positions were statistically different between DBH and the top in the 450°C ramp, while DBH in the 500°C ramp was the position that differed from the others.

The highest values for fixed carbon were for the 500°C Carbonization Ramp, with the largest being the DBH value (80.96%), and the lowest values of the 450°C Ramp being the lowest DBH value (73.46%). These values are lower than those found by Oliveira *et al*. (2010) for the *E. pellita* species of 86.10% and 86.66% in the 450°C and 500°C Ramps, respectively; and by Reis *et al*. (2013), who found average values between 71.74% and 76.93% for species of the *Eucalyptus* genus, with the values being considered close to those observed in this study for three species of the *Eucalyptus* genus. Fixed carbon is a parameter of great importance for the calorific power of charcoal, as they have direct proportionality. Resolution SAA - 40 (2015) recommends approximately 73.00% fixed carbon for good quality charcoal. The values of the present work were approximate, thus defining the *E. urograndis* species as being optimal for energy potential. The carbonization ramps were statistically different from each other, the positions were statistically different between DBH and top in the 450°C ramp, and DBH in the 500°C ramp was the position that differed from the others. Since the volatile material and fixed carbon levels are inversely proportional, the lowest value for fixed carbon was observed in the treatment with the highest value for volatile material, and vice versa.

The highest value for ash content was 0.66% for the base at the 450°C Carbonization Ramp, while the lowest value was 0.43% for the DBH at the 500°C Ramp. These values are lower than those found in the study by Oliveira *et al*. (2010) for the *E. pellita* species, which were 1.86% and 2.19% in the 450°C and 500°C Ramps, respectively. In a study with *Eucalyptus* hybrids of different ages, Soares *et al*. (2015) found ash content at five years of age of 0.87%, being higher than the values of the present study. Ashes are not useful for energy use, as they have no purpose in Energy production; they constitute a waste which can cause corrosion and require greater maintenance in boilers when in large quantities, so the lower the ash content the better for the industry, as this means less waste and less maintenance costs. Resolution SAA - 40 (2015) recommends a value of less than 1.50% of ashes, and the ash content of the present work was much lower than recommended, thus characterizing the *E. urograndis* species as a great alternative for charcoal production due to generating little waste in the energy industry. The carbonization ramps only had a significant difference for the base position, and the base differed significantly from the other positions.

The calorific value (still in Table 7) presented higher values in the Carbonization Ramp of 500°C, and the highest value was 7628.13 kcal/kg, but it was lower than that found in the same 500°C Ramp for *E. pellita* in the work of Oliveira *et al*. (2010), which was 8237.00 kcal/kg. The DBH position in this Ramp presented significant difference from the other positions in the present study. The carbonization Ramp of 450°C presented the lowest values, with the lowest being 7378.57 kcal/kg, which is lower than that found in the same Ramp of 450°C for *E. pellita* in of 8309.00 kcal/kg the study by Oliveira *et al*. (2010). In a study conducted with the *Corymbia citriodora* species and species of the *Eucalyptus* genus, Zanuncio *et al.* (2015) found a value of 7545.41 kcal/kg at the final temperature of 450°C, close to the values found in this study. the DBH and top positions in this Ramp presented a statistically significant difference. All positions had significant difference in the comparison between the two different Carbonization Ramps, and therefore the Carbonization Ramp significantly interferes in the calorific value because it directly interferes with the fixed carbon content.

The calorific power values can be explained due to the existence of a positive correlation between the calorific value and the fixed carbon content, as evidenced by the calculated R value (1.00), which shows a strong positive correlation between the two parameters.

CONCLUSIONS

According to what was found, it is concluded that:

- The retractibility of *E. urograndis* wood showed values which characterize the wood as more stable when compared to other *Eucalyptus* species. For energy purposes, this is a good feature to look into in order to ensure less cracked charcoal and higher strength.
- The basic wood density was considered low (<0.550g/cm³);
- The apparent density of *E. urograndis* charcoal was in compliance with the literature for the *Eucalyptus* genus;
- The charcoal yield was higher in the base and had no interference from the carbonization ramps. It presented high values compared to other works, and high charcoal yield is synonymous with high production.
- The yields for condensable and non-condensable gases were significant, since the condensable gases showed a high yield and can be used for various purposes as fertilizer, disinfectant, sterilizer, as a food additive, and for energy purposes.
- The breaking index of charcoal was low, thus being characterized as resistant to breakage.
- The fixed carbon content was inversely proportional to the volatile content, and were generally considered ideal values for high quality charcoal. The ash content was low, which is interesting as ash is not useful for energy purposes.
- The superior calorific value was within the stated standards for good quality charcoal.
- Overall, the results were within those recommended by resolution SAA - 40 (2015), thus characterizing *Eucalyptus urograndis* as a good option for energy production in the state of Tocantins.

REFERENCES

ABRAF. Anuário estatístico da ABRAF 2013: ano base 2012. **ABRAF** – Brasília, 2013.

AMERICAN SOCIETY FOR TESTING AND MATERIALS – ASTM. **D1762-84**: standard method for chemical analyses of wood charcoal. Philadelphia, p.2, 2007.

AMERICAN SOCIETY FOR TESTING AND MATERIALS – ASTM. **D-2395**: standard test methods for specific gravity of wood and wood-based materials. Philadelphia, p.8, 2005.

ASSIS, M. R. D.; PROTÁSIO, T. P.; ASSIS, C. O.; TRUGILHO, P. F.; SANTANA, W. M. S. Qualidade e rendimento do carvão vegetal de um clone híbrido de Eucalyptus grandis x Eucalyptus urophylla. **Pesquisa florestal Brasileira,** Colombo, PR, v. 32, n. 71, p. 291-302, jul./set. 2012.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT. **NBR 7416**: carvão vegetal: determinação do índice de quebra. Rio de Janeiro, 1984.

BATISTA, D. C.; KLITZKE, R. J.; SANTOS, C. V. T. Densidade básica e retratibilidade da madeira de clones de três espécies de *Eucalyptus*. **Ciência Florestal**, Santa Maria, v.20, n.4, p. 665-674, 2010.

CHAVES, A. M. B.; DO VALE, A. T.; MELIDO, R. C. N.; ZOCH, V. P. Características energéticas da madeira e carvão vegetal de clones de *Eucalyptus* spp. **Enciclopédia Biosfera**, Centro Científico Conhecer – Goiânia, v.9, n.17, 2013, 533p.

Coradin, V.T.R.; Camargos, J.A.A.; Pastore, T.C.M.; Christo, A.G. 2010. Madeiras comerciais do Brasil: chave interativa de identificação baseada em caracteres gerais e macroscópicos. (http://www.ibama.gov.br/lpf/madeira/introducao.htm). Acesso em 02/12/2018.

COMISSION PANAMERICANA DE NORMAS TECNICAS. **COPANT 462**: Maderas: método de determinación de la contracción. Caracas, 1972.

VALE, A. T. do; ABREU. V. L. S.; GONÇALES, J. C.; COSTA. A. F. da. Estimativa do poder calorífico superior do carvão vegetal de madeiras de *Eucalyptus grandis* em função do teor de carbono fixo e do teor de material volátil. **Brasil Florestal**, nº 73, 2002.

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS – FAO. 2017. Avaliable from: <http://www.fao.org/forestry/energy/en/>. Access on: 30 nov. 2017.

GONÇALEZ, J. C.; SANTOS, G. L.; SILVA JUNIOR, F. G.; MARTINS, I. S. COSTA, J. A. Relações entre dimensões de fibras e de densidade da madeira ao longo do tronco de *Eucalyptus urograndis*. **Scientia Forestalis**, Piracicaba, v. 42, n. 101, p. 81-89, março de 2014.

OLIVEIRA, A. C.; CARNEIRO, A. C. O; VITAL, B. R.; ALMEIDA, W.; PEREIRA, B. L. C.; CARDOSO, M. T. Parâmetros de qualidade da madeira e do carvão vegetal de *Eucalyptus pellita* F. Muell. **Scientia Forestalis**, Piracicaba, v. 38, n. 87, p. 431-439, 2010.

REIS, C. A.; ASSIS, T. F.; SANTOS, A. M.; FILHO, E. P. Corymbia citriodora: estado da arte de pesquisa no Brasil. Colombo: **Embrapa Florestas**, 2013. 59 p. (Embrapa Floresta. Documento 255).

Resolução **SAA – 40** de 14 de dezembro de 2015. Define Norma de Padrões Mínimos de Qualidade para Carvão Vegetal, como base para Certificação de Produtos pelo Sistema de Qualidade de Produtos Agrícolas, Pecuários e Agroindustriais do Estado de São Paulo, 2015.

SANTOS, A. F. dos; AUER, C. G.; RODRIGUES, L. M. R.; RODRIGUES NETO, J. Ocorrência de mancha foliar bacteriana em plantios de eucalipto no estado de Mato Grosso e de Santa Catarina. Tropical Plant **Pathology**, Lavras, v.35, p.232, 2010. Suplemento.

SANTOS, R. C.; CARNEIRO, A. C. O.; CASTRO, A. F. M.; CASTRO, R. V. O.; BIANCHE, J. J.; SOUZA, M. M.; CARDOSO, M. T. Correlações entre os parâmetros de qualidade da madeira e do carvão vegetal de clones de eucalipto. **Scientia Forestalis**, Piracicaba, v. 39, n. 90, p. 221-230, jun. 2011.

SILVEIRA, L. H. C.; REZENDE, A. V.; VALE, A. T. Teor de umidade e densidade básica da madeira de nove espécies comerciais amazônicas**. Acta Amazônica**, Manaus, v. 43, n. 2, p. 179–184, 2013.

SOARES, V. C.; BIANCHI, M.L.; TRUGILHO, P.F.; HOFLER, J.; PEREIRA, A.J. Análise das propriedades da madeira e do carvão vegetal de híbridos de *Eucalyptus* em três idades. **Cerne**, Lavras, MG. v. 21, n. 2, p. 191-197, abr./jun. 2015.

VIEIRA, R. D. S.; LIMA, J.T.; MONTEIRO, T.C.; SELVATTI, T.S.; BARAÚNA, E.E.P.; NAPOLI, A. Influência da temperatura no rendimento dos produtos da carbonização DE *Eucalyptus microcorys*. **Cerne,** Lavras, MG. v. 19, n. 1, p. 59-64, jan./mar. 2013.

VILAS BOAS, M. A., CARNEIRO, A. C. O., VITAL, B. R.; CARVALHO, A. M. M. L., MARTINS, M. A. Efeito da temperatura de carbonização e dos resíduos de macaúba na produção de carvão vegetal**. Scientia Forestalis**, Piracicaba, SP. v. 38, n. 87, p. 481-490, 2010.

ZANUNCIO, A. J. V.; CARVALHO, A.G.; SILVA, E.M.G.C.; MONTEIRO, T. C.; LIMA, J. T.; SILVA, J. R. M. Da. Propriedades energéticas da madeira e carvão de *Corymbia* e *Eucalyptus* em diferentes condições de secagem. **Revista Brasileira de Ciências Agrárias**. Recife, PE, v. 10, n. 3, p. 432-436, jan. 2015.