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NOVOS PARAMETROS PARA OTIMIZAR O PROCESSO DE FABRICAÇÃO DE LENHA ECOLÓGICA A PARTIR DE REJEITOS DE BIOMASSA FLORESTAL

NEW PARAMETERS FOR THE FOREST BIOMASS WASTE ECOFIREWOOD MANUFACTURING PROCESS OPTIMIZATION

RUOSO, Ana Cristina[1]; BITENCOURT, Lisiane Corrêa[1]; SUDATI, Lucas Urach[1]; KLUNK, Marcos Antônio[2]; CAETANO, Nattan Roberto[1]*

[1] Federal University of Santa Maria, Av. Roraima 1000, 97105-900 Santa Maria, RS, Brazil

[2] University of Vale do Rio dos Sinos, Av. Unisinos 950, 93020-190 São Leopoldo, RS, Brazil

** Correspondence author*
e-mail: nattan.caetano@ufsm.br

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RESUMO

A biomassa apresenta grande participação na matrix de geração de energia, devido aos benefícios econômicos regionais. Este trabalho tem como objetivo principal avaliar os parametros utilizados na fabricação de briquetes produzidos com resíduos florestais e a engenharia econômica para a fabricação. Os resíduos florestais foram: cavacos e lascas de madeira de *Eucalyptus spp.* e cascas de *Pinus taeda*. As avaliações realizadas foram caracterização química dos resíduos florestais e custos envolvidos no processo de briquetagem. Os resíduos florestais apresentaram em sua composição química extrativos e lignina. Os custos de produção dos briquetes foram afetados principalmente pela briquetadeira, sendo que as cascas de Pinus a que apresentou maior custo produção. Os custos de produção obtidos nesse estudo são de 20% menores que os custos empregando os métodos tradicionais. O valor energético da biomassa permite a redução da dependência de energia, que pode ser utilizada para a geração de vapor ou eletricidade, para subsistência. Um fato para conversão de energia é avaliar a umidade do material. É adequado para queimar resíduos com umidade entre 45 e 55%. A energia elétrica consumida é importante para avaliar os custos totais. Os resíduos florestais são uma importante fonte de produção de lenha ecológica, contribuindo para a geração de energia e diminuição dos resíduos sólidos armazenados na empresa. Desta forma, os novos parâmetros para a biomassa de briquetagem de resíduos florestais mostrados neste trabalho, que é uma etapa importante do processo, tornam economicamente viável e ambientalmente adequada a produção de lenha ecológica.

Palavras-chave: *Resíduos Florestais, Energia Renovável, Custos Produtivos, Energia de Biomassa*

ABSTRACT

Biomass has a large share in the energy generation matrix, due to the regional economic benefits. This work has as main objective to evaluate the parameters used in the manufacture of briquettes produced with forest residues and the economic engineering for the manufacturer. The forest residues were: wood chips and chips of Eucalyptus spp. and barks of Pinus taeda. The evaluations were the chemical characterization of forest residues and the costs involved in the briquetting process. The forest residues presented extractive chemical composition and lignin. The production costs of the briquettes were affected mainly by the equipment, being the Pinus taeda barks the one that presented higher production cost. However, the production costs obtained in this study are approximately 20% lower than the production costs using traditional methods for forest firewood. The energy value from biomass allows the reduction of the dependence of energy, which can be used for the generation of steam or electricity, for subsistence. A fact for energy conversion is to evaluate the material moisture. It is suitable to burn residues with moisture between 45 to 55%. The consumed electric energy is important to evaluate the total costs. The energy required depends on the quality of raw material and the system employed. Forest residues is an important source for eco firewood production, contributing to energy generation and decreasing of the solid waste stored at the company. In this way, the new parameters for briquetting biomass forest wastes shown in this work, which is an important stage of the process, make economically viable and environmentally suitable the eco firewood production.

Keywords: *Forest Waste, Renewable Energy, Productive Costs, Biomass Energy.*

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1. INTRODUCTION

Biomass is related to all organic matter, from vegetable or animal origin, used for energy production (Zhao *et al.,* 2018, Campbell *et al.,* 2018, Li *et al.,* 2017). It is useful for use as an energy source (ValeFntim *et al.,* 2019; Maslennikov *et al.,* 2019; Cataluña *et al.,* 2018). Combustion of raw material is a way of biomass that considered energetically viable (Chan *et al.*, 2019, Caetano *et al.,* 2018; Milovanovich *et al.,* 2017; Pahla *et al.,* 2017, Xin-Gang *et al.,* 2015, Prado *et al.,* 2015; Zhang *et al.,* 2014; Xiu and Shahbazi, 2012; Caetano *et al.,* 2015a). The energy source is obtained by the decomposition of non-woody, woody and organic residues (Alvarez *et al.,* 2018; Cai *et al.,* 2016; Liu and Balasubramanian, 2013; Abbas *et al.,* 2011; Muangrat *et al.,* 2010).

Non-woody are classified by main energy storage substance: i) saccharide - has as storage tissue the sugars (saccharose). These sugars are used for the production of ethanol; ii) cellulosic - uses carbohydrates as storage tissue; iii) starchy - have starch storage tissue. Starches are complex carbohydrates. This was transformed into simpler sugars for fermentation; iv) oilseed - which have oils and fats extracted through industrial processes; v) aquatic - are plants and algae that have potential for energy generation (Chan *et al.,* 2019; Sun *et al.,* 2019; Haykiri-Acma *et al.,* 2011; Fan *et al.,* 2013; Cataluña *et al.,* 2017; Fagundez *et al.,* 2017; Yang *et al.,* 2017; Yellapu *et al.,* 2019; Bharathiraja *et al.,* 2015; Caetano *et al.,* 2015b; Ojeda *et al.,* 2011).

The woody is able to produce firewood as a sustainability fabric (Vandecasteele *et al.,* 2016). The production of wood used in technological processes allows the conversion of energy (Shi *et al.,* 2013). Planned plantations produce a large volume of biomass (Zhou *et al.,* 2018). Therefore, all the organic waste from agriculture is useful as fuel (Velásquez *et al.,* 2017; Akbi *et al.,* 2017; De Boni, 2017; Paradelo *et al.,* 2013; Dias *et al.,* 2012; Quintero *et al.,* 2008;). The energy stored in these residues is very significant, having as main representative the biogas (Lizasoain *et al.,* 2016; Montingelli *et al.,* 2016; Santos *et al.,* 2016; Pöschl *et al.,* 2010; Holm-Nielsen *et al.,* 2009). The energy value from biomass allows the reduction of the dependence of energy, which can be used for the generation of steam or electricity, for subsistence (Pedrazzi *et al.,* 2016; Caetano *et al.,* 2015c). A fact for energy conversion is to evaluate the material moisture. It is suitable to burn residues with moisture between 45 to 55% (Yadav and Devi, 2018).

Biomass production in Brazil is in large scale, with extensive areas and good weather conditions (Felfli *et al.,* 2011).

In environmental terms, the use of biomass contributes to the low emissions of carbon dioxide (CO_2). These low carbon dioxide emissions can be predicted by geochemical modeling (Klunk *et al.,* 2019a; Klunk *et al.,* 2018; Klunk *et al.,* 2015; Saffy *et al.,* 2015; García *et al.,* 2011; Szklo *et al.,* 2005). Another important factor of the use of biomass is to include the residues in the process of synthesis of zeolites to be used in industrial processes (Klunk *et al.,* 2019b; Massoudi Farid *et al.,* 2017; Kramb *et al.,* 2014).

An industrial process takes to the attention of companies linked to the energy, which consists of the compaction of material, in order to higher the energy concentration (Balasubramani *et al.,* 2016; Flórez-Orrego *et al.,* 2015; Stolarski *et al.,* 2013; Felfli *et al.,* 2011; Wu *et al.,* 2010).

This technique is effective in the way of taking benefits using biomass residues (Sordi and Manechini, 2013). The process pressurizes the particles of biomass to make it one solid block of high density (Trubetskaya *et al.,* 2019; Zhang *et al.,* 2018; Prasityousil and Muenjina, 2013; Do Rosário, 2011). The quality of the eco firewood is influenced by the physical and chemical characteristics of the raw material and mainly by the parameters of production (Shekhar, 2011; Vilas Boas, 2011; Purohit *et al.,* 2006). The production presents several advantages, the volume reduction to lower the cost of transportation and the higher the calorific power (Balasubramani *et al.,* 2016). Thus, the process cost of production is dominated by the characteristics of the raw material and the energy dissipated by the equipment (Zhang *et al.,* 2018; Turdera, 2013).

The production plant has an influence on the costs and therefore, was evaluated as a function of the volume (Filippetto, 2008; Purohit *et al.,* 2006). Operating costs has been specified as fixed: equipment depreciation, business, maintenance, industrial installation, and transportation (Guerra *et al.,* 2014). The variable costs: raw material, fuel processing, expenses, and energy (Da Silva *et al.,* 2006).

The consumed electric energy is important to evaluate the total costs. The energy required depends on the quality of raw material and the system used (Trubetskaya *et al.,* 2019; Lowesmith *et al.,* 2007). Thus, was considered the electric energy consumed in a period, which is expressed in (kWh) (Bigaton *et al.,* 2015; Bigaton *et al.,* 2016; Bigaton *et al.,* 2017; Xin-Gang *et al.,* 2015; Pedrazzi *et al.,* 2016).

2. MATERIALS AND METHODS

Forest biomass residues were processed in mills and separated in classes dependent on the species of the biomass (Table 1).

The moisture content of the particles was determined according to the TAPPI T 210 cm-93. The forest residues processed in the mills were classified for the chemical analysis. Granulometry was used of 40-60 mesh, according to TAPPI T 204 cm-97. The determination of the total extractive contents acid-insoluble lignin and inorganic compounds were applied TAPPI T264 cm-97, TAPPI T222 om-98, TAPPI T211 om-93. Holocellulose content (HC) was determined (Álvarez *et al.,* 2018; Rosa, 2003):

HC (%) = 100 - (insoluble lignin content + total extractive content) (Eq.1)

The determination of the residues bulk density was performed by 10 mL of the material (Dukes *et al.,* 2013). The production machine is LIPPEL^{TM} model LB-32, under pre-defined manufacturing parameters.

Tests revealed that the best-operating conditions of the equipment were: i) 100 bar; ii) 393 K, with three minutes of compression and six minutes of cooling time.

The apparent density (AD) (g/cm^3) was determined by the stereometric method (ratio of mass/volume with moisture content) (Sova *et al.,* 2018). The diameters were carried by a digital caliper. The mass of the briquettes was determined by means of an analytical balance.

The higher calorific value (HCV) were classified in 60 mesh and placed in an oven at 105 ± 5ºC during 48 that the total moisture evaporates (Antwi-Boasiako and Acheampong, 2016). The 0.5 g of the sample was placed in an adiabatic pump IKA^{TM} model C5000.

The energy density (ED) was calculated by the product of the calorifc value (CV) and the apparent density (AD), according to the equation:

$$ED = (CV \times AD) / 1000 \quad \text{(Eq.2)}$$

where, ED is (Mcal/m^3), UCV (kcal/g) e AD is (g/cm^3).

The UCV was obtained from the lower calorific value (LCV), using the following equations:

$$LCV = HCV \times (1 - MC_{w.b}) - (600 \times MC_{w.b}) \quad \text{(Eq.3)}$$

$$UCV = LCV \times [(100 \times MC_{w.b}) / 100] - 6H \quad \text{(Eq.4)}$$

where LCV, HCV, and UCV are expressed in kcal/m^3, MCw.b is moisture content, H is the hydrogen content (% on a dry basis.

The electric power was measured in the mills (1 and 2) and in the eco firewood using ET-5060C/ET-5060 Power Quality Analyzer - Minipa^{TM} equipment to calculate the electric energy consumption in the production. The energy released by the equipment was calculated by the integral of the active power (W) during the operation time (Fraga *et al.,* 2014; Klunk *et al.,* 2012). Thus, the energy consumed by equipment was calculated by the equation:

$$W = \int_{t_1}^{t_2} p(t)dt \quad \text{(Eq.5)}$$

where t_2 - t_1 is the time interval between measurements and p (t) is the power at the same time step. The energy consumption was calculated by the results obtained by Equation 6:

$$E = W \times 10^6 / w \quad \text{(Eq.6)}$$

where E is the energy consumption (kWh/ton), W is the work done by the equipment *w* is the weight of the briquette (g). The cost of production was based on the commercial value of electricity, which was multiplied by the total work obtained, according to the equation:

$$C_1 = W \times ET(10^3 / 3600) \quad \text{(Eq.7)}$$

where C_1 is the cost for the production of 1 sample expressed in R$ (BRL), W is the work done by the equipment, and ET is electric tariff (0,53 R$/kWh). The energy cost was estimated to 1 ton, regarding the weight of the forest residue used (class E = 70 g and class P = 64 g), according to the equation:

$$C_2 = C_1 (10^6 / w) \quad \text{(Eq.8)}$$

where C_2 is the cost for 1 ton of briquette (R$/ton), and *w* is the weight of the biomass (class E or P).

3. RESULTS AND DISCUSSION

3.1. Moisture content

It is recommended for the manufacture of briquettes the moisture content of the material between 8 and 15% (Antwi-Boasiako and Acheampong, 2016; Paula, 2010). Therefore, the values obtained in this work are in agreement with the literature (Bamgboye and Bolufawi, 2009; Eriksson and Prior, 1990). There is no influence of moisture in determining the calorific value of the samples.

3.2. Bulk density

The average values of the bulk density are presented in Table 2.The forest residue of the genus *Eucalyptus SSP*. (class E) presented a 3% higher result than the genus *Pinus Taeda* (class P), which was expected. Bulk density is a property related to the granulometry (Dukes *et al.,* 2013; Phanphanich and Mani, 2009). Bulk density must be considered in the use of biomass for energy generation (Zamora-Cristales *et al.,* 2015; Peng *et al.,* 2013).

3.3. Chemical analysis

In order to determine the biomass quality of the different samples for energy purposes, Table 3 shows the composition values for the residues. The classes of forest residues presented different chemical composition. The highest values of extractives and lignin were observed in the P residue class, due to its composite *Pinus taeda*. On the other hand, the class of residues E presented high content of minerals and holocelulose (Haykiri-Acma *et al.,* 2014; Kumar *et al.,* 2009). The bark of the trees presents chemical differences when compared to the wood, due to the higher levels of extractives and ashes and, lower concentration of cellulose and hemicellulose (Álvarez *et al.,* 2018; Hu *et al.,* 2016).

3.4. Calorific value

The average values of the higher calorific value (HCV) were 4,363.95 kcal/kg and 4,631.94 kcal/kg, respectively, for the classes of residues E and P. According to the results, class P presented an HCV of 5% higher, according to expected because it was the residue with the highest values of extractives and lignin (Table 3). The higher calorific value of wood, further moisture, is influenced by the chemical composition of the material, mainly lignin and extractives (resins, oils, resins, greases, oils) (Antwi-Boasiako and Acheampong, 2016). Lignin has a carbon content of about 50% higher than that found in polysaccharides (Raud *et al.,* 2016; Fu *et al.,* 2015).

Therefore, this type of biomass presents great potential for energy production. In addition, volatile extractives are important in the direct burning of wood, as they dissociate more quickly and help to maintain combustion. Thus, even though the consumption of electricity is higher for the manufacture of briquettes of this type of biomass, the energy balance is made feasible (Caetano and Silva, 2017; Stolarski *et al.,* 2013). In addition, biomass in the form of briquettes facilitates transport, due to compaction and organization, which can be a crucial factor in the sale price of this material as fuel (Nguyen *et al.,* 2013). Briquettes also make easier the storage, which could influence biomass employment as fuel (Cortez *et al.,* 2008).

3.5. Electric energy consumption

The measured values of power in all stages of the briquetting process are presented in Figure 1. The power is the energy consumed by the facilities per unit of time (He *et al.,* 2018; Bilgili *et al.,* 2017). Figure 1 and Table 4 shows that class E has consumed more energy (868 kW) which was increased to 1,005 kW at the period of 20 s and reduced to 626 kW in 35 s, rising to 821 kW in 50 s. Thus the global cost is 93 BRL/ton for the production.

Considering the Pinus, the power measured was 970 kW, reducing to 677 kW at 10 s, which yields a cost of 25 BRL/ton. The higher power consumed by mill 1 and the higher energy cost for the production of Eucalyptus is due to the hard character of this material, given by the lower porosity, as shown by higher bulk density (Table 2). Mill 2 shown the larger energy consumption for Eucalyptus, 42 BRL/ton, comparing to Pinus, 22 BRL/ton. The grinding of the Eucalypts begun with energy consumption of 168 kW and in 6 s turns to 640 kW, remaining constant until 30 s (684 kW), after that, it fell again until 40 s (297 kW). The Pinus sample remained with values initially of 296 kW reaching 237 kW in 30 s. The power consumed by Eucalyptus was 493 kW, showing an increase to 725 kW in 80 s and for Pinus, with 498 kW, showed an increase of 657 kW in 70 s. This result is due to the wide space required by the Pinus in the compressing capsule and the lower bulk density of this material (Table 2). This requires an increase in the time of the process, which consumes more energy and, consequently, increases the production cost.

The compression was the stage that required the highest energy, BRL 281 for

Eucalyptus and BRL462 for Pinus, due to the warming process, which melt the lignin and increase the adhesive. Moreover, press time and temperature parameters during the briquetting were used smaller than those found in the literature and, due to the care in the grinding process and the qualification of the particles. However, the production cost observed for Eucalyptus was 416 BRL/ton and for Pinus 509 BRL/ton, which are higher than the values found in the literature (Tan *et al.,* 2017; May- Moulin *et al.,* 2017). However, these values can be reduced if production is carried out on a large scale in the industrial production system.

4. CONCLUSIONS

The cost to produce eco firewood was calculated as 416 BRL/ton for Eucalyptus and 509 for Pinus. The most expensive part of the process is the compacting phase, which costs 281 for Eucalyptus and 462 for Pinos. Also, the forest residues produced by the industry is an important source for the production of eco firewood, contributing to energy resource of the company (energy generation) and a significant decrease of the solid waste stored at the company. In this way, considering the new parameters for briquetting forest wastes is an economically viable and environmentally important stage of the process.

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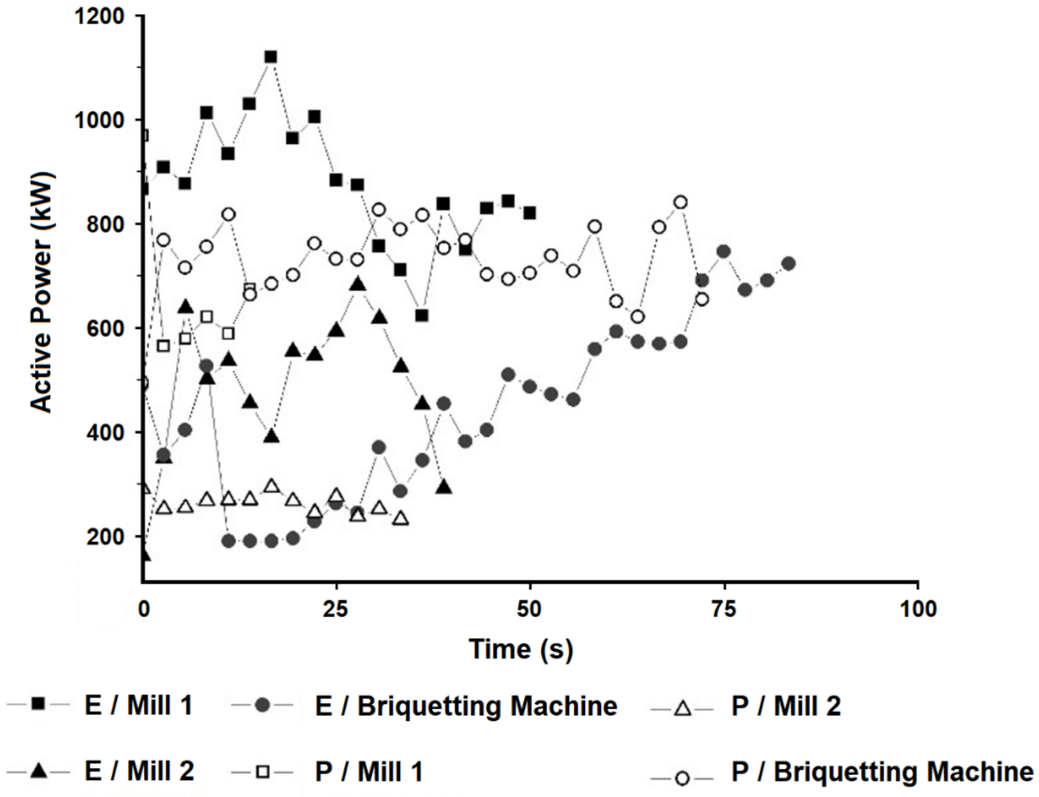

***Figure 1. P**ower consumed by mills in function of time by the production process.*

Table 1. Classification of forest residues according species, sampling and biomass type.

Class	Species	Sampling	Type
E	*Eucalyptus spp.*	Industrial area	Wood chips
P	*Pinus taeda*	Forecourt wooden	Bark

Table 2. Average values of bulk density of residues.

Classe	Density (kg/m³)
E	375
P	364

Table 3. Average values of the chemical composition of the forest waste class

Class	TE (%)	LC (%)	MC (%)	HC(%)
E	5	16	4	79
P	18	42	3	40

TE = total extracts; LC = lignin content; MC = minerals content or ash; HC = holocellulose content

Table 4. Electric energy costs per equipment and the total cost for the production of briquettes of classes E and P.

Equipment	Costs (R$/ton)	
	Class E	**Class P**
Mill 1	92.70	24.60
Mill 2	41.70	22.21
Briquetting Machine	281.30	462.16
Total	**415.70**	**508.96**