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Technological characterization of wood residues from the Amazon for the production of briquettes*

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Abstract — *The study aimed to evaluate the potential of briquettes produced from wood residues from five forest species in the Amazon. Wood residues were obtained in Manaus - AM/Brazil, fragmented to obtain sawdust and determination of the Physical and Chemical Properties of wood, coal and briquettes. In chemical analysis, Extractives ranged from 9.76 to 12.08% , and the Ash content was 0.48% on average. As for physical properties, Basic density ranged from 870 to 980 Kg/m^3, Moisture from 7.38 to 9.03%, and PCS from 5,213.50 to 5,883.50 Kcal/Kg. The PCS of coal was higher than that of wood, and the best correlations of PCS were with Extractives, Lignin, Moisture and Basic density. Regarding the DE estimate considering wood as firewood, Jatobá residues presented the highest valor, and this material when compacted (Briquette), the energy efficiency increased effectively with a range of 6.36 to 7.51 MKcal/m^3. The material, when carbonized, presents a higher concentration of fixed carbon, which justifies the high DE values for both coal and coal briquettes, where in the coal a variation of 6.25 to 8.51 MKcal/m^3 and coal briquettes from 8.01 to 11.42 MKcal/m^3. The studied residues presented high PCS, both wood and coal. In general, all species showed high Basic density and low Moisture, which favors the indication of these materials for energy purposes. Charcoal briquettes from Angelim pedra and Angelim vermelho showed Energy density above 10.00 MKcal/m^3, indicating the energy potential of this product that combines technical and economic viability.*

Keywords*— *Amazonian woods, Briquettes, Energy density and Higher calorific value.

I. INTRODUCTION

The forest-based industry has been growing significantly in the world market, where wood, whether planted or managed area, is the main raw material for the cellulose, energy, furniture and reconstituted products sector. One of the major bottlenecks in the timber industry in the Amazon is the low yields in the split, which causes a large amount of waste. The correct use of these residues has become a sustainable practice, given its possibility of recycling, as well as the elimination of waste, thus being an alternative for environmental balance [1 and 2].

Substrates based on wood, agricultural and agro-industrial residues can be used for energy purposes, in poultry farming, cultivation of edible fungi and also for the production of agglomerates. The use of biomass as an energy source is technically and economically viable, given the large supply of this material and the demand by the steel industry [3, 4 and 5].

The plant matrix consists of Cellulose and Hemicellulose (Polysaccharides), Lignin (Aromatic polymer) and also low molecular weight substances such as extracts and mineral residues. The quantification of these compounds is essential for the technological characterization of aggregate products that will indicate the best energy efficiency of biomass, such as, for

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example, the high content of aromatic substances, such as some Extractives and Lignin, generates a coal with a higher Basic density and more resistant, in terms of Physical-Mechanical properties [6 and 7].

A product from wood that produces more energy than firewood and charcoal is called a briquette. Also known as ecological firewood, it is a product of the wood residues densification process. Briquetting is an alternative to add value to waste of agroforestry origin and consists of compacting the sawdust at high pressures and temperature, but for this, sophisticated equipment is necessary to reach the level of compactness or densification. In general, briquettes are formed from charcoal powder that has already undergone carbonization. Recognized by companies in the forestry sector as the energy of the future, the briquette is very useful in generating heat energy in greenhouses, boilers, stoves with automatic feeding, in industries, as well as in maintaining fire in fireplaces, barbecues and homes [8 and 9].

In Brazil, around 1.2 million tons of briquettes are produced per year, of which 930 thousand tons are made of wood. The manufacture of wooden briquettes is a smart way to take advantage of discarded sawmill items such as deformed logs, coastal logs, shavings, shavings, and especially sawdust [10]. Knowledge about raw materials for indication in briquetting is important to discipline the use of stocked resources, under the new paradigm of the sector, which is sustainable development. Technological knowledge about the properties of wood is fundamental for the generation of standardized and eco-efficient products in the Amazon, however, the Amazon biome presents forest species that have not been studied for energy purposes [11, 12 and 13].

Briquette technology, as a fuel and energy production process, has not been fully explored. Therefore, it is necessary to develop research that will increase the yield of this matrix, as well as diagnose species with energy potential. Falemara et al. [14] evaluated the Physical and Energetic properties of briquettes produced from agroforestry residues, and concluded that the sawdust of the African tropical species *Anogeissus leiocarpus* (African birch) contained low Mineral content and high Superior calorific value (PCS = 8,222 Kcal/Kg), and the mixture with others agricultural substrates generated a product with better quality in terms of densification and combustion, therefore suitable as an alternative to an ecologically healthy energy source.

Antwi-Boasiako and Acheampong [2] studying the energetic potential of sawdust briquettes from three tropical woods of different densities (Ako - *Antiaris toxicaria*, Samaúma - *Ceiba pentandra* and Okan - *Cylicodiscus gabunensis*), found that wood Density was a limiting factor for an efficient composite, that is, Samaúma wood had low yields and PCS = 3,825 Kcal/Kg. In Brazil, Pinheiro et al. [15] used waste from the agricultural and tropical Brazilian wood sectors to determine its energy density. The result was an average PCS of 4,500 to 5,000 Kcal/Kg. While Gentil1 and Vale [16] using *Pinus* based briquettes with different Moisture, obtained an average PCS of 4,837 Kcal/Kg, where the substrate with a high Moisture content, presented low energy yield. Corrêa [17] was one of the forerunners of studies on the chemical conversion of Amazonian wood into energy, when he described processes for manufacturing briquettes from alternative forest products for energy generation. Species of botanical families Chrisobalanaceae, Humiraceae, Lecythidaceae, Leguminosae and Sapotaceae were used for charcoal production and later compaction in briquettes, where it found PCS of 6,602 Kcal/Kg, indicating the energy potential of wood in the region.

In this context, the study aimed to assess the potential of briquettes produced from wood waste from five forest species in the Amazon.

II. MATERIAL AND METHODS

The residues constituted by shavings, battens and backlines were collected at Company Portela Wood (Manaus - AM/Brazil) and transported to the Cellulose and Paper/Charcoal Laboratory/COTEI/INPA - Brazil. Initially, cuts were obtained to obtain sampling for species identification (Table 1), which was the responsibility of specialist JA Freitas from the Laboratory of Anatomy and Wood Identification - LAIM/COTEI/INPA - Brazil. At the same time, the material was fragmented to obtain sawdust (20, 40 and 60 mesh) that was used to determine the Physical and Chemical properties of wood, coal and briquettes.

2.1 Characterization of Physical Properties

2.1.1 Basic density

This property was determined as described in NBR 7190: 1997 [18], using the water displacement method. Initially, specimens were made (2.00 x 2.00 x 3, 00 cm), and then they were saturated to obtain the green volume determined by the liquid displacement method, then they were dried in an oven (100 ± 3 ºC) until they reach constant weight (72 h). Subsequently, the Basic density was calculated according to the formula: Basic density = P_d/V_s, P_d = Dry weight in grams, Vs = Volume of the sample in a saturated state in cm^3.

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Table 1: Taxonomic identification of wood residues.

Species	Xiloteque Registration	General characteristics*
Angelim pedra *Hymenolobium petraeum* Ducke	X – 8894	Medium density wood, light brown heartwood with dark hues, yellowish sapwood, interlocked grain, medium to coarse texture, indistinct smell and taste.
Angelim vermelho *Dinizia excelsa* Ducke	X – 7978	High density wood, light reddish-brown heartwood, slightly different from red dish-gray sapwood, straight to irregular grain, medium texture, characteristic smell and indistinct taste.
Cumaru *Dipterix odorata* (Aubl.) Willd	X-8,338	High density wood, dark brown-yellow heartwood, light beige sapwood, interlocked grain, medium texture, unpleasant smell when green, disappearing after drying, of moderate luster and indistinct taste.
Cumarurana *Dipterix polyphylla* Huber	X -8,355	High density wood, dark brown heartwood, creamy yellowish sapwood, interlo cked grain, medium texture relatively prominent figure indistinct smell and taste.
Jatobá *Hymenaea courbaril* L.	X-10,12	Medium density wood, red heartwood accentuated to reddish-brown with some times dark spots, grayish-white sapwood, straight to wavy grain, medium textu re indistinct smell and taste.

* [13 and 33]

2.1.2 Moisture

1.00 g of wood sawdust (40 mesh) were weighed in a weighing filter, being subjected to drying in an oven at 100 ± 3 ºC, in a period of 4 hours, according to the norm of ABNT 8112: 1986 [19]. At the end, the material was weighed to constant weight, and the Moisture was calculated according to the formula: $Moisture_{\%} = P_w - P_d/P_d$ x 100, P_w = Weight of wet mass and P_d = Weight of the dry mass.

2.1.3 Calorific value

The Superior calorific value (PCS) were performed on a dry basis, with the aid of a calorimetric pump, ASTM D2015-00: 2000 [20]. About 0.80 g of sawdust (60 mesh) was placed in the metallic capsule and a wool thread was inserted into the pump and placed next to the ignition wire, the pump is closed, and oxygen gas is injected. The pump is placed in a metal bucket with water, and the ignition system of the calorimeter is coupled to the pump, where quantification begins. After 15 min. the operating system of the PARR calorimeter prints the result of the reading in Kcal/Kg. This determination was made for wood and coal.

The Lower calorific value (PCI) was estimated by the equation of Brum et al. [21]: PCI = PCS - (600*9 (H/100), where the percentage of hydrogen was 6% and the result in Kcal/Kg.

2.2 Characterization of Chemical Properties

2.2.1 Extractives

The Extractives content (Ethanol; Ethanol-toluene) was determined from 2.00 g of sawdust (60 mesh) in Soxhlet extractor for a period of 8 hours, TAPPI 264 om-88:1996 [22]. At the end, the solubilized Extractives was weighed and quantified by the equation: $Extractives_{\%} = P_{ext}/P_d$ x 100, P_{ext} = Mass - final extract and P_d = Weight of the dry base sample.

2.2.2 Lignin

In the material obtained after extraction (extraction-free sawdust), 1.00 g of sawdust was hydrolyzed with 72% H_2SO_4 for about six hours, TAPPI 222 om-02: 2006 [23]. At the end, this material is washed with hot water, filtered, dried in an oven at 100 ºC, being subsequently weighed and the lignin content calculated. The percentage of Lignin is determined using the formula: $Lignin_{\%} = P_{Lig}/ P_d$ x 100, P_{Lig}= Lignin weight obtained and P_d= Weight of the dry base sample.

2.2.3 Ash

In porcelain crucible 1.00 g of sawdust (60 mesh) is added and taken to the oven (100 ± 3 ºC) for 1 hour, to remove moisture. Then, the container is taken to the muffle for incineration, starting with the gradual heating up to 580 – 600 ºC, ASTM D1102-84: 2013 [24]. After incineration, the crucible is weighed to a constant weight. The ash content is determined by the formula: $Ash_{\%} = P_{Ash}/P_d$ x 100, P_{Ash} = Ash weight and P_d= Weight of the dry base sample.

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2.2.4 Holocellulose

The holocellulose content was estimated by adding the percentages of extractives, lignin and ash, and subtracting this value from 100% according to Silva et al. [11]: $Holocellulose_{\%} = 100 - (Extractives + Lignin + Ash)$.

2.3 Production and Analysis of Briquettes

Initially, the residues of each wood and wood mixture (Mix) were carbonized at 400 °C in an electrically heated retort at the Cellulose and Paper/Charcoal Laboratory/COTEI/INPA - Brazil. A set of parameters was initially evaluated to define the briquette pattern, they were granulometry (20, 40 and 60 mesh), pressure (500 to 1,000 Kgf/cm^2, temperature (100 to 130 °C) and mass (20.00, 30.00 and 40.00 g). The briquettes were prepared in a Briquette Machine (Fig. 1) at a temperature of 120 °C (± 5 °C), pressure of 700 and 1,000 Kgf/cm^2, compaction time of 5 min., where the ideal humidity of the material to be briquetted must be 12%, Silva et al. [25].

Fig. 1: Briquetting machine (Lippel- model LB-32) used in the study (Cellulose and Paper/Charcoal Laboratory/COTEI/INPA – Brazil).

30.00 g of coal were used for each briquette, obtaining at the end a sample of ~ 3.00 cm in length and ~ 4.00 cm in diameter. Ten briquettes were produced per wood, totaling 50 briquettes. For each sample, the actual volume (Digital caliper), Density (m/v) and finally the Energy density - DE (Material density x PCS) were determined.

2.4 Data analysis

The values of the results obtained in the chemical, physical and energetic tests of the wood and briquettes were submitted to analysis of variance (ANOVA) with the aid of the software PAST Version 2.17c, in order to verify if there was a statistical difference between the treatments. For data that differed statistically, that is, when the F value was significant ($\alpha = 0.05$), the Tukey mean test at 5% significance level was applied.

III. RESULTS AND DISCUSSION

Vegetable biomass, which can be obtained from various sources, such as agricultural and forest residues, is one of the sources of energy that presents the most economic and sustainable viability since its raw material can be obtained from renewable resources, such as wood. However, its properties are parameters that can influence the amount of energy, hence the need to evaluate the chemical, physical and energetic properties of the studied residues.

3.1 Chemical Properties

The wood consists of Cellulose, Hemicellulose and Lignin, these being macro components of cellular appearance and also Extractives and Mineral compounds. In this study, the chemical composition of wood residues from the Amazon was evaluated, a raw material commonly wasted by the regional industry. Table 2 shows the average values of Extractives (ethanol-toluene), Lignin, Holocellulose (Cellulose + Hemicellulose) and Ash (Mineral residues) of the five residues studied.

The Tukey test ($p \leq 0.05$) showed a significant difference for the content of Extractives, Lignin and Ash. Regarding the content of extractives, the concentration varied from 9.76 to 12.08%, Angelim pedra and Angelim vermelho, respectively. For Lignin, the variation was from 30.47% (Angelim vermelho) to 41.72% (Cumarurana). Holocellulose was 54.48%, while the ash content was 0.48% on average.

Chemical characterization is a primary step in studies of raw materials for energy purposes, given the influence of chemical compounds, mainly Lignin and Extractives that have a positive correlation with Calorific value [11 and 26]. Santana and Okino [27] evaluating the chemical composition of 36 Amazonian woods obtained Extractives values of up to 17.30%. While Moutinho et al. [28] when studying the energetic characteristics of wood of the genus *Eschweilera* (Lecythidaceae) found Extractives values that

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ranged from 3.63 to 11.16%. Regarding Lignin, Cavalcante et al. [29] found 23.74% of Lignins for various woods of the genus *Eperua* (Fabaceae). Silva et al. [11] evaluating wood residues obtained average values of 27.90%, in our study the Lignin concentration was much higher (34.06%). According to Fengel and Wegener [30], Lignin is the second chemical constituent in greater proportion in wood, varying from 20-40%, depending on the species, which gives a certain difference in the results obtained.

Table 2: Chemical properties of the studied woods.

Wood	Extr%	Lign%	Holocell%	As%
Angelim pedra	9.76 b	32.57 c	57.19	0.48 b
Angelim verm	12.08 a	30.47 d	56,70	0.75 a
Cumaru	11.76 a	31.21 d	56.71	0.32 b
Cumarurana	11.62 a	41.72 a	46.30	0.36 b
Jatobá	9.93 b	34.35 b	55.49	0.23 b
	1.03	34.06	54.48	0.48
Average	(0.98)	(4.06)	(4.13)	(0.19)

Legend: Extr = Extractives; Lign = Lignin; Holocell = Holocellulose; As= Ash. Means followed by the same letter do not differ statistically by the Tukey test at the 5% probability level; Value in parentheses standard deviation.

Printes et al. [31] characterizing wood residues from Central Amazonia found Holocellulose values from 43.58 to 54.85% (Louro faia - *Roupala montana*, Jatobá - *Hymenaea courbaril*, respectively). Silva et al. [11] also studying other wood residues from the same region, reached higher values such as 58.68% (Louro - *Ocotea* sp.) to 70.55% (Cedrinho - *Scleronema* sp.). Holocellulose is the main component of vegetables and one of nature's most abundant carbon compounds and encompasses both Cellulose and Hemicellulose. Depending on the origin of each species, it can vary from 40 to 60% of the dry weight of the wood, considering both hardwood and coniferous woods [32]. In this study, Cumarurana wood obtained the lowest percentage (46.30%) while Angelim pedra presented the highest content (57.19%), which are within the range defined in the literature.

Regarding the Ash content, Cunha et al. [33] is a reference study for woody species in the Amazon, which quantified the ash from 55 woods, finding values that varied from 0.03 to 3.00%. However, Mitchual et al. [34] evaluating the energetic properties of six tropical wood species from Ghana found values of 5.04% of Ash for Aniégré (*Aningeria robusta*) wood. In this study, the highest Ash concentration was 0.75% (Angelim vermelho). However, Pettersen [35] reports that Ash values for tropical wood are usually high, where the greatest exception ever recorded was for Guayacan (*Tabebuia guayacan*)with ~ 13%. According to Martins [36], the ashes are products of the combustion of biomass, however certain Mineral residues do not degrade becoming undesirable elements for the generation of energy.

3.2 Physical and Energetic Properties

The Basic density, Moisture, Superior and Lower calorific value (PCS, PCI) of wood and coal can directly answer about the efficiency of the waste energy potential. Table 3 shows the results of these properties. The Density values varied from 870 to 980 Kg/m^3, and for this property there was no statistical difference between the woods, which confirms the grouping of the woods in high density class. While, for dry Moisture, it varied from 7.38 to 9.03%, where the statistical analysis indicated the formation of three groups/class for this property. The Calorific values ranged from 5,213.50 to 5,883.50 Kcal/Kg (PCS), and from 3,931.64 to 4,602.33 Kcal/Kg (PCI), for the PCS the Tukey test did not reveal statistical differences between the woods, and for PCI only Angelim pedra was grouped in another class. The PCS and PCI of coal were superior to those of wood, with a variation from 6,385.00 to 9,367.50 Kcal/Kg (PCS), and from 5,103.83 to 8,086.33 Kcal/Kg (PCI).

The results also show, with the exception of Angelim pedra, that the residues of the other species can be used together for the production of energy without interfering in quality.

The Density expresses the amount of mass contained in a given volume of material. According to Nascimento et al. [37], the Basic density is the most important parameter for technological studies of wood, as this property is related to several characteristics, such as Anatomical, Physical, Chemical and Energetic. Barros et al. [38] evaluating the energetic potential of Acácia, Ingá and Tachi wood (*Acacia mangium*, *Inga edulis* and *Tachigalia chrysophyllum*) for firewood production, obtained the average value for Basic density of 530 Kg/m^3, and Silva et al. [11] found values close to 600 Kg/m^3 for wood residues from the Amazon. While Cunha et al. [33] reached a larger spectrum (350 to 1,040 Kg/m^3) that included low, medium and high Density wood. High Density wood generates firewood/charcoal with higher energy quality. In this study, all wood showed high Density, which may explain the high energy potential of the residues.

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Table 3: Physical and energetic properties of wood residues from the Amazon.

Wood/Waste	Basic density (g/cm^3)	Moisture (%)	Calorific value (Kcal/Kg)			
			PCS*	PCI*	PCS**	PCI**
Angelim pedra	870 a	8.10 b	5,213.50 a	3,931.64 b	9,367.50 a	8,086.33 a
Angelim verm	980 a	9.03 a	5,497.50 a	4,216.33 a	8,689.00 a	7,407.83 a
Cumaru	970 a	7.38 c	5,675.00 a	4,393.83 a	7,453.50 b	6,172.33 b
Cumarurana	950 a	8.24 b	5,488.00 a	4,206.83 a	6,741.50 bc	5,462.72 b
Jatobá	980 a	8.50 ab	5,832.00 a	4,550.83 a	6,385.00 c	5,103.83 b
Mixture (MIX)	-	-	5,883.50 a	4,602.33 a	-	-
Average	950 (50.00)	8.25 (0.60)	5,598.25 (249.89)	4,316.97 (250.11)	7,727.30 (1,271.18)	6,446.61 (1,270.72)

Legend: * Wood; ** Coal; Means followed by the same letter do not differ statistically by the Tukey test at the 5% probability level; Value in parentheses standard deviation.

The acceptable Moisture content for a biomass to be considered of good quality, for energy purposes, should not exceed 12% [39]. Antwi-Boasiako and Acheampong [2] call attention to other factors that Moisture can influence when calculating economic viability, for example, costs with pre-drying of very humid material and another in transport, a biomass with a high content of general humidity increase in transport cost. However, Moisture cannot always be considered a negative characteristic. Demirbas and Sahin-Demirbas [40]. reported that a high Moisture content can favor the compressive strength and fracture index of the briquette.

Antwi-Boasiako and Acheampong [2] evaluating the resistance and Calorific value of tropical wood briquestes observed a Moisture variation of 12.05 to 12.95%. Mean values of 13% were found by Silva et al. [11] for Amazonian forest residues. In the present study, the maximum Moisture content on a dry basis was 9.03% for residues of Angelim vermelho wood, which may be a good indicator for the energetic properties of wood.

The Calorific value is a physical variable that expresses the amount of heat released by the complete combustion of the fuel mass unit, it is widely used as an energy parameter. Moutinho et al. [28] reached average PCS values of 4,554.30 Kcal/Kg for woods of matá-matá (*Eschweilera* sp.) hyperdominant species in the Amazon rainforest. Mitchual et al. [34] found PCS values for tropical African woods that varied from 4,815.13 Kcal/Kg for Mokolongo (*Celtis mildbreadii*) and 5,307.16 Kcal/Kg for Limba (*Terminalia superba*). In Germany DIN 51731/DINplus defines the range of 4,179.80 - 4,657.50 Kcal/Kg for the use of energy biomass [41], and in Austria NORM M7135 the minimum value for PCS is 4,299.23 Kcal/Kg [42]. As expected, the PCS of charcoal is superior to wood, and this behavior may be associated with the reduction of humidity, and the potentiation of carbon fixation in the substrate. The biomass quantified in the current study was an average of 5,598.25 Kcal/Kg for wood and 7,727.30 Kcal/Kg for coal, which indicates excellent parameters for energy production.

After evaluating the results of the Chemical, Physical and Energetic tests of the wood, the existence of a correlation between the data was verified by means of Pearson's coefficient (Table 4). The correlation measures the direction and the degree of the linear relationship between the quantitative variables, in statistical terms, two variables are associated when they have similarities in the distribution of their scores. More precisely, they can be associated through the distribution of frequencies or through the sharing of variance [43]. In all evaluated properties, a significant and directly proportional correlation was detected.

The PCS variable is the best indicator in energy studies and a direct correlation with the other properties can explain several events. The best correlations of PCS were with Extractives (0.8540), Lignin (0.9820), Moisture (-0.9359) and Basic density (0.8451). For Extractives and Ash, R^2 = 0.5583, although the coefficient was a little low, it was still considered significant.

Cunha et al. [33] reached similar relationships to this study when he observed a direct correlation between the PCS and the Basic density and also with the Lignin content. Moutinho et al. [28] and Silva et al. [11] found significant correlations when analyzing the content of Extractives and Lignin, this event was also observed in the study, possibly explaining that the higher the content of Extractives, the greater the concentration of Lignin and consequently the PCS. A high negative correlation was observed for Moisture *v* PCS (R^2 = -0.9359), this fact is well explained in energy studies of biomass, since the higher the Moisture content of the wood, the lower its combustion power due to moisture evaporation process, which absorbs energy in combustion [26].

Table 4: Pearson's correlation coefficient, obtained from the correlations between Chemical, Physical and Energetic variables.

	Extractives	Lignin	Holocellulose	Ash	Moisture	Basic density	PCS	PCI
Extractives		0.9844	0.6631	0.5583	0.9549	0.5642	0.8540	0.8531
Lignin			-0.9660	0.8882	0.9882	0.9442	0.9820	0.9823
Holocellulose				0.6769	0.9679	0.8881	0.6874	0.5880
Ash					0.5674	0.9148	-0.5789	-0.5783
Moisture						0.7118	-0.9359	0.9362
Basic density							0.8451	0.8455
PCS								0.9998
PCI								

All results show significant; test done with 95% confidence.

3.3 Energy Properties of briquettes

Briquettes are sustainable products made up of several biomasses where their greatest characteristic is the compaction of agroforestry substrates, at temperatures above 120 ºC, high pressures forming a block with reduced volume, but with great calorific value [44]. In Fig. 2, the general aspects of the briquettes produced with the residues of Amazonian wood can be observed. The standard moisture was 12% and the average dimensions Ø = 3.25 cm, l = 2.77 cm and color ranging from light yellow to dark brown.

Fig. 2: Briquettes produced with wood residues from the Amazon.

Energy density (DE) comprises the amount of energy per unit volume and can be used to compare the energy efficiency of various materials such as wood, coal and briquettes [45]. The DE estimate of wood waste is shown in Fig. 3. Considering wood as firewood, Angelim Pedra and Jatobá residues had the lowest and highest DE (4.53 and 5.71 MKcal/m^3), and this material when compacted (Wood briquette), energy efficiency effectively increased with a variation of 6.36 to 7.51 MKcal/m^3 (Angelim Pedra, and mixture of all residues/MIX). The material, when carbonized, presents a higher concentration of fixed carbon, which justifies the high DE values for both coal and coal briquettes, where in the coal a variation of 6.25 to 8.51 MKcal/m^3 (Jatobá, Angelim Vermelho) and coal briquettes from 8.01 to 11.42 MKcal/m^3 (Jatobá, Angelim pedra).

DE is one of the main properties that define the quality of the briquette, as it summarizes the physical-chemical characteristics and the amount of heat of the final product in a single variable. Silva et al. [11] evaluating the energetic properties of tropical wood residues, reached DE 3.09 MKcal/m^3 (Piquiarana – *Caryocar villosum*), where this variable showed a positive

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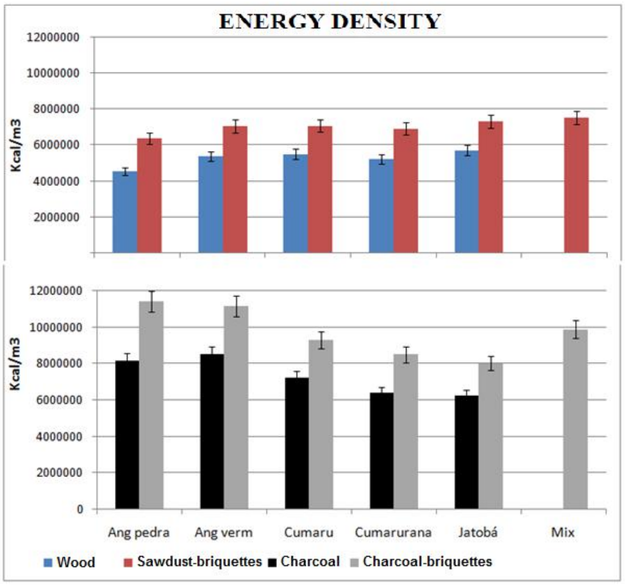

Fig. 3: Energy estimates of briquettes made from Amazonian wood residues.

Standard error bar (5%).

correlation with Basic density. When compacted sawdust for making briquettes, Souza and Vale [43] reached an average DE of 4.61 MKcal/m^3, where the Cumaru wood briquette (*Dipterix odorata*) showed values of 4.67 MKcal/m^3. Close values were found for briquettes made with a mixture of Baru (*Dipterix alata*) and Eucalyptus residues (Eucalyptus spp.) 4.88 MKcal/m^3 [44]. In the current study, the amount of heat produced by volume was much higher compared to data from the literature, on average 5.27 MKcal/m^3 for wood sawdust and 7.04 MKcal/m^3 for wood briquette, that is, compaction guarantees an energy gain of about 25%.

Sette Junior et al. [46]. evaluated the energy potential of coal and coal briquettes from bamboo sawdust, found DE for coal of 2.72 MKcal/m^3 and 5.13 MKcal/m^3 for coal briquettes. The estimate for DE of coal and coal briquette made from waste from Amazonian wood was higher than the research cited, on average 7.31 MKcal/m^3 for coal and 9.71 MKcal/m^3 for coal briquette. As it is biomass with a different chemical (Lignin, Extractives, and Ash) and physical (Moisture and Density) profile, these values may be in line with a matrix derived from tropical woods [26 and 34]. As for the increase in energy of the coal and compacted biomass matrix (Briquette), the variables that can explain this increase are compaction density, PCS, Extractives and Lignin, that is, higher values of these variables corroborate with greater amount of energy, as well as lower ash concentration.

The general data on Energy density presented in Fig. 3 allows us to draw a relationship of the type of material with energy efficiency: Charcoal briquette > Charcoal > Wood briquette > Wood. When comparing these different types of materials, whether by compaction (Briquetting) or carbonization, it appears that it is possible to enhance the use of regional wood residues as a good energy input, due to their physical-chemical characteristics. Using briquette means improving this input through compaction, which facilitates storage and transportation. And, depending on the purpose of using this input, carbonizing it is a way to enhance these residues. From an economic point of view, the energy produced from wood waste may be an alternative for use by a small community, even by companies in the wood industry segment. While, from the environmental point of view, plant biomass is a sustainable product in the long term, which avoids the disposal of this direct matrix in the environment, avoiding the production of decomposing gases such as methane [34 and 47].

IV. CONCLUSION

The indication of the use of biomass for the generation of energy products depends on several chemical and physical characteristics of this material. The study evaluated the energy properties of wood residues from Amazonian forests. It can be concluded by the results that the studied residues presented high PCS, both wood and coal, ranging from 5,213.50 - 5,883.50 Kcal/Kg for wood and from 6,385.00 - 9.367,50 Kcal/Kg for coal. The residues of Angelim vermelho, Cumaru and Cumarurana presented the highest value of total Extractives, and for Lignin the highest concentrations were found for the woods of Angelim pedra and Jatobá, while the lowest Ash content was obtained for the Jatobá residue. Regarding physical properties, Density and Moisture, in general all species showed high Density and low Moisture content, which favors the indication of these materials for energy purposes. The results also indicated that the briquettes charcoal of Angelim pedra and Angelim vermelho showed Energy density above of 10 MKcal/m^3, where the densification of sawdust and coal for the production of briquettes is technically and economically feasible, since its attainment comes from residues from the timber industry.

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REFERENCES

[1] Cavalcanti, M.A.; Nascimento, C.C. (2012). Avaliação do rendimento de duas espécies de madeiras da Amazônia. In: Vianez, B.F. et al. (Org.), *Potencial tecnológico de madeiras e resíduos florestais da Amazônia Central*. Manaus: INPA, pp. 225-234. https://repositorio.inpa.gov.br/handle/1/34012

[2] Antwi-Boasiako, C.; Acheampong, B.B. (2016). Strength properties and calorific values of sawdust-briquettes as wood-residue energy generation source from tropical hardwoods of different densities. *Biomass and Bioenergy*, v. 85, pp. 144-152. February. https://doi.org/10.1016/j.biombioe.2015.12.006

[3] Cacuro, T.A.; Waldman, W.R. (2015). Cinzas da Queima de Biomassa: Aplicações e Potencialidades. *Revista virtual de química*, v. 7, n. 6, pp. 2154-2165. November/ December. DOI: 10.5935/1984-6835.20150127

[4] Saad, A.L.M.; Viana, S.R.F.; Siqueira, O.A.A.P.; Sales-Campos, C.; Andrade, M.C.N. (2017). Aproveitamento de resíduos agrícolas no cultivo do cogumelo medicinal *Ganoderma lucidum* utilizando a tecnologia chinesa 'Jun-Cao'. *Ambiência, Guarapuava*, v. 13, pp. 271-283. January. DOI: 10.5935/ambiencia.2017.03.03

[5] Azambuja, R.R.; Castro, V.G.; Trianoski, R.; Iwakiri, S. (2018). Recycling wood waste from construction and demolition to produce particleboards. *Maderas, Ciencia y Tecnologia*, Concepción, v. 20, pp. 1-16. October. http://dx.doi.org/10.4067/S0718-221X2018005041401

[6] Varejão, M.J.C.; Nascimento, C.S.; Cruz, I.A. (2012). Avançando fronteiras: potencial químico, ecológico-econômico de espécies florestais de São Gabriel da Cachoeira, AM. In: Souza, LAG; Guillermo-Castellón, E.. (Org.). *Desvendado as Fronteiras do conhecimento na região Amazônica do alto rio Negro*. Manaus: INPA - Projeto FRONTEIRAS, pp. 51-67. https://repositorio.inpa.gov.br/handle/1/34376

[7] Vindaurre, G.B.; Carneiro, A.C.O.; Vital, B.R.; Santos, R.C.; Valle, M.L.A. (2012). Propriedades energéticas da madeira e do carvão de paricá (*Schizolobium amazonicum*). *Árvore*, Viçosa, v. 36, n. 2, pp. 365-371. March. http://dx.doi.org/10.1590/S0100-67622012000200018.

[8] Dias, J.M.C.S.; Souza, D.T.; Onoyama, M.M.; Miranda, C.H.B.; Barbosa, P.F.D.; Rocha, J.D. (2012). *Produção de briquetes e péletes a partir de resíduos agrícolas, agroindustriais e florestais*. Brasília: Embrapa Agroenergia, 130 p.

[9] Silva, C.J.; Vale, A.T. (2018). Energy density model for forest species from cerrado. *Revista Caatinga*, Mossoró, v. 31, n. 2, pp. 396 – 404. April/June. https://doi.org/10.1590/1983-21252018v31n216rc

[10] Arranz, J.I.; Miranda, M.T.; Montero, I.; Sepúlveda, F.J.; Rojas, C.V. (2015). Characterization and combustion behaviour of comercial and experimental wood pellets in South West Europe. *Fuel*, Londres, v. 142, pp. 199–207. February. https://doi.org/10.1016/j.fuel.2014.10.059

[11] Silva, D.A.; Almeida, V.C.; Viana, L.C.; Klock, U.; Muñiz, G.I.B. (2014). Avaliação das propriedades energéticas de resíduos de madeiras tropicais com uso da espectroscopia NIR. *Floresta e Ambiente*, Rio de Janeiro, v. 21, n. 4, pp. 561-568. October/December. DOI: 10.1590/2179-8087.043414

[12] Nascimento, C.S.; Nascimento, C.C.; Higuchi, N.; Cruz, I. A. Caracterização tecnológica da madeira de matá-matá (*Eschweilera odora* Poepp. Miers). In: *Seminário Internacional de Ciências do Ambiente e Sustentabilidade na Amazônia*, 5, 2018, Manaus. Anais. Manaus: EDUA, pp. 1-14. https://repositorio.inpa.gov.br/handle/1/24949

[13] Araujo, R.D.; Santos, J.; Nascimento, C.C.; Nascimento, C.S.; Barros, S.V.S.; Lima, M.P. (2019). Surface roughness of Edge Glued Panels (EGP) of amazon grown species. *Ciência e Agrotecnologia*, Lavra, v. 43, pp. 1-8. December. https://doi.org/10.1590/1413-7054201943019119

[14] Falemara, B.C.; Joshua, V.I.; Aina, O.O.; Nuhu, R.D. (2018). Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues. *Recycling*, v. 3, n. 37, pp. 1-13. August. DOI: 10.3390/reciclagem3030037

[15] Pinheiro, G. F.; Rondeiro, G.; Pinho, J. T. (2005). Densidade energética de resíduos vegetais. *Biomassa & Energia*, v. 2, n. 2, pp. 113-123. June.

[16] Gentil, L.V.; Vale, A.T. (2015). Energy balance and efficiency in wood sawdust briquettes production. *Floresta*, Curitiba, v. 45, n. 2, pp. 281 – 288. April/June. DOI: http://dx.doi.org/10.5380/rf.v45i2.36954

[17] Corrêa, A.A. (1980). Conversão química de madeiras da Amazônia - carvão e briquetes de carvão vegetal. *Acta amazonica*, Manaus, v. 18, n.1-2, pp. 93-108. January/February. http://dx.doi.org/10.1590/1809-43921988182108

[18] Associação Brasileira de Normas Técnicas – ABNT. (1997). *Determinação da densidade, do teor de umidade e da retração - NBR 7190*. Rio de Janeiro: ABNT, 105 p.
Associação Brasileira de Normas Técnicas – ABNT. (1986). *Análise imediata - NBR 8112*. Rio de Janeiro: ABNT, 5 p.

[19] American Society Testing and Materials – ASTM. (2013). *Standard test method for gross calorific value of coal and coke by the adiabatic bomb calorimeter (Withdrawn 2000) - ASTM D2015-00/2000.* West Conshohocken, PA. 6 p.

[20] Brun, E.J.; Bersch, A.P.; Pereira, F.A.; Silva, D.A.; Barba, Y.R.; Dorini Junior, J.R. (2018). Caracterização energética da madeira de três materiais genéticos de *Eucalyptus* sp. Floresta, Curitiba, v. 48, n. 1, pp. 87-92. January/March. DOI: 10.5380/rf.v48i1.51673

[21] Technical Association of the Pulp and Paper Industry – TAPPI. (1996). *Solvent extractives of wood and pulp (Proposed revision of T 204 cm-97) - TAPPI 264 om-88*. Peachtree Corners, GA: TAPPI, 4 p.

[22] TAPPI 222 om-02: 2006 Technical Association of the Pulp and Paper Industry – TAPPI. (2006). *Acid-insoluble lignin in wood and pulp (Reaffirmation of T 222 om-02) - TAPPI 222 om-02*. Peachtree Corners, GA: TAPPI, 7 p.

[23] American Society Testing and Materials – ASTM. (2013). *Standard test method for ash in wood - ASTM D1102-84*. West Conshohocken, PA. 2 p.

[24] Silva, D.A.; Yamaji, F.M.; Barros, J.L.; Roz, A.L.; Nakashima, G.T. (2015). Caracterização de biomassas para a briquetagem. *Floresta*, Curitiba, v. 45, n. 4, pp. 713-722. October/December. DOI: 10.5380/rf.v45i4.39700

[25] Assis et al. 2016). Assis, M.R.; Brancheriau, L.; Napoli, A.; Trugilho, P.F. (2016). Factors affecting the mechanics of carbonized wood: Literature review. *Wood Science and Technologic*. Berlin, v. 50, pp. 519–536. March. DOI: 10.1007/s00226-016-0812-6

[26] Santana, M.A.E.; Okino, E.Y.A. (2007). Chemical composition of 36 Brazilian Amazon Forest Woods species. *Holzforschung*, Berlin, v. 61, pp.468-477. May. DOI: 10.1515/HF.2007.084

[27] Moutinho, V.H.P.; Couto, A.M.; Lima, J.T.; Aguiar, O.J.R.; Nogueira, M.O.G. (2011). Energetic characterization of Matá-Matá wood from the Brazilian rainforest (*Eschweilera* Mart Ex Dc). *Scientia Forestalis*, Piracicaba, v. 39, n. 92, pp. 457-461. October. https://www.ipef.br/publicacoes/scientia/nr92/cap08.pdf

[28] Cavalcante, C.M.; Varejão, M.J.C.; Cruz, I.A. (2012). Poder calorífico de casca e madeira de espécies de *Eperua*: *E. falcata* Aubl., *E. leucantha* Benth., *E. purpurea* Benth. e. *schomburgkiana* Benth. In: *I Congresso de Iniciação Científica PIBIC/CNPq - PAIC/FAPEAM I*, 2012, Manaus. Anais. Manaus: INPA, pp.1-4. https://repositorio.inpa. gov.br/handle/1/4193

[29] Fengel, D.; Wegener, G. (2003). *Wood—Chemistry, ultrastructure, reactions*. New York: De Gruyter, 2003, 613 p.

[30] Printes, G.; Barbosa, A.P.; Varejão, M.J.C.; Silva, G.A. (2004). Determinação de constituintes químicos nos resíduos madeireiros da Amazônia Central. In: *XIII Jornada de iniciação cientifica – I Encontro de iniciação cientifica PIBIC-JR. CNPq - PAIC/FAPEAM*, 13, 2004, Manaus, Anais. Manaus: INPA, pp.1-4.

[31] Sjostron, E. (2013). *Wood chemistry. Fundamentals and applications*. 2nd ed. Finland: Academic Press, 293 p.

[32] Cunha, M.P.S.C.; Pontes, C.L.F.; Cruz, I. A.; Cabral, M. T. F. D.; Cunha Neto, Z.B.; Barbosa, A.P.R. (1989). Estudo químico de 55 espécies lenhosas para geração de energia em caldeiras. In: *Encontro brasileiro em madeiras e em estruturas de madeira*, 3, 1989, São Carlos. Anais. São Carlos: USP, pp.93-121.

[33] Mitchual, S.J.; Frimpong-Mensah, K.; Darkwa, N.A. (2014). Evaluation of fuel properties of six tropical hardwood timber species for briquettes. *Journal of Sustainable Bioenergy Systems*, v. 4, pp. 1-9. February. DOI: 10.4236/jsbs.2014.41001

[34] Pettersen, R.C. (1984). The chemical composition of wood. In: Rowell, R. (Ed), *The chemistry of solid wood*. Washington, D.C.: American Chemical Society, pp. 54-126.

[35] Martins, H. (1980). Madeira como fonte de energia. In: Penedo, W.R. (Ed). *Uso da madeira para fins energéticos*. Belo Horizonte: CETEC, pp. 9-26.

[36] Nascimento, C.C.; Brasil, M.M.; Nascimento, C.S.; Barros, S.V.S. (2017). Estimativa da densidade básica da madeira de *Eschweilera odora* (Poepp.) Miers por espectroscopia no infravermelho próximo. Ciência da Madeira, Pelotas, v. 8, pp. 42-53. October. DOI: 10.12953/2177-6830/rcm.v8n1p42-53

[37] Barros, S.V.S.; Nascimento, C.C.; Azevedo, C.P. (2012). Caracterização tecnológica da madeira de três espécies florestais cultivadas no Amazonas: Alternativa para produção de lenha. *Floresta*, Curitiba, v. 42, pp. 725-732. June. DOI: 10.5380/rf.v42i4.22514

[38] Quirino, W.F.; Pinha, I.V.O.; Moreira, A.C.O.; Souza, F.; Tomazello Filho, M. (2012). Densitometria de raios x na análise da qualidade de briquetes de resíduos de madeira. Scientia *Forestalis*, Piracicaba, v. 40, n. 96, pp. 525-536. April. http://www.ipef.br/publicacoes/scientia/nr96/cap11.pdf

[39] Demirbas, A.; Sahin-Demirbas, A. (2006). Alternative & renewable energy industries; environmental engineering; gas industries. *Petroleum Oil Industries*, v. 26, n. 1, pp. 83-91. April.

[40] Deutsches Institut Fürnormung – DIN. (1996). *Testing of solid fuels – Compressed untreated wood - DIN 5173*. Berlin. 10 p.

[41] Ostrreiches Normungs Institut – ONORM. (2000). *Compressed wood or compressed bark in natural state – pellets and briquettes, Requirements and test specifications – ONORM M 7135*. Vienna. 4 p.

[42] Figueiredo Filho, D.B.; Silva Júnior, J.A. (2009). Desvendando os mistérios do coeficiente de correlação de Pearson (r). *Revista Política Hoje*, Recife, v. 18, n. 1, pp. 115-146. January/June. DOI: 10.11606/issn.2237-4485.lev.2014.132346

[43] Souza, F.; Vale, A.T. (2016). Densidade energética de briquetes de biomassa lignocelulósica e sua relação com os parâmetros de briquetagem. *Pesquisa florestal brasileira*, Colombo, v. 36, n. 88, pp. 405-413, October/December. DOI: 10.4336/2016.pfb.36.88.879

[44] Vale, A.T.; Bustamante, K.; Fortes, M.M.; Lima, M.B.O..; Josino, M.N. (2017). Análise energética de briquetes de resíduos de *Eucalyptus* spp., *Dipterix alata*, *Caryocar brasiliense* e *Musa* spp. *Enciclopédia biosfera, Centro Científico Conhecer*, Goiânia, v. 14 n. 25, pp. 102-113. June. DOI: 10.18677/EnciBio_2017A10

[45] Sette Junior, C.R.; Lima, P.A.F.; Lopes, D.M. M.; Barbosa, P.V.G.; Coneglian, A.; Almeida, R.A. (2017). Characterization of biomass, charcoal and briquette of *Phyllostachys aurea* Carr. ex A. & C. Rivière. *Scientia Forestalis*, Piracicaba, v. 45, n. 116, pp. 619-628. DOI: 10.18671/scifor.v45n116.03

[46] Zanoni, M.M.V.; Zanatta, J.A.; Dieckow, J.; Kan, A.; Reissmann, C.B. (2015). Emissão de metano por decomposição de resíduo florestal inundado. *Revista Brasileira de Engenharia Agrícola e Ambiental*, Campina Grande, v. 19, n. 2, pp. 173–179. February. https://doi.org/10.1590/1807-1929/agriambi.v19n2p173-179