WASTE WOOD OF URBAN ORIGIN FOR ENERGY USE[1]

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ABSTRACT – The increasing demand for energy propels new areas of research in the search for sources that are economically viable and sustainable from an environmental point of view. In this sense, the objective of this study was to characterize a batch from urban wood waste aimed at energy use. We evaluate six different types of waste: solid wood, plywood, chipboard, MDF, OSB, and veneer. The residues were collected in a recycling plant in Piracicaba - SP and were taken to the laboratory to carry out the physical, chemical and thermogravimetric analyses. The experiment was conducted in a completely randomized design with three replicates per treatment (waste). Data analysis was performed by analysis of variance (ANOVA) and the Tukey test applied for multiple comparisons of means. Overall, there were no major differences between the results of solid wood residues and waste panels. Waste analyzed showed potential for energy use. It is recommended further studies to investigate the influence of different panels resins and coatings in its thermal degradation process.

Keywords: Energy woody biomass; Panels; Wood chips for fuel

RESÍDUOS DE MADEIRA DE ORIGEM URBANA VISANDO USO ENERGÉTICO

RESUMO – A crescente demanda por energia impulsiona novas frentes de pesquisas na busca por fontes que sejam economicamente viáveis e sustentáveis do ponto de vista ambiental. Neste sentido, o objetivo deste trabalho foi caracterizar um lote de resíduos de madeira de origem urbana visando uso energético. Foram avaliados seis diferentes tipos de resíduos: madeira maciça, compensado, aglomerado, MDF, OSB e chapa. Os resíduos foram coletados em uma estação de reciclagem no município de Piracicaba - SP e foram levados ao laboratório para realização das análises físicas, químicas e termogravimétricas. O experimento foi conduzido sob um delineamento inteiramente casualizado com três repetições por tratamento (resíduos). Para análise dos dados foi realizada a análise de variância (ANOVA) e aplicado o teste de Tukey para comparações múltiplas das médias. De maneira geral, não foram observadas grandes diferenças entre os resultados dos resíduos de madeira maciça e os resíduos de painéis de madeira. Os resíduos analisados apresentam potencial para uso energético. Recomenda-se novos estudos para verificar a influência das resinas e dos diferentes revestimentos de painéis no seu processo de degradação térmica.

Palavras-chave: Energia da biomassa lenhosa; Painéis; Cavacos para combustível.

1. INTRODUCTION

The use of biomass residues in Brazil has proven to be a promising alternative for generating income and mitigating impacts for both the private and the public sectors. This is especially true after the approval of Law 12,305 / 2014, which instituted the National Solid Waste Policy in the country.

Regarding the reuse of wood waste, Macfarlane (2009) draws attention to those of urban origin, since they can reliably offer a significant amount of wood with potential for use as fuel sources and heat/energy generation. This also contributes to the reduction of fossil fuels, as well as reducing pressure on destroying forests.

In Brazil, the generation of waste originates, above all, in the industrial activities of logging and also in urban areas, which in turn derive from the civil construction, afforestation, and defective packaging sectors (Brasil, 2009a). Lyon and Bond, (2014) still include wood leftovers from homes renovations, discarded old furniture, crates, and defective pallets.

Data from the Ministry of the Environment (Brasil, 2009b) estimate that the construction sector and urban areas alone account for 2.79 million tons of wood waste in the country, for which the most common destinations are: landfills for civil works; landfill for sanitary waste; landfill for inert material; Recycling stations; and irregular waste deposits.

To be used for energy purposes, the wood should not have moisture content above 20%, as higher values reduce the heat capacity of the combustion, the temperature of the firing chamber, and the temperature of the exhaust gas (Farinhaque, 1981). According to Brito (1986), the presence of water represents a negative calorific value, due to the fact that part of the released energy is spent in the vaporization and that very significant variations in the moisture content can hinder the combustion process. Such effects would lead to constant adjustment of system settings. Brand and Muñiz (2012) verified that the chemical composition, calorific value, and humidity of the forest biomass suffer variations in relation to the time of storage. This situation, to a certain extent, resembles the conditions observed for final disposal piles of urban wood waste, thus justifying their characterization.

As for the energy potential of wood panels from old furniture that are discarded in the trash, Farage et al. (2013) found that the technical and economic feasibility for its reuse is directly related to its moisture, heat ,and ash.

In addition to the mentioned characteristics, the thermogravimetric evaluation of the material (TGA) is of great importance. Through TGA, it is possible to quantify the combustion and decomposition characteristics of the fuels reliably and simply, which can provide a prediction for the combustion efficiency, boiler projects being an example (Vamvuka and Sfakiotakis, 2011; Yuzbasi and Selçuk, 2011; Moon et al., 2013).

Therefore, there are many properties that can interfere with the energetic use of the wood, and in the case of wood that is discarded in the garbage, limited information is available in the literature. Thus, the objective was to evaluate the energy potential of wood residues present in municipal solid waste in the city of Piracicaba - SP.

2. MATERIALS AND METHODS

2.1 Material e Amostragem

Six types of wood waste were evaluated: a) solid wood, b) MDF panels, c) plywood panels, d) chipboard, e) oriented structure board (OSB), and f) veneer.

The samples were provided by a recycling company based in the city of Piracicaba - SP. Sampling of residues was conducted according to standard NBR 10007 (ABNT, 2004). 240 samples of solid wood residues and 240 samples of panel residues were collected. The samples were stored in plastic bags and sent to the laboratory for further identification and analysis.

2.2 Physical Properties

Moisture Content

The moisture content was evaluated in the residues in their original forms, as collected in the field. The procedure used was NBR 14929 (ABNT, 2003).

Bulk Density

Bulk density was performed according to procedure NBR 6922 (ABNT, 1981). Samples of industrial chips

processed in the waste recycling plant were used. Part of the chips was sent for other analysis.

2.3 Chemical Composition

The lignin content was obtained according to standard TAPPI 222 05-74, (1974). The total extractives content was obtained according to standard TAPPI T-264 (1993). Holocellulose content was determined by the difference.

2.4 Immediate Constituent Analysis

The immediate constituent analysis was carried out to determine the volatile materials, ashes, and fixed carbon according to procedure NBR 8112 (ABNT, 1986).

2.5 Higher Calorific Value

The higher calorific value was determined using an Ika C200 bomb calorimeter according to procedure NBR 8633 (ABNT, 1984).

2.6 Thermogravimetric analysis

The equipment used was a SHIMADZU DTG-60H. The test had an initial temperature of 30 °C and a final temperature of 600 °C, with a heating rate of 10 °C.min^{-1}. A nitrogen flow of 50 mL.min^{-1} was used. The first derivative of the TG curve, which establishes mass loss as a function of temperature, was used to identify the rate of mass loss per second and the peaks characteristic of thermal degradation of biomass.

2.7 Statistical Analysis

The data were submitted to analysis of variance (ANOVA) using a completely randomized design with three replicates per treatment (residues) and, when necessary, the Tukey test was applied for multiple comparisons of the means. The analysis was performed using Minitab16.1® software and Microsoft Excel's Action supplement, all at 95% probability.

3. RESULTS

The results for the different types of residues sampled, percentages in dry mass, respective moisture contents, and bulk density are listed in Table 1.

In analyzing Table 1, it can be noticed that the largest participation was 56% for solid wood residues when considering the universal sample. Within the group of panels, the largest numbers of samples were for plywood residues, representing 23% of the total dry mass collected, followed by residues of MDF, chipboard, veneer, and OSB, with 10%, 23%, 4% 4%, and 3%, respectively.

In relation to the moisture content, the highest value found was from MDF residues, with 15% moisture content, and the lowest value was veneer with 10.24%. It is important to note that the residue moisture contents is close to the average equilibrium humidity of the collection municipality, which is 12.9% (Jankowsky and Galina, 2013). This is viewed as satisfactory for drying of the material in consideration of energy.

For the bulk density results, the highest observed value was for solid wood with 0.183 g.cm^{-3}, being statistically equal to the plywood, chipboard, and OSB. The MDF and veneer had the lowest density 0.104 g.cm^{-3} and 0.139 g.cm^{-3}, respectively. This result may have been observed because MDF and veneer are produced from fibers that would better fit the spaces in the measuring vessel.

Table 2 shows the total extractive, holocellulose, and lignin contents of the analyzed solid residues.

It can be observed in Table 2 that the average

Tabela 1 – Teor de umidade médio dos resíduos sólidos amostrados.
***Table 1** – Average moisture content of the sampled waste.*

Residues	N	MS (g)	TU (%)	DG (g.cm^{-3})
Solid wood	240	68.84 [56]	12.26 *(34.07)*	0.183 *(1.01)* a
Plywood	92	28.54 [23]	12.73 *(34.32)*	0.177 *(517)* a
Chipwood	23	5.32 [4]	13.93 *(31.16)*	0.168 *(2.94)* a
MDF	76	12.48 [10]	15.00 *(28.86)*	0.104 *(2.03)* c
OSB	20	3.98 [3]	11.01 *(40.01)*	0.168 *(4.96)* a
Veneer	29	4.52 [4]	10.24 *(42.85)*	0.139 *(1.06)* b

N: Number of Samples. MS: Dry Weight. TU: Base Moisture Content. DG: Bulk Density. Values between brackets [ ] represent the percentage of dry mass of each type of waste in relation to the total collected. Values between parenthesis ( ) are the variation coefficients of the analyzed wastes.

Tabela 2 – Teores de extrativos totais, de holocelulose e de lignina.
Table 2 *– The content of total extractives, holocelulose and lignin.*

Resídues	ET (%)	THO (%)	L (%)
Solid Wood	16.67 *(1.14)* a	51.76 *(0.21)* c	31.57 *(0.94)* bc
Plywood	12.14 *(1.79)* cd	53.21 *(2.34)* bc	34.65 *(3.56)* a
Chipwood	12.51 *(1.18)* c	56.64 *(0.46)* b	30.84 *(0.86)* bc
MDF	14.26 *(0.79)* b	57.08 *(2.01)* b	28.65 *(4.16)* c
OSB	11.26 *(0.91)* d	55.63 *(3.59)* bc	33.10 *(5.86)* ab
Veneer	11.78 *(7.69)* cd	64.15 *(3.86)* a	24.06 *(6.87)* d

ET: Total extractives content; THO: holocelulose content; L: lignina content; Values between parenthesis ( ) are the variation coefficients of the analyzed wastes.

total extractive content for solid wood was higher than the other residuals analyzed. One possible explanation may be the possibility of this segment being formed by an unknown number of species, native or not. Another possibly is that it presents higher extractive contents in its composition as compared to Pinus sp. and Eucalyptus sp, which are traditionally used in the manufacturing of reconstituted panels.

The highest holocellulose content was 64.15% for veneer, and the lowest was for solid wood with 51.76%. Regarding the lignin contents, the highest values were for OSB and plywood with 33.10% and 34.65%, respectively.

Figure 1 shows the average values of ash, volatile materials, fixed carbon, and higher calorific value of the analyzed solid residues.

The mean values found for the fixed carbon contents are statistically the same for the analyzed residues. On the other hand, the volatile materials are repeated only when considering the panel residues.

From the absolute point of view, the maximum value observed for fixed carbon was 20.83% for plywood residues, and the maximum for volatile materials was 82.64% for solid wood residues. For ash values, the results ranged from 0.9% to 1.7% for solid wood and veneer, respectively. As for the higher calorific value, the highest observed value was for the residues of OSB with 20117.57 KJ.kg^{-1}, and the lowest value was for MDF of 18191.65 KJ.kg^{-1}.

The mass loss as a function of temperature (TG curve) of the residues is presented in figure 2.

Three distinct regions can be observed: the 1st region (with temperatures from 30 to 230 ºC) is where volatization of water and extractives occur; the 2nd region (with temperatures from 230 to 370 ºC), the release of volatile materials occurs; and in the 3rd

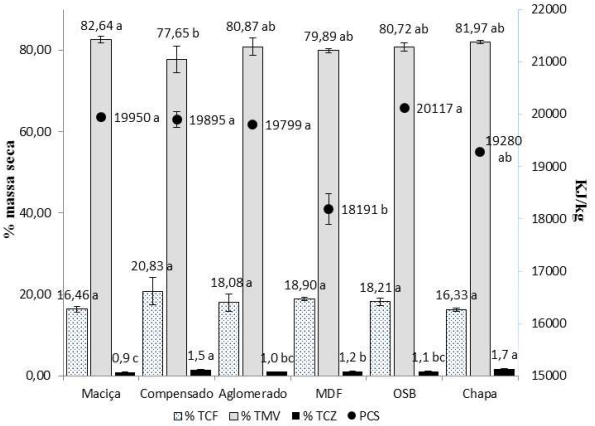

Figura 1 – Análise química imediata dos resíduos e poder calorífico superior.
Figure 1 *– Immediate constituent analyses of waste and higher calorific value.*

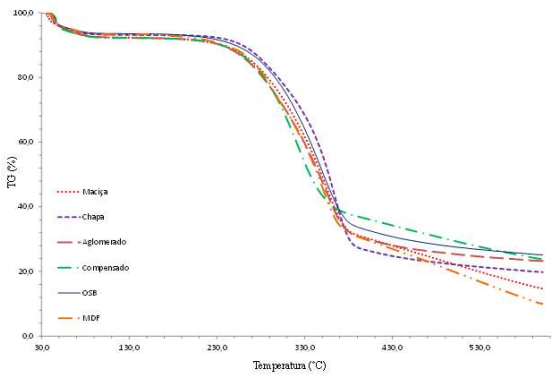

Figura 2 – Perda de massa em função da temperatura para os diferentes resíduos lenhosos.
Figure 2 *– Weight loss versus temperature for different waste timber.*

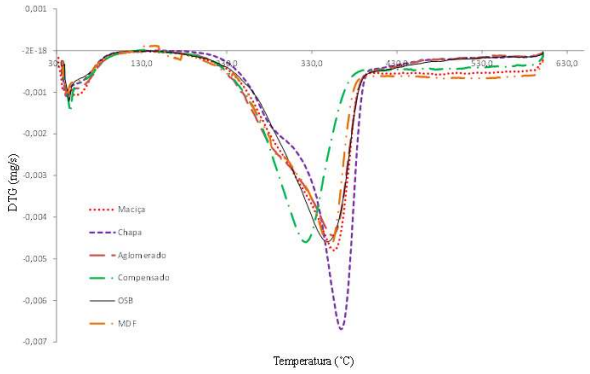

Figura 3 – Curvas de DTG para os resíduos lenhosos analisados.
***Figure 3** – DTG curves for wood residues analyzed.*

region (with temperatures above 370 ºC), pyrolysis reactions occur.

The DTG curves graph for the analyzed residues is shown in Figure 3.

Analyzing the DTG curves (Figure 2), a certain similarity between the curves for solid wood, chipboard, OSB, and MDF can be observed. It is also observed that there is a formation of a higher intensity inverted peak for veneer residues in the 340 ºC range, inferring that this is the moment of maximum degradation of the hemicelluloses of this material. This, in turn, can be explained by its high content of holocellulose (64.15%), which was verified during the chemical analyzes.

4. DISCUSSION

Dry Weight

Solid wood residues had a higher share of dry mass when compared to veneer, probably due to the fact that it presented higher bulk density.

Moisture

The values found for moisture content are in accordance with those reported in the literature. According to the work of Farage et al. (2013), which evaluated wood pulp residues from furniture in Ubá-MG, moisture levels were found to be 22.7% for plywood, 10.3% for MDF, ranging from 9.8% to 10.3 % for chipboard, and between 16.5% and 17.8% for solid wood. The equilibrium humidity for the municipality of Ubá is 14.37% (Lima and Mendes, 1995), which is slightly above that reported for the city of Piracicaba and, therefore, should also justify the higher moisture content of the plywood found in the literature. In addition to the influence of environmental conditions, one must also consider the conditions of sampling, time of year, size of the pile, and time of exposure of the waste to the elements. For the remaining residues, the values were very close to those of this work.

Bulk Density

Farage et al. (2013) found the bulk density of MDF residue values to be 303 $kg.m^{-3}$, and 200 $kg.m^{-3}$ for solid wood, the latter being close to what was found in this work.

Chemical Analysis

The values found in this work for chemical analysis are in agreement with those reported by Morais; et al. (2005), who studied wood of *Pinus oocarpa* and found extractive contents of 11.8% and lignin content of 25.18%. In studies by Barbosa et al. (2014), the authors evaluated residues of *Pinus elliottii* and found holocellulose contents of 61.79% and lignin content of 26.40%. Silva et al. (2014) studied four species of tropical wood and found total extractive contents varying between 3.55% and 7.68%, holocellulose varying from 58.68% to 70.55%, and lignin varying between 25.13% and 33.64%.

On the other hand, Ferreira (2013) studied MDF wood waste from the furniture sector and found values of 13.9% for extractives in water, 50.7% for cellulose, 22.3% for hemicellulose, and 13.1% for lignin. In this case, the values were 15.92% higher for holocellulose (cellulose + hemicellulose) and 15.55% lower for lignin compared to those found in the current study. One possible explanation may be that they are residues from different origins whose variations in relation to their chemical characteristics are not yet well known.

The results for ash contents are in accordance with those reported by Farage et al. (2013), which found ash content for MDF, solid wood, plywood, and chipboard to be 0.74%, 0.48%, 0.79%, and 0.95%, respectively.

Calorific Potential and Immediate Constituent Analysis

The values of higher calorific value, volatile materials, fixed carbon, and ash are very close to those reported in literature for similar woody biomass. Farage et al. (2013) reported higher calorific values of 19811.94 $KJ.kg^{-1}$ for MDF, 19803.56 $KJ.kg^{-1}$ for solid wood, 18501.47

KJ.kg-1 for plywood, and 18953.64 KJ.kg-1 for chipboard.

Poletto; et al. (2014) found MDF values of 78.3% for volatile materials, 21.17% for fixed carbon, 0.53% for ash, and 19005 KJ. kg^{-1} for calorific value.

Yorulmaz and Atimtay, (2009) analyzing MDF panels found 86.68% to be volatile materials, 11.06% for fixed carbon, 2.29% for ash, and 19310 $KJ.kg^{-1}$ for higher calorific value.

Souza et al.(2012), studying waste from *Pinus taeda,* found values of volatile materials varying from 82.57% to 86.24%, fixed carbon varying from 13.44% to 17.01%, ash ranging from 0.20% to 0.42%, and higher calorific value varying between 18987 $KJ.kg^{-1}$ and 20624 $KJ.kg^{-1}$.

In a study by Silva et al. (2014) on four types of tropical wood residues, the authors found values of volatile materials varying from 80.94% to 82.76%, fixed carbon varying from 16.99% to 18.94%, ash ranging from 0.119% to 0.562%, and higher calorific value ranging from 19292 $KJ.kg^{-1}$ to 20632 $KJ.kg^{-1}$.

The similarity between the results found in the literature and those obtained in this work suggests promising potential in the use of these residues for energy purposes.

T G A - D T G

The analysis of the temperature ranges of this work is similar to that found by Kercher and Nagle (2001) for MDF, and close to the flammability range (270-280 ° C) found by Vamvuka et al, (2015) in mixtures of urban wood waste.

Above 370 ºC, the plywood and OSB residues presented greater thermal stability when compared to the others. This can be explained by the higher lignin content of these residues (Figure 1). This result is in accordance with those found by Sharma et al. (2004); Yang et al. (2006); Protásio et al. (2013), who verified that lignin provides greater thermal stability when compared to the other molecular groups. This is due to the carbon-carbon bonds between the monomeric phenyl propane units, and consequently, the stability of their aromatic matrix, in addition to the high molecular weight.

At the end of the treatment, the highest degradation or loss of mass was verified for the MDF panels. This group was followed by solid wood, which proved to have the lowest lignin content in the chemical analysis, confirming the previous reasoning.

The fact that most of the panel residues presented higher thermal stability when compared to solid wood residues suggests that the resins, used as binders and different types of coatings and finishes common in the manufacturing of panels, may present greater stability than the wood when subjected to combustion tests. However, this impression needs to be confirmed by further research.

Different results were observed by Protásio et al. (2013), who showed degradation peaks at 288.9 ° C, and in works by Poletto et al. (2012) with a peak of 300 ºC for eucalyptus sawdust.

In a study by Kim et al. (2006), the authors defined the range of 180 °C and 350 °C for hemicelluloses degradation. Shafizadeh (1985), defined the degradation range for cellulose being between 305 °C and 375 °C and lignin between 250 °C and 500 °C. In this same context, Popescu et al. (2011) found that wood components behave differently if they are isolated or closely linked. The authors studied the degradation of different species of wood and verified that the degradation of hemicellulose begins around 170 °C and extends up to 380 ° C; Lignin degradation also starts at 170 °C and extends to temperatures above 600 ° C; the degradation of the cellulose occurs between 280 and 400 °C.

Thus, the results found for the DTG curves are within the standards surveyed in the literature, supporting the idea use of these wastes for energy. Although no clear influence of panel resins on TG/DTG curves has been observed in the present work, a more detailed analysis of the degradation of these binder compounds is recommended in future work.

5. CONCLUSION

The wood residues present in urban solid waste that were analyzed in this work presented characteristics similar to the traditional woody biomass used for energy purposes and, therefore, have a promising potential for this purpose.

In general, residues of solid wood and residues of wood panels showed similar values for technological properties.

For thermal study of wood panels, special attention should be given to the possible influence of the resins

and the different types of coatings common for panels when studying the process of thermal degradation.

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