

## Evaluation of Biomass Properties for the Production of Solid Biofuels

José Cláudio Caraschi<sup>1</sup> , Danielle Goveia<sup>1,2</sup>, Glauton Dezajacomo<sup>1</sup>,  
Glauca Aparecida Prates<sup>1</sup>

<sup>1</sup>Universidade Estadual Paulista Julio de Mesquita Filho – UNESP, Itapeva/SP, Brasil

<sup>2</sup>Faculdade de Ciências e Letras, Universidade Estadual Paulista Julio de Mesquita Filho - UNESP, Araraquara/SP, Brasil

### ABSTRACT

The efficient use of biomass as fuel requires prior knowledge of the composition and properties of the material in order to be able to develop technologies for its efficient combustion while ensuring that emissions of pollutants remain within acceptable limits. Therefore, the analysis of the physical and chemical properties of these materials is essential in order to evaluate their potential for energy purposes. Given the need for improved understanding of biofuels, this study aimed to characterize biomass waste obtained from the manufacturing process of wood panels and urban waste for the production of solid biofuels. Biomass wastes were characterized in terms of their physical and chemical properties. Wastes that presented the poorest qualities for use as fuels were eucalyptus bark, industrial waste, and sweepings, which had high ash contents and low calorific values. The remaining wastes showed satisfactory characteristics for use as solid biofuels.

**Keywords:** bioenergy, heat combustion, lignocellulosic wastes.

## 1. INTRODUCTION

---

The rising global demand for energy, which is mainly consolidated around fossil fuels, has resulted in great dependence on an energy source whose use is expensive, potentially unreliable, and harmful to the environment. This situation has led to the search and development of alternative sources of energy, with growing emphasis on the use of renewable ones due to recent shifts in environmental awareness (Adams & Lindegaard, 2016; Bach et al., 2016).

Amongst the various renewable options, vegetal biomass, which was in the past considered inferior fuel, has become increasingly attractive (Gravalos et al., 2016; Tao et al., 2012a; Tao et al., 2012b; Williams et al., 2012). This material can be used in a variety of systems to produce bioenergy and consequently contribute to the development of more sustainable human societies.

The efficient use of biomass as fuel requires prior knowledge of the composition and properties of the material in order to be able to develop technologies for its efficient combustion while ensuring that emissions of pollutants remain within acceptable limits.

Biofuels can be characterized in terms of their chemical and physical properties, once data obtained are used to establish the most suitable combustion conditions. However, a greater number of operational factors influence the combustion of solid biofuels, compared to gases or liquids. It is therefore essential to analyze these materials in terms of their calorific value, elemental and immediate chemistry, moisture content, particle size, and apparent density. Knowledge of these properties enables biofuels to be used more efficiently for energy production (Tao et al., 2012a; Tao et al., 2012b).

The calorific value of a substance is defined as the amount of energy per mass unit released in the form of heat during material combustion. Immediate analysis (proximate analysis) of a fuel provides volatile matter, fixed carbon, and ash percentages. During combustion of a solid fuel, volatile substances present are released as gases that burn in the form of a flame. The heat generated is then dispersed around the combustion zone, which avoids high heat intensity at localized points. The combustion of fuels containing high levels of volatile substances is both faster and easier. The fixed carbon fraction consists of the material that

is combusted in the solid state, and fuels with higher fixed carbon contents are preferable, because they burn more slowly. The ash fraction is the residue that remains after combustion is complete, and consists of inorganic components such as calcium, potassium and magnesium, which are present in the form of salts including sulfates, phosphates, carbonates, and silicates, among others. In biofuels, the ash fraction can vary from around 0.5% to more than 5%, depending on variables such as plant species and amounts of bark and soil. High ash levels result in the need for more frequent cleaning of combustion equipment and can lead to greater corrosion of metal components.

In Brazil, the energy generated from biomass is seen as an opportunity by various sectors of industry (mainly agro-industry and forestry) in which large amounts of biomass wastes are generated during the productive chain (Cortez et al., 2008; Santos et al., 2013). These industrial activities include the sugar/alcohol and timber processing sectors. In the latter case, wastes generated include wood fragments, tree bark, roots, and sawdust. Other agro-industry wastes include rice husks and materials generated in the paper/cellulose sector (Santos et al., 2013; Protásio et al., 2011; Paula et al., 2011; Andrade et al., 2013; Brand et al., 2014).

Given the need for an improved understanding of biofuels, the objective of the present work was to evaluate the properties of vegetal biomass waste derived from the manufacturing process of wood panels (*Eucalyptus* spp.), as well as urban waste for the production of solid biofuels, used as sources of energy. Waste materials were produced during the different stages of MDF manufacture (medium density fiberboard), and were classified as follows: industrial waste (a mixture of MDF agglomerates, hard chips, laminate panels, MDF panels, and other wood materials); eucalyptus bark; eucalyptus fines; waste from sweeping; eucalyptus particles; eucalyptus particles with resin and additives; eucalyptus wood dust; and wood dust with resin, additives, and urban waste (without defined composition).

## 2. MATERIAL AND METHODS

---

Waste materials were produced during the different stages of MDF manufacture (medium density fiberboard), and were classified as follows:

industrial waste (a mixture of MDF agglomerates, hard chips, laminate panels, MDF panels, and other wood materials); eucalyptus bark; eucalyptus fines; waste from sweeping; eucalyptus particles; eucalyptus particles with resin and additives; eucalyptus wood dust; and wood dust with resin, additives, and urban waste (without defined composition). The different types of lignocellulosic wastes analyzed in this work are detailed in Table 1.

Wastes were characterized in terms of their physical and chemical properties, following standard procedures. Analyses were performed in triplicate.

Physical properties apparent density (ABNT NBR 6922, SCAN-C46:92 and ABNT NBR 14984) and moisture content on wet basis ( $MC_{wb}$ ) of waste samples were determined according to the Brazilian Technical Standards Association NBR 14929. Chemical properties determined were moisture content, immediate analysis, higher and lower calorific values, and calorific values, including the influence of moisture (net calorific values).

Immediate chemical analyses of samples considered mass fractions of moisture, volatile matter (VM), ash, and fixed carbon (FC). The VM, FC, and ash contents (on a dry basis) were determined according to procedures described in Standards Methods (ABNT NBR 8112, ASTM E 711-82, ASTM E 872-82 and ASTM D 1102-84), substituting a platinum crucible for a porcelain crucible, and using temperature of 600 °C for ash determination.

Higher calorific values (HCV) of wastes were determined according to ASTM E 711-87 standard, using Model C 5000 calorimeter (IKA-Werke). For quantification of the lower calorific values (LCV), the heat released during the condensation of moisture

present in samples was ignored, and only the heat obtained from fuel actually used was considered. The LCV calculation used an average elemental hydrogen content of 6% in dry wood and Equation 1 ( $\text{kJ kg}^{-1}$ ).

$$LCV = HCV - 1,356.52 \text{ (kJ kg}^{-1}\text{)} \tag{1}$$

Where:

$LCV$  = lower calorific value, in  $\text{kJ kg}^{-1}$ ;

$HCV$  = higher calorific value at 0% moisture, in  $\text{kJ kg}^{-1}$ ;

$H$  = wood hydrogen content, estimated at 6.0%.

The net calorific value (NCV) was determined using Equation 2.

$$NCV_{\%MC_{wb}} = LCV \times \frac{100 - \%MC_{wb}}{100} - \Delta H_v \times \frac{\%MC_{wb}}{100} \tag{2}$$

Where:

$NCV_{\%MC}$  = net calorific value of samples, in  $\text{kJ kg}^{-1}$ ;

$\%MC_{wb}$  = percentage moisture content of samples on wet basis;

$\Delta H_v = 2,512.08 \text{ J} = 600 \text{ cal}$ , this is the amount of energy (latent heat) required to evaporate 0.540 kg of water formed during the combustion of 1.0 kg of moisture-free (dry) vegetal biomass, assuming average elemental hydrogen content of dry wood of 6.0%.

### 3. RESULTS AND DISCUSSION

Results are discussed in terms of the physical and chemical properties of biomass wastes.

The Table 2 presents the values obtained for apparent density, along with moisture contents in biomass wastes.

The R-Dust/R/A waste showed the highest apparent density ( $255.7 \text{ kg m}^{-3}$ ), which could be explained by

**Table 1.** Types of lignocellulosic wastes and their abbreviations.

N.	Wastes	Abbreviation
1	MDP residues	R-MDP
2	MDF residues	R-MDF
3	Industrial waste	R-Ind
4	Mixture of industrial and urban wastes	R-Mix
5	Fines waste	R-Fines
6	Bark waste	R-Bark
7	Sweepings waste	R-Sweep
8	Refining process particles waste	R-Par/Re
9	Particles with resin and additives	R-Par/R/A
10	Refining process wood dust	R-Dust/Re
11	Wood dust from milling	R-Dust/Mo
12	Wood dust with resin and additives	R-Dust/R/A

**Table 2.** Average values for moisture content (MC), apparent density ( $d_{\text{bulk}}$ ) and standard deviation (SD) of wastes.

Wastes	MC (%)	$d_{\text{bulk}}$ ( $\text{kg m}^{-3}$ )	SD
R-MDP	8.6	222.9	2.3
R-MDF	6.2	158.6	1.5
R-Ind	21.7	236.3	1.1
R-Mix	27.0	174.2	3.3
R-Fines	44.3	187.2	2.1
R-Bark	11.4	164.3	0.4
R-Sweep	11.7	155.3	0.6
R-Par/Re	7.4	175.8	1.5
R-Par/R/A	5.8	230.7	2.3
R-Dust/Re	2.8	175.9	1.4
R-Dust/Mo	2.7	194.0	1.0
R-Dust/R/A	4.6	255.7	3.2

the presence of resin and additives incorporated in the wood. Although the R-Par/R/A material had the same composition as the dust, the greater density of dust was due to the material packing (less empty space among dust particles). The moisture contents of both materials were similar, around 5%.

The industrial waste (R-Ind) also presented high apparent density, because the largest fraction of the material consisted of MDP panels, which, in addition to containing resin and additives, is a compacted material.

Another feature observed was the high moisture content of eucalyptus bark (R-Bark). High moisture level can negatively affect the calorific value and significantly increase transportation costs. For example, in the case of eucalyptus bark with this moisture content (11.4%), 60% of the transported weight would consist of water.

Sweeping waste (R-Sweep) showed the lowest apparent density,  $155.3 \text{ kg m}^{-3}$ , because a significant proportion consisted of de-fibered eucalyptus bark with low moisture content. Overall, wastes containing resins and additives presented the highest apparent density.

The immediate analysis of results obtained for materials are given in Table 3. It was observed that samples contained high levels of volatile material, within the 74-89% range reported in literature (Brand, 2010). This material usually consists of substances that burn more easily and rapidly (Yaman, 2004; Brand, 2010). However, other factors also need to be taken into consideration in deciding how a certain fuel will behave during combustion. It is necessary to analyze the capacity of the volatile matter to combust, which in turn depends on factors including temperature,

moisture content, and specific surface area. The last factor influences the rate at which the volatile matter is released. Nonetheless, in general terms, higher content of volatiles tends to favor combustion reactions (which are also dependent on other variables).

The highest volatile matter content (84.6%) was obtained for waste generated in the refiner (R-Par/Re), while the lowest contents were found for eucalyptus bark (73.7%), followed by industrial waste (75.1%), and sweepings (77.4%).

The highest ash content (9.5%) was obtained for industrial waste, followed by sweepings (9.4%) and eucalyptus bark (8.1%). Some individual results showed ash contents close to 10%. These high levels probably resulted from previous operations involving storage, handling, and addition of glues, and contributed to lower contents of volatile matter shown by the three wastes. The lowest ash content (0.1%) was measured for particles generated in the refiner (which showed the highest volatile matter content). The remaining wastes presented ash contents between 0.7 and 3.1%, similar to values previously reported (García et al., 2015).

An important issue that needs to be highlighted concerns the maintenance and cleaning of the combustion equipment, which needs to be performed more frequently when fuel has high ash content. The presence of ash, as well as moisture, can decrease the rate of combustion reactions, although in many practical situations their values must necessarily be tolerated.

The average fixed carbon content in wastes was 16%, close to values reported in literature (García et al., 2015; Brand, 2010). The highest values (both 18.1%) were

**Table 3.** Mean values of volatile matter (VM), fixed carbon (FC) and ash (Cz) contents of the wastes.

Wastes	Immediate analysis		
	VM (%)	FC (%)	Cz (%)
R-MDP	79.8	18.1	2.1
R-MDF	82.9	16.4	0.70
R-Ind	75.1	15.4	9.5
R-Mix	81.9	16.3	1.8
R-Fines	81.9	15.8	2.3
R-Bark	73.7	18.1	8.1
R-Sweep	77.4	13.2	9.4
R-Par/Re	84.6	15.3	0.10
R-Par/R/A	82.3	16.4	1.2
R-Dust/Re	80.5	16.4	3.1
R-Dust/Mo	83.9	14.9	1.3
R-Dust/R/A	82.9	16.3	0.80

obtained for eucalyptus bark and MDP dust, while the lowest value (13.2%) was found for sweepings. The fixed carbon percentage refers to the fraction that is burned in the solid state, and fuels with higher fixed carbon levels are usually preferable as they burn more slowly (Komilis et al., 2012; Pirraglia et al., 2012). However, in the present case, despite the fact that the eucalyptus bark presented greater percentage of fixed carbon, which should be an advantage, values obtained for the other variables (lower volatile matter content, and higher ash content) negatively influenced its quality as a fuel.

The Table 4 presents the net calorific values of fuels, together with the corresponding moisture contents and the higher and lower calorific values.

High standard deviations were obtained for the net calorific values of MDP dust (342 kJ kg<sup>-1</sup>), eucalyptus dust (254 kJ kg<sup>-1</sup>), dust with resin and additives (180 kJ kg<sup>-1</sup>), eucalyptus bark (163 kJ kg<sup>-1</sup>), and MDF waste (128 kJ kg<sup>-1</sup>). These can be explained by heterogeneity within the same sample, in terms of both wood and other components (such as resin and additives).

Comparison between the net calorific value (fresh waste containing moisture) and the higher calorific value (dry basis) provides an indication of the negative influence of the moisture content on the energy available per mass unit. (Furtado et al., 2012). The greatest difference among values, due to the effect of the moisture content on the net calorific value, was obtained for fine eucalyptus waste (difference of 4,866 kJ kg<sup>-1</sup>).

The highest higher calorific value (19,897 kJ kg<sup>-1</sup>) was found for dust with resin and additives, followed by the urban and industrial waste (19,835 kJ kg<sup>-1</sup>). Nine out of the 12 fuels analyzed showed higher calorific values in the 19,400-19,900 kJ kg<sup>-1</sup> range. The lowest higher calorific value was obtained for eucalyptus bark (16,937 kJ kg<sup>-1</sup>), followed by industrial waste (17,886 kJ kg<sup>-1</sup>) and sweepings (18,349 kJ kg<sup>-1</sup>), which were fuels containing the highest percentages of inert material (ash). This demonstrates the negative influence of ash on the calorific value.

The calorific values obtained for wastes were within the range reported in literature for eucalyptus wood (Protásio et al., 2012; Furtado et al., 2012; Carneiro et al., 2014; Reis et al., 2012; Couto et al., 2013).

Data provided in Table 4 reveal the negative influence of moisture on the net calorific values of wastes. The moisture contents of samples were adjusted to 0 (LCV), 30 and 50%. Since the calculation for each waste was based on the higher calorific value, and using the same equation, the decrease in the calorific value was linear for all samples, with an inverse relationship between moisture content and calorific value.

As shown in Table 4, higher moisture content resulted in smaller amount of energy available per mass unit of fuel. In the absence of moisture, all wastes showed net calorific values greater than 16,500 kJ kg<sup>-1</sup>, while with the addition of moisture, values progressively decreased to below 8,000 kJ kg<sup>-1</sup> (for 50% moisture content).

**Table 4.** Moisture contents and calorific values (on a dry basis) of wastes.

Wastes	HCV (kJ kg <sup>-1</sup> )	LCV* (kJ kg <sup>-1</sup> )	NCV <sub>10%</sub> (kJ kg <sup>-1</sup> )	NCV <sub>30%</sub> (kJ kg <sup>-1</sup> )	NCV <sub>50%</sub> (kJ kg <sup>-1</sup> )
R-MDP	19,717	18,361	16,273	12,099	7,924
R-MDF	19,558	18,202	16,130	11,987	7,845
R-IND	17,886	16,530	14,625	10,817	7,009
R-Mix	19,835	18,479	16,379	12,181	7,983
R-Fines	19,613	18,257	16,180	12,026	7,872
R-Bark	16,937	15,581	13,771	10,153	6,534
R-Sweep	18,349	16,993	15,042	11,141	7,240
R-Par/Re	19,664	18,308	16,226	12,062	7,898
R-Par/R/A	19,513	18,157	16,090	11,956	7,822
R-Dust/Re	19,695	18,339	16,253	12,083	7,913
R-Dust/Mo	19,390	18,034	15,979	11,870	7,761
R-Dust/R/A	19,897	18,541	16,435	12,099	8,014

\* LCV (Lower Calorific Value) = NCV<sub>0%</sub>.

#### 4. CONCLUSION

The characterization of the different wastes examined in this work provides a better understanding of these lignocellulosic fuels. Wastes that presented the poorest quality for use as fuels were eucalyptus bark, industrial waste, and sweepings, which had high ash contents close to 10%, as well as the lowest calorific values. Among these three fuels, eucalyptus bark was likely to be the most difficult to burn, due to its high moisture content and presence of large particles.

Despite the low moisture content, industrial waste would be likely to cause problems due to the high ash level, resulting in increased maintenance requirements. The same considerations can be applied to sweeping wastes.

The remaining wastes showed satisfactory characteristics for use as fuels, with performance being determined by the moisture content, particle size, and type of combustion equipment used. From the environmental perspective, preference should be given to wastes that do not contain resin and additives in their composition.

The results could be used in studies using mixtures of these fuels, with the aim of improving the characteristics of wastes with worse performances.

#### SUBMISSION STATUS

Received: 12 nov., 2018

Accepted: 13 dec., 2018

#### CORRESPONDENCE TO

**José Cláudio Caraschi**

Universidade Estadual Paulista – UNESP,  
Câmpus de Itapeva, Rua Geraldo Alckmin, Vila  
Nossa Senhora de Fátima, 519, CEP 18409-010,  
Itapeva, SP, Brasil  
e-mail: j.caraschi@unesp.br

#### REFERENCES

- Adams PWR, Lindegaard K. A critical appraisal of the effectiveness of UK perennial energy crops policy since 1990. *Renewable & Sustainable Energy Reviews* 2016; 55: 188-202. <http://dx.doi.org/10.1016/j.rser.2015.10.126>.
- Andrade TCGR, Barros NF, Dias LE, Azevedo MIR. Biomass yield and calorific value of six clonal stands of *Eucalyptus urophylla* S. T. Blake cultivated in Northeastern Brazil. *Cerne* 2013; 19(3): 467-472. <http://dx.doi.org/10.1590/S0104-77602013000300014>.
- Bach Q, Tran K, Skreiberg Ø. Hydrothermal pretreatment of fresh forest residues: effects of feedstock pre-drying. *Biomass & Energy* 2016; 85: 76-83. <http://dx.doi.org/10.1016/j.biombioe.2015.11.019>.
- Brand MA. *Energia de Biomassa Florestal*. Rio de Janeiro: Ed. Interciência; 2010. 131 p.
- Brand MA, Stahelin TSF, Ferreira JC, Neves MD. Produção de biomassa para geração de energia em povoamentos de *Pinus taeda* L. com diferentes idades. *Revista Árvore* 2014; 38(2): 353-360. <http://dx.doi.org/10.1590/S0100-67622014000200016>.
- Carneiro ACO, Castro FNM, Castro RVO, Santos RC, Ferreira LP, Damasio RAP et al. Potencial energético da madeira de *Eucalyptus* sp em função da idade e de diferentes

- materiais genéticos. *Revista Árvore* 2014; 38(2): 375-381. <http://dx.doi.org/10.1590/S0100-67622014000200019>.
- Cortez LAB, Lora EES, Gómes EO. *Biomassa para energia*. Campinas: Ed. UNICAMP; 2008. 736 p.
- Couto AM, Protásio TP, Trugilho PF, Neves TA, Sá VA. Multivariate analysis applied to evaluation of *Eucalyptus* clones for bioenergy production. *Cerne* 2013; 19(4): 525-533. <http://dx.doi.org/10.1590/S0104-77602013000400001>.
- Furtado TS, Ferreira JC, Brand MA, Neves MD. Correlação entre teor de umidade e eficiência energética de resíduos de *Pinus taeda* em diferentes idades. *Revista Árvore* 2012; 36(3): 577-582. <http://dx.doi.org/10.1590/S0100-67622012000300020>.
- García R, Pizarro C, Álvarez A, Lavín AG, Bueno JL. Study of biomass combustion wastes. *Fuel* 2015; 148: 152-159. <http://dx.doi.org/10.1016/j.fuel.2015.01.079>.
- Gravalos I, Xyradakis P, Kateris D, Gialamas T, Bartzialis D, Giannoulis K. An experimental determination of gross calorific value of different agroforestry species and bio-based industry residues. *Natural Resources* 2016; 7(1): 57-68. <http://dx.doi.org/10.4236/nr.2016.71006>.
- Komilis D, Evangelou A, Giannakis G, Lymperis C. Revisiting the elemental composition and the calorific value of the organic fraction of municipal solid wastes. *Waste Management* 2012; 32(3): 372-381. <http://dx.doi.org/10.1016/j.wasman.2011.10.034>. PMID:22119517.
- Paula LER, Trugilho PF, Rezende RN, Assis CO, Baliza AER. Produção e avaliação de briquetes de resíduos lignocelulósicos. *Pesquisa Florestal Brasileira* 2011; 31(66): 103-112. <http://dx.doi.org/10.4336/2011.pfb.31.66.103>.
- Pirraglia A, Gonzalez R, Saloni D, Wright J, Denig J. Fuel properties and suitability of *Eucalyptus benthamii* and *Eucalyptus macarthurii* for torrefied wood and pellets. *BioResources* 2012; 7(1): 217-235.
- Protásio TP, Bufalino L, Tonoli GHD, Couto AM, Trugilho PF, Guimarães M Jr. Relação entre o poder calorífico superior e os componentes elementares e minerais da biomassa vegetal. *Pesquisa Florestal Brasileira* 2011; 31(66): 113-122. <http://dx.doi.org/10.4336/2011.pfb.31.66.113>.
- Protásio TP, Tonoli GHD, Guimarães M Jr, Bufalino L, Couto AM, Trugilho PF. Correlações canônicas entre as características químicas e energéticas de resíduos lignocelulósicos. *Cerne* 2012; 18(3): 433-439. <http://dx.doi.org/10.1590/S0104-77602012000300010>.
- Reis AA, Protásio TP, Melo ICNA, Trugilho PF, Carneiro ACO. Composição da madeira e do carvão vegetal de *Eucalyptusurophylla* em diferentes locais de plantio. *Pesquisa Florestal Brasileira* 2012; 32(71): 277-290. <http://dx.doi.org/10.4336/2012.pfb.32.71.277>.
- Santos F, Colodette JL, Queiroz JH. *Bioenergia & Biorrefinaria: cana-de-açúcar & espécies florestais*. Viçosa: Os Editores; 2013. 551 p.
- Tao G, Lestander TA, Geladi P, Xiong S. Biomass properties in association with plant species and assortments I: A synthesis based on literature data of energy properties. *Renewable & Sustainable Energy Reviews* 2012a; 16(5): 3481-3506. <http://dx.doi.org/10.1016/j.rser.2012.02.039>.
- Tao G, Lestander TA, Geladi P, Xiong S. Biomass properties in association with plant species and assortments. II: A synthesis based on literature data for ash elements. *Renewable & Sustainable Energy Reviews* 2012b; 16(5): 3507-3522. <http://dx.doi.org/10.1016/j.rser.2012.01.023>.
- Williams A, Jones JM, Ma L, Pourkashanian M. Pollutants from the combustion of solid biomass fuels. *Progress in Energy and Combustion Science* 2012; 38(2): 113-137. <http://dx.doi.org/10.1016/j.pecs.2011.10.001>.
- Yaman S. Pyrolysis of biomass to produce fuels and chemical feedstocks. *Energy Conversion and Management* 2004; 45(5): 651-671. [http://dx.doi.org/10.1016/S0196-8904\(03\)00177-8](http://dx.doi.org/10.1016/S0196-8904(03)00177-8).