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URBAN LIGNOCELLULOSIC WASTE POTENTIAL AS BIOFUEL

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Abstract. *The continuous development of new technologies for renewable solid biofuels upgrading and the waste management concern due to biowaste accumulation in urban landfills increased the biomass's attention as an energy resource. Recent studies have shown an encouraging evolution in thermal processing treatments aiming to enhance the lignocellulosic waste energetic potential. Knowing the benefits of torrefaction treatment, this paper aims to evaluate the thermal behavior of organic blends composed by pruning residues from different species with the most representativeness within the ecosystem forest of Brasília, DF. The biomass mixture was torrefied (225, 250, and 275°C) and chemically analyzed to assess the torrefied product's thermal treatment impact. Regarding the energetic upgrade, the calorific power results showed an enhancement of 2.63, 6.64, and 11.10% for 225, 250, and 275 °C torrefaction treatments, respectively. The results could support afforestation action bids in upcoming segments of the growing city, indicating specific tree species holding a higher energetic potential.*

Keywords: *Torrefaction, waste-to-energy, pruning-tree-residue, thermal-upgrading, biofuel*

1. INTRODUCTION

Afforestation is an essential activity to maintain the quality of life in urban centers. Most Brazilian cities do not consider urban afforestation when planning their urban districts. This issue results in inadequate pruning waste management strategies. The lack of an efficient management model for pruning waste aggravates the environmental problems resulting from its inadequate disposal (MEIRA, 2010).

Biomass as an energy resource can be employed directly in combustion systems. However, the inherent disadvantages of lignocellulosic residues as elevated volatile matter and moisture content, higher O/C ratio, lower density and calorific value, and poorer grindability in comparison with coal (VAMVUKA et al., 2020). Alternatively, it is possible to apply different conversion routes and upgrade this biofuel, overcoming the inherent drawbacks.

The implementation of thermochemical technologies presents a promising pathway for taking advantage of urban residues (SILVA-MARTÍNEZ et al., 2020). Torrefaction appears as a thermal-modifying process operating between 200-300 °C in an inert or partially oxidative atmosphere aiming to upgrade solid biomass fuel (CAHYANTI; DODDAPANENI; KIKAS, 2020; NIU et al., 2019; SINGH; SARKAR; CHAKRABORTY, 2020). In this paper, the torrefaction process was applied to improve the biomass's physical and chemical composition. Torrefaction enhances the performance of biomass during co-combustion and gasification (CHEN et al., 2011). The torrefied biomass possesses increased carbon content, decreased H/C, O/C ratios, increased mass-energy density, and similar chemical compositions with coal (NIU et al., 2019).

Brasília, despite its planned city concept, suffers from the pruning tree residues disposal. Leaves and branches are crushed for composting, and the larger diameter logs are sold for heat production on bakery/pizzeria and poultry farms. This work aims to identify, characterize, and compose a solid fuel blend with the six species of trees that have the most representativeness on the ecosystem forest of Brasília. Three different torrefaction experiments (225, 250, and 275 °C) were conducted to evaluate the residue blend's thermal upgrading. The thermal behavior was assessed by its thermogravimetric analysis (TG, DTG), proximate, and calorific analysis of raw and torrefied blends.

2. MATERIAL AND METHODS

2.1 Biomass feedstock

The blend was composed of six different species selected considering the number of species and pruning calls. The biomass samples were supplied by NOVACAP (Urbanization Company of Brazil's New Capital) and are composed of *Mangifera indict* (mango tree), *Ficus benjamina* (ficus), *Pelthophorum dubium* (cambuí), *Persea americana* (avocado), *Anadenanthera colubrina* (angico) and *Tapirira guianensis* (pombeiro). The raw biomasses calorific and proximate analyses and the blend proportions are in Tab. 1.

Table 1: Calorific analysis (High Heating Value - HHV (MJ. Kg^{-1})) and Proximate (Volatiles (%) and Fixed Carbon (%)) for each species.

Species / %	**Vol**	**FC**	**HHV**
1. *Mangifera indica* (35%)	72.8	23.2	19.2
2. *Ficus benjamina* (20%)	75.8	20.2	18.4
3. *Pelthophorum dubium* (16%)	72.9	21.5	19.4
4. *Persea americana* (16%)	78.7	16.1	19.3
5. *Anadenanthera colubrina* (6%)	71.1	24.5	19.7
6. *Tapirira guianensis* (7%)	72.9	23.9	18.9
Blend (100%)	77.6	17.9	19.3

The samples were cut into branches with husks and sliced by a hammer mill to decrease particle size. After that, they were sieved (60mesh) for separation. The sample preparation was conducted for each species separately. The mixture was delineated by distinct percentages of each biomass, pondering the assessed representativity. The biomasses samples were dried in an oven at 104 °C until dry conditions before torrefaction analysis and chemical experiments.

2.2 Torrefaction experiments

The flow diagram of blend residues thermal modification assessment is presented in Fig. 01. The torrefaction was carried out in a macro-thermo-gravimetric apparatus consisting of a nitrogen steel cylinder, a rotameter, a reaction unit (TGA 2000A), and a computer to control and data processing (SILVEIRA, 2018; SILVEIRA et al., 2019). The inert atmosphere was promoted by the carrier gas (nitrogen) with a 3.5L min^{-1} flow rate, a 7°C min^{-1} heating rate, and a drying process at 104°C until weight stabilization before the torrefaction treatment.

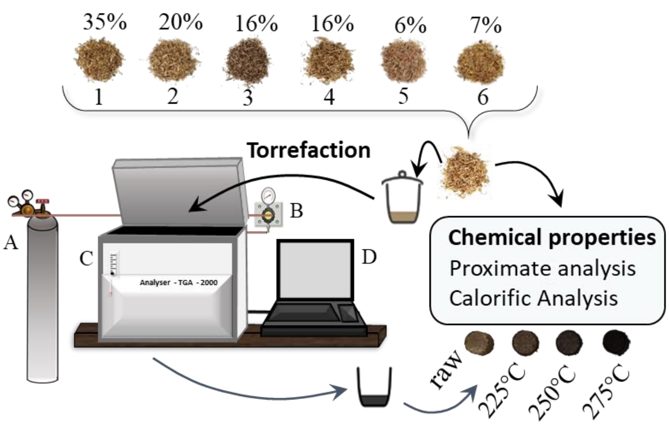

Figure 1. Flow diagram of blend residues thermal modification assessment. Experimental system: A) N_2 cylinder, B) Gas control rotameter, C) Thermal analyzer TGA-2000A, D) Computer.

The samples (2,60 ± 0,5 g) were allocated into ceramic crucibles, with lids, during the torrefaction. The tests were carried out in triplicate, and the mean values and standard deviations were considered. The sample's thermal behaviors were evaluated for the three temperatures (T) 225, 250, and 275 °C with a 60 minutes treatment time. The mass loss, calculated over time, is described by Eq. (1) (LIN et al., 2019a, 2017; SILVEIRA, 2018; SILVEIRA et al., 2017):

$$Mass\ loss^{\ T}(t) = 100 - \left(\frac{m_i(t)}{m_0} \times 100\right) \tag{1}$$

Here m_0 is the dried mass before torrefaction; $m_i(t)$ is the solid mass during torrefaction, t is the residence time, and T the experiment temperature. The macroscale thermal degradation analysis provided information about the dynamic profiles of mass loss.

2.3 Proximate and calorific analysis

The raw and torrefied samples underwent proximate and calorific analysis. The volatile matter (VM) and ash content experiments were conducted following the ISO standards 18123-2015 and 18122-2015 procedures, respectively. The calorific test followed the ISO 1928-2009 for the equipment calibration and ISO 17225-2014 for HHV calculation. In all tests, the dry basis was considered for the calculations. According to the Eq. (2) (LIN et al., 2019a; SILVEIRA et al., 2020), the gain of HHV was determined by the enhancement factor (EF), calculated with the ratio between treated and untreated blends.

$$EF^T = \frac{HHV^T_{treated}}{HHV_{untreated}} \tag{2}$$

3. RESULTS

The calculated mass loss with Eq. 01 was normalized after the drying stage (104 °C) (SILVEIRA et al., 2018), and the profiles for 225, 250 and 275°C treatments are presented in Fig. 2(a). Evaluating the thermal decomposition, the thermal stability is identical for the different treatments, beginning the decomposition around 183 °C (12 min), agreeing with (CANDELIER et al., 2016).

The treatment temperatures highly influenced the blend residues thermal degradation, and the mass loss final values were 6.60 (225 °C), 13.94 (250 °C), and 22.14 % (275 °C). For the 225 °C, the weight loss profile is nearly linear at the end of the treatment, but in the case of 250 and 275 °C, it can be seen that the mass-loss curves continue to go up mainly because of the cellulose degradation, followed by lignin, in addition to the hemicelluloses (TUMULURU et al., 2011).

The solid yield derivative profiles are plotted in Fig. 02(b). Temperature treatments of 225, 250, and 275 °C had a maximum decomposition of -0.003, -0.0071, and -0.0163%.min^{-1}, respectively, between 40-50min.

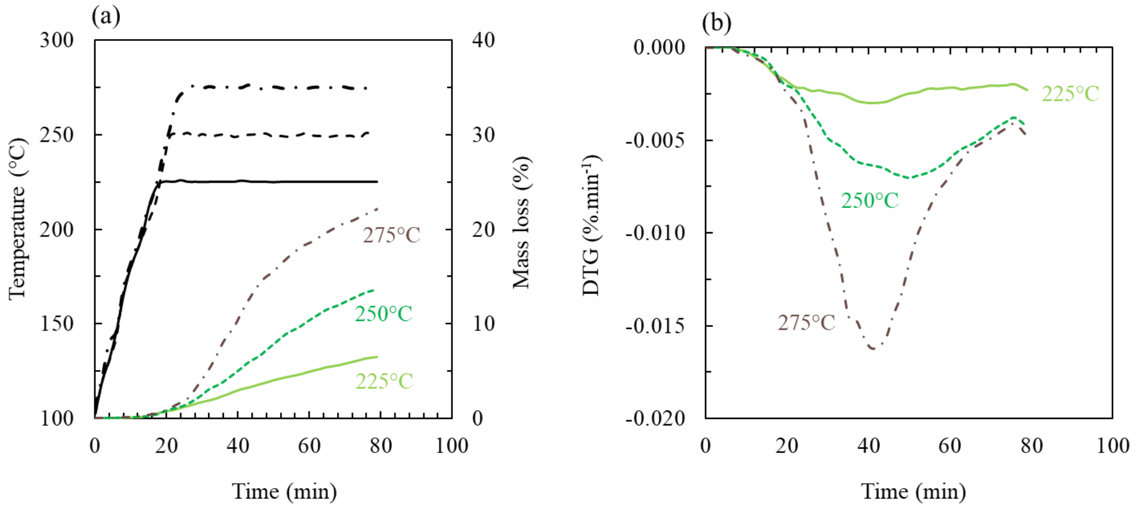

Figure 2. Solid yield dynamic profiles (a) and DTG profiles (b) for the blend torrefaction treatments.

Comparing Tab. 1 and 2, the raw blend's resulting properties showed a good description of the six species. As reported in the literature (CAHYANTI; DODDAPANENI; KIKAS, 2020; GALVÃO et al., 2020), the FC increased, and the VM decreased with the mass loss, agreeing with obtained results Tab. 2. During torrefaction treatment, H_2O and light volatiles (hydrocarbons) are produced at an intensifying rate and extent with increasing temperature treatments, resulting in a decrease of volatile matter, leading to increased fixed carbon content (BARSKOV et al., 2019). Enhanced FC results in increased HHV (LIN et al., 2019b; NIU et al., 2019), corroborating with the obtained HHV enhancement of 2.63, 6.64, and 11.10% for 225, 250, and 275 °C treatments, respectively.

Table 2: Calorific analysis (HHV (M.J. Kg^{-1}) and Proximate (Volatiles (%), Ash (%), and Fixed Carbon (%)) for raw and torrefied blends.

Treatment	**Mass loss (%)**	**HHV (MJ. Kg^{-1})**	**Volatiles (%)**	**Ash (%)**	**FC (%)**
Raw	0.00	19.3232	77.61	4.49	17.90
225°C	6.60	19.8305	75.56	4.56	19.88
250°C	13.94	20.6058	70.68	5.01	24.31
275°C	22.14	21.4664	64.25	5.55	30.20

Fig. 3 shows that an accurate linear correlation (R^2=0.99) was obtained between the high heating value (HHV) and fixed carbon (FC), as well as for the HHV Enhancement Factor and Mass loss. HHV tends to enhance with solid biomass thermal decomposition; thus increasing fixed carbon and decreasing volatile material, and typically follows a linear trend for all of the lignocellulosic waste materials (BARSKOV et al., 2019; SANTANNA et al., 2020). Regarding Fig. 3(b), the HHV and mass-energy density increase with increased mass loss. The mass loss of torrefied biomass is mainly dominated by hemicellulose decomposition and a small cellulose and lignin part. The thermal upgrade conferred 2.63, 6.64, and 11.10% enhanced HHV for 225, 250, and 275 °C treatment, respectively.

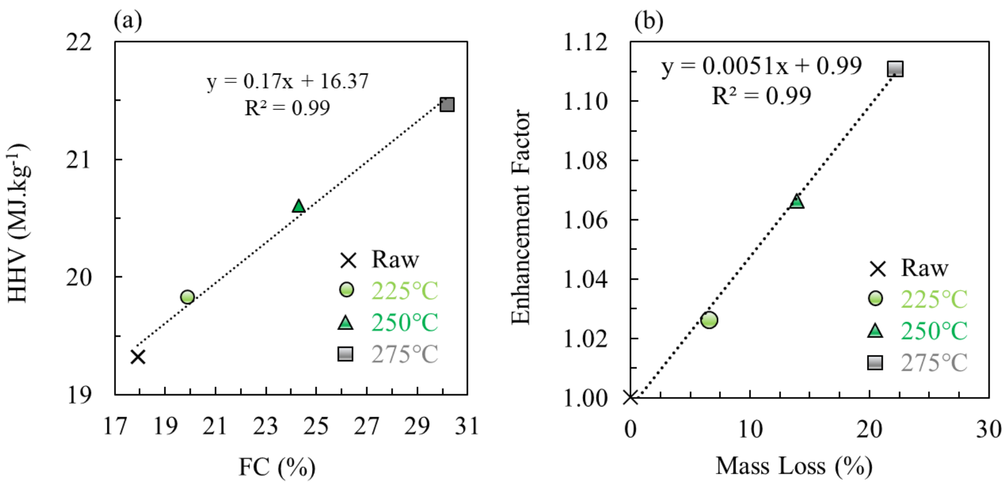

Figure 3. Correlation between (a) HHV and FC (b) HHV enhancement factor and Mass loss.

4. FINAL CONSIDERATION

Results indicate that the resulted properties of the raw blend showed a good description of the six species. The torrefaction temperature highly affects the blend samples, and the mass loss showed a good process performance indicator to evaluate urban residue torrefaction. The torrefaction step represents an additional unit operation in the biomass utilization chain. An increase of HHV means a higher carbon content in a small density of the material, which is considered ideal for transportation and storage. The results showed that the torrefaction is a good form of pretreatment to increase the burning power of lignocellulosic material and improve homogeneity, grindability and hydrophobic behavior. The process helps raise the fuel used to generate energy in boilers at thermoelectric plants, replacing the mineral coal with charcoal. However, the attendant capital and operating costs and conversion losses are offset by savings elsewhere (VAN DER STELT et al., 2011).

About the pruning waste, there is an energy potential that can be applied to gasification systems improving the use of these biomaterials and reduce the impacts of landfills' disposal. Further analysis regarding a comparison with different blends proportion, kinetics prediction and elemental composition experiments to fulfill a gasification model will be the subject of a forthcoming study.

5. ACKNOWLEDGEMENTS

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