INFLUENCE OF TORREFACTION SEVERITY ON WOOD BLEND FROM AMAZONIAN RESIDUES

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ABSTRACT: This study investigated and characterized the torrefaction treatment of Amazonian wood residues blend. Six wood residue materials from legal wood processing from the Jacundá National Forest (Rondônia, Brazil) were blended and torrefied at 225, 250 and 275 °C for 60min in an inert atmosphere (N_2). The wood residues comprised *Peltogyne lecointei* (S1), *Erisma uncinatum* (S2), *Martiodendron elatum* (S3), *Handroanthus incanus* (S4), *Dipteryx odorata* (S5), and *Allantoma decandra* (S6). The solid yield (SY) and torrefaction severity index (TSI) were applied to evaluate the torrefaction process severity. The pyrolysis of torrefied biomass and chemical analysis (proximate, ultimate, and calorific) allowed to evaluate the influence of torrefaction severity on the blend. The preliminary results showed that torrefaction temperature highly affects the blended samples, with a weight loss of 4.9% for 225 °C and 34.96% for 275 °C torrefaction. A goodness of fit was achieved between the calculated TSI and volatile matter (R^2 =0.99), fixed carbon (R^2 =0.99), and ash contents (R^2 =0.93). HHV showed an improvement of up to 7% for 275 °C torrefaction. The results provided valuable information to determine the process parameters for further torrefaction and pelletizing processes (TAP) aiming at fuel production in decentralized systems, reducing diesel dependence on the Amazon region.
Keywords: Amazon; Residues; Thermochemical Conversion; Torrefaction; Biofuel.

1 INTRODUCTION

Through selective logging and other methods of timber exploitation, sustainable forest management (SFM) enables the preservation of the majority of the forest and its biodiversity [1]. Such a model provides simultaneous social, economic, and environmental benefits because it generates income and employment while preserving biodiversity and carbon stocks [1]. Furthermore, following Brazilian law (Forest Code-Law 4771, Article 5, 2006), the legal harvesting practices are supported since it preserves environmental services and also creates goods (both timber and nontimber products) [2].

SFM entails a maximum harvest intensity (HI) of 30 m³ of extracted timber per hectare, observing a cutting cycle of 30 years and a minimum class diameter on diameter at breast height (DBH) of 50 cm [1,2]. This model is called conventional logging (L30) because it keeps the forest from being destroyed while enabling timber production and money. In addition, lumber is extensively used in many constructions (such as floor covering, roof structures, and window frames). These applications have kept carbon stored for decades and prevented carbon dioxide emissions. [1]. Since carbon is kept in long-lasting wood products and remains stable throughout time, it is conceivable to think of harvested wood products as a form of carbon stock [3].

Brazil has more than 250 isolated systems, with most located in Rondônia, Acre, Amazonas, Roraima, Amapá, and Pará. Isolated Systems represent less than 1% of electricity consumption in Brazil. However, they stand out for the predominance of diesel-fired thermal generation, which accounts for around 96% of supply. Diesel is an expensive and polluting source with relatively volatile prices, which presents an excellent opportunity for alternative sources, including residual woody biomass, that can benefit from the high opportunity costs in the region.

The total waste production factor reaches 1.65 m³/m³ of processed log wood in the Amazon context. Considering a density of 0.8 t/m³ for log wood (typical for Amazonian species), the production factors of woody residue per ton of extracted log wood are 0.8 and 0.52 in management and industrialization, respectively. Within this broader geographic scope, residual woody biomass would support an installed capacity of 6.5 GW [4].

The future biomass feedstock for thermochemical routes valorization will likely be a biomass blend. The bottleneck of residue recovery depends on surpassing its heterogeneity and feedstock's steady supply (seasonal dependence availability) [5]. The relevance of this work relies on increasing energy density and homogeneity of biomass residues blend, which can be potentially utilized as biofuel. Torrefaction is a pretreatment that promotes oxygen/carbon and hydrogen/carbon ratio reduction on lignocellulosic biomass by partially decomposing hemicellulose, dehydrating cellulose, and lignin thought moisture content and light volatiles release [6]. As a result, grinding, homogeneity, storage (hydrophobicity and fungal decay), calorific value, energy density, and particle size are increased [7,8]. Therefore, it could advance resource-efficient management in decentralized systems by enhancing the performance and efficiency of the overall integrated plants (torrefaction and combustion or gasification) [5,9–12].

Accordingly, this study aims to analyze the impact of different torrefaction temperatures on Amazonian wood residues. Torrefaction treatment and pyrolysis of torrefied wood were conducted to clarify the natural wood blend's thermal behavior and degradation mechanism. Chemical analysis (proximate analyses) was also performed. Thus, this could be considered for enhancing the economic viability of future torrefaction plants and decentralized energy conversion systems.

2 MATERIAL AND METHODS

2.1 Material

The six wood residues used as feedstock in this study were obtained from the Jacundá National Forest (Rondônia, Brazil). The samples were grounded and sieved (60 mesh). The exact proportions of 16.66% were adopted for each species, defining the blend (100%). Before torrefaction experiments, the residues mixture was dried at 104 °C until weight stabilization. The description of wood residue species, as well as torrefaction operational conditions, are shown in Table I.

**Table I:** Wood residue species and torrefaction process parameters.

Species	Torrefaction conditions			
	Aspect	Time	HR	Temp.
1. Peltogyne lecointei				
2. Erisma uncinatum				
3. Martiodendron elatum				225
4. Handroanthus incanus		60	5	250
5. Dipteryx odorata				275
6. Allantoma decandra				

Time (min); HR (°C.min⁻¹); Temperature (°C).

2.2 Torrefaction experiment

The torrefaction process was performed for a solid mixture of six different residues samples (2.8 ± 0.5 mg) within a thermogravimetric analyzer TGA-2000 (Fig. 1). A continuous nitrogen flow (3.5 L.min⁻¹) provided the inert atmosphere during the entire experiment. Three temperatures (T) of 225, 250, and 275 °C were explored to characterize light, mild, and severe torrefaction for 60 minutes of residence time (t). The continuously measured weight $w_i(t)$ and anhydrous weight w_0 allowed the calculation of the weight loss $WL^T(t)$ by Eq. (1) [13–16].

$$WL^T(t) = \frac{w_i(t)}{w_0} \times 100 \qquad (1)$$
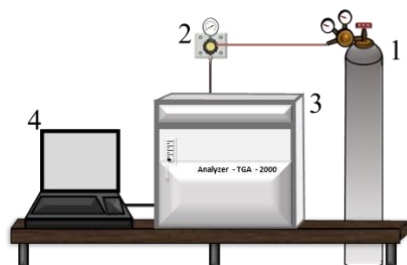
Figure 1: Reactor system. 1) N₂ cylinder, 2) Gas control rotameter, 3) TGA-2000A, 4) Computer.

2.3 Chemical analysis

The proximate analysis was conducted to determine the volatile matter, ash, and fixed carbon content, following the ISO standards 18123-2015 and 18122-2015, respectively.

2.4 Torrefaction severity index (TSI)

In the present work, the torrefaction severity index (TSI), initially proposed by Chen et al. (2014) [17], an indicator of torrefaction performance in the range of 0-1, was applied to assess the thermodegradation phenomena of the blended residues. The TSI is determined with Eq. (2) [17] for the temperature (T), residence time (t), and weight loss at the most severe torrefaction condition of 275 °C for 60 min, specifically, $WL^{275}(60)$.

$$TSI = \frac{100 - WL^T(t)}{100 - WL^{275}(60)} \qquad (2)$$

2.5 Torrefied product pyrolysis

Pyrolysis analysis was conducted on the torrefied product to describe how torrefaction affects biomass components degradation. The same analyzer (TGA-2000) was performed from 25 to 1000 °C with a 20 °C.min⁻¹ heating rate and a 3.5 L.min⁻¹ N₂ flow rate. The temperature was held for 15 min at 105 °C to guarantee dry conditions.

3 RESULTS AND DISCUSSIONS

3.1 Experimental wood torrefaction

The normalized (after drying) weight loss profiles during torrefaction and final values are presented in Fig. 2(a) and (b). The torrefaction treatment severity affected the thermal degradation of the blend residues. As a result, the weight loss values were 4.90 (225 °C), 13.84 (250 °C), and 34.96 wt.% (275 °C). For 225 °C, the weight loss profile is nearly linear at the end of the treatment, but in the case of 250 and 275 °C, the weigh-loss curves continue to go up mainly because of the cellulose degradation, followed by lignin, in addition to the hemicelluloses.
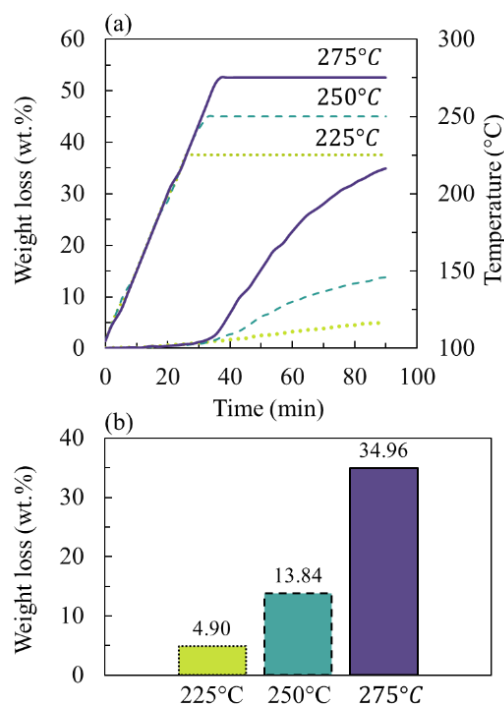

Figure 2: Solid yield dynamic profiles (a) and final solid

product yield (b) for samples torrefaction treatment.

3.2 Torrefaction severity index (TSI)

Previous studies have pointed out that the thermal degradation of wood started at temperatures of 180–200 °C [15]. Because of this, the weight loss was normalized at 175 °C for better readability without any information lost [16]. Chen et al. (2014) showed that the TSI is a feasible parameter to indicate the thermal degradation extent of biomass in torrefaction [17], and, due to the TSI being a normalized index, weight loss affected by biomass nature can be minimized [18]. The torrefaction process' TSI 3D surface and 2D contour mapping are shown in Fig. 3(a) and (b).
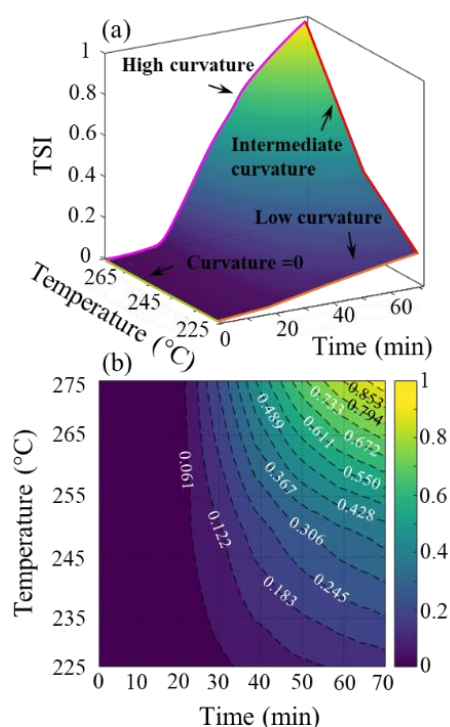
Figure 3: (a) Three-dimensional profiles and (b) two-dimension contour maps of torrefaction severity index for Amazon residues blend.

According to [17,19], by analyzing the TSI 3D surface, it is possible to identify two temperature-dependent and two time-dependent curvatures. The temperature-dependent curvatures are the Zero and the Intermediate, along the torrefaction time of 0 and 60 min, respectively. The time-dependent curvatures are the Low and High, with 225 °C and 275 °C temperatures, respectively.

Physically, the greater the inclination of the curvature profile, the more sensitive the biomass weight loss to the torrefaction operation [17]. The wood residues blend TSI showed a higher temperature dependence. The Low curvature has an almost flat and linear behavior representative of a minor t-dependence when compared to the High curvature. Regarding the High curvature, TSI gradients are more significant for shorter time variation when compared to the Intermediate until 260 °C temperature and 50 min residence time. The TSI values vary between 0–0.24 for (225–235 °C), 0.24–0.39 (235–250 °C), and 0.39–1.00 (250–275 °C), respectively.

3.3 Torrefied blend properties

The torrefaction performance of the torrefied wood residues blend was evaluated by its proximate analysis and is shown in Fig. 4. The volatile matter decreased, and fixed carbon increased with torrefaction severity, as expected [20,21]. Considering the obtained linear correlations, the TSI was a good process performance indicator with $R^2 = 0.99$ for VM and FC and $R^2 = 0.93$ for ash content.

3.4 Torrefied solid product pyrolysis results

The torrefied blends were pyrolyzed, allowing the assessment of the wood residue mixture product. The TG and derivative thermogravimetric (DTG) curves are illustrated in Fig. 5(a) and (b), respectively. Pyrolysis experimental results agree with the wood biomass behavior reported by [22]. The thermal stability enhancement can be analyzed by the high initial degradation temperature and the high char yield extent [23]. Fig. 5 (a) indicates that the thermal stability for 225 °C treatment was short, starting its degradation earlier (330.15 °C), followed by the 250 and 275 °C with 362.6 and 408.6 °C, respectively.
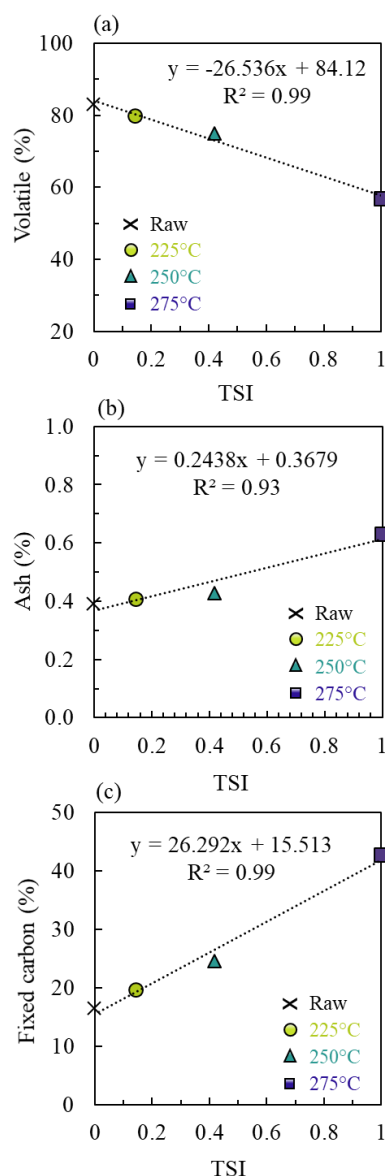
Figure 4: Predicted profiles of (a) volatile matter, (b) ash content, and (c) fixed carbon versus torrefaction severity

index during the thermal upgrading.

The torrefied products pyrolysis final yields (Fig. 5(a)) were 25.8, 30.9, and 46.6 wt.% for 225, 250 and 275 °C, respectively. The greater value of char yield for 275 °C was because of the superior wood component degradation throughout treatment [13,24].
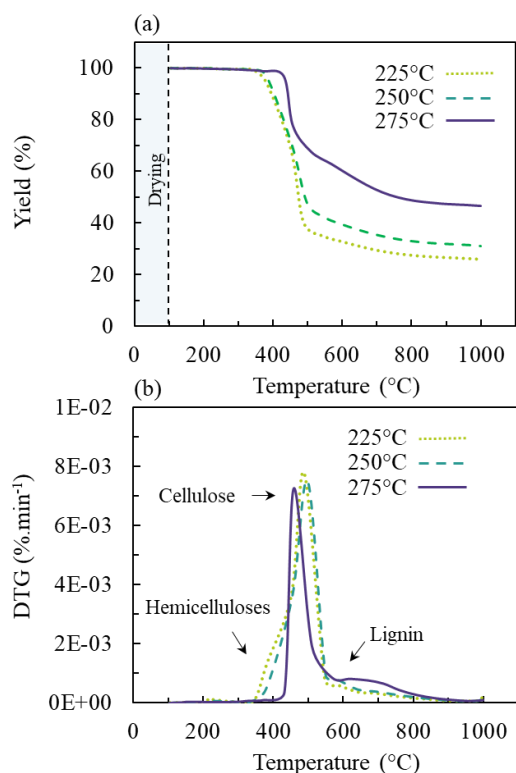
Figure 5: (a) Solid yield and (b) DTG profiles of pyrolysis experiment for the three torrefied product.

In the present study, the maximum DTG peaks (attributed to cellulose decomposition) occurred between 440 and 550 °C (Fig. 4(b)). The shoulders ahead of the maximum peaks allow the detection of hemicellulose consumption for individual biomass treatments [25]. Higher shoulders were obtained for 225 °C torrefied product between pyrolysis temperatures of 320–440 °C. It is observed that the shoulders reduce their intensities as the treatment severity increases, and this component reaches high degradation, agreeing with [25].

The smaller identified shoulders after the maximum peaks regard the lignin degradation [25]. For higher temperatures (>600 °C), the lignin is almost wholly converted [25]. The results in the present work reported higher pyrolysis temperatures to attempt the three different shoulders compared to the literature [26]. This behavior could be explained because the analyzed sample is a blend of different biomasses, which might occur synergetic effects between them.

The higher temperature treatments reported higher hemicellulose decomposition (Fig. 5(b)). Thus, the 250 and 275 °C torrefied products retain a higher cellulose and lignin extent. Furthermore, the breakdown of the hemicelluloses matrix and the formation of unsaturated structures result in greater bulk and energy densities [27]. Therefore treatments between 250–275 °C could be helpful in TAP process applications due to greater extents of lignin compounds retained during wood torrefaction

that can act as natural adhesives during the pelletizing process [27,28].

4 CONCLUSIONS

The thermal upgrading via torrefaction treatment of six Amazonian wood residues blends was successfully assessed.

The torrefaction temperature highly affects the blended samples. The TSI reported an excellent process performance indicator to evaluate torrefaction severity and predict process parameters. The 275 °C torrefied product showed a higher hemicellulose decomposition, greater lignin retained extent, and higher fixed carbon contents, showing that it was an excellent pretreatment.

Further investigations on blends pelletization [29], oxidative torrefaction [30], kinetic modeling [31,32], life cycle assessment [33–35], and 3e (environmental-economic-exergy) analysis of decentralized and integrated systems are recommended and will be the subject of future publications.

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7 LOGO SPACE