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COMPARATIVE STUDY OF TORREFACTION OF BRAZILIAN LIGNOCELLULOSIC BIOMASSES

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Abstract. *Biomass has a low energy density and its direct use in conventional combustion systems faces major challenges. To increase the energy density, recent studies suggest the torrefaction of biomass as a simple, inexpensive and easy to implement process; possessing great potential for its industrial insertion. Torrefied biomass (biochar) is not only cheap and environmentally friendly, but also, it is the only biofuel that could be burned directly in conventional combustion systems. However, there is a lack of technical information on the quality of biochar as an alternative biofuel. This lack of knowledge can lead to the production of biochar not suitable for burning, increasing problems related to the production of slag and scale and reducing combustion efficiency. In Brazil, there are three lignocellulosic biomasses relevant to the energy sector (i.e. sugar cane, sweet sorghum and sorghum biomass) and the evaluation of the value added to the application of biochar as biofuel could provide some advantages and is a viable option for increase the use of biomass efficiently in the Brazilian energy sector; but little is known about this. This work aims to assess the potential of various biomasses as solid fuels. Biochars will be produced from sugarcane bagasse (SBC), sweet sorghum bagasse (SSB) and sorghum biomass bagasse (BSB) by torrefaction processes. This work brings technical information relevant to future studies on the use of biomass in combustion and oxy-combustion processes.*

Keywords: *Torrefaction, energy densification, biomass*

1. INTRODUCTION

As the world population increases, there is a significant increase in energy demand, which leads not only to a decrease in fossil fuel reserves but also to serious pollution problems due to significant greenhouse gas emissions (GHG)[1]. Many efforts are being directed at the development of renewable energies, particularly biomass energy due to their wide availability worldwide [1–5].

Currently, biomass combustion is considered the strategy with low economic risk for the generation of energy, encouraging its use within the energy sector[5,6,1] and also has the potential to assist several governments to provide energy through renewable sources[3,7]. However, untreated (i.e. in nature) biomass is not an ideal energy loader and its direct use in conventional combustion systems faces major challenges, from its inherent properties to the design of new combustion chambers[5].

To improve the energetic content of biomass, recent studies suggest that the torrefaction process could be used, as it has a great potential for industrial use and increases the yield of biochar production[2,3,5-12]. Studies by Chen et al. [8], Da Silva et al. [6], Conag et al. [9,10], Cha et al. [11] and Puente et al. [12] suggest that the biochar produced by torrefaction is not only cheap and environmentally friendly but also, it is the only biofuel that could be burned directly in conventional combustion systems. Already studies by Conag et al. (2018) suggest that biochar could conserve or improve the combustion efficiency of coal in the generation of heat and energy when compared to in nature biomass.

Although the elemental composition of the biochar is carbon (C), hydrogen (H), oxygen (O), ash, traces of nitrogen (N) and sulfur (S), it varies according to the type of biomass from which biochar was produced, as well as the torrefaction conditions. According to Liu and Han [5], although there is much work on the production of biochar, most studies are directed to use in soil remediation or GHG reduction. Consequently, limited studies are available on the use of biochar in the energy sector and they have simple thermal characterizations for kinetic studies, however, there is a lack of technical information on the quality of the biochars produced to be used as alternative biofuels in conventional combustion systems. This lack of knowledge can lead to the production of biochar not suitable for burning and leading to problems related to the production of slag and scale in the combustion chambers. Recent studies by Conag et al. [10] indicate that there are currently no specific standards to evaluate the quality of biochar as an alternative biofuel; however, standards related to solid fossil fuels could be adopted.

In Brazil, the demand for biomasses exclusive to the energy sector (i.e. sweet and biomass sorghums) favored research on the production of first and second generation biofuels, as well as, in cogeneration, however, it was observed a significant quantities of residues generated by sweet sorghum and biomass sorghum are as large as that produced by sugarcane, presenting the same problems in their final disposal. Recently, Da Silva et al. [6] pointed out that Brazil could become the main producer of torrefied biomass in the world due to its climatic conditions. In this situation, the study of value added to the application of biochar as biofuel in the energy sector can provide some advantages and is a viable option to increase the use of biomass efficiently in the Brazilian energy sector[6].

This work aims to evaluate the potential of several biochars as alternative biofuel for this will be used several combustion indexes. The biochars will be produced from sugarcane bagasse (SCB), sweet sorghum bagasse (SSB) and biomass sorghum bagasse (BSB) through torrefaction process. This will bring technical information relevant to future studies on the use of biomass in combustion and oxy-combustion processes.

2. MATERIALS AND METHODS

2.1 Materials

In this study the most important biomass bagasse for the Brazilian energy sector will be used, being sugarcane bagasse (SCB), sweet sorghum bagasse (SSB) and biomass sorghum bagasse (BSB) (Fig.1). Samples of each biomass was prepared to torrefaction tests (i.e. grinding, milling and sifting). The average particle size obtained to biomass characterization and torrefaction test was 463 μm.

(a) (b) (c)

Figure 1 – Brazilian lignocellulosic biomass: (a) sugarcane bagasse, (b)sweet sorghum bagasse and (c) Biomass sorghum bagasse

2.2 Methodology

In each torrefaction test, the prepared biomass will be weighed and placed in the alumina crucible, which will be inserted into the tubular Oven (Fig. 2), so an N_2 purge gas at a flow rate of 100 mL/min will be injected into the furnace, and only after 10 min of N_2 injection, this should guarantee a completely inert medium. The oven will be heated from room temperature to process temperatures at a heating rate of 10 °C/min, the torrefaction process temperatures will be evaluated, being: 300°C. For each evaluated process temperature, two residence times (or isotherms) will be used, being: 20min and 30min. These tests should be done using the three biomasses, i.e. SCB, SSB, and BSB. All the biochars produced were characterized to determine the energy potential and quality of biochar as alternative solid biofuel.

Figure 2 – Tubular Oven RTV of FORTLAB 1200/IZ used to torrefaction test

2.2.1 Characterization of biochar produced

The biochar produced will be characterized by proximate analysis and calorimeter analisys. The proximate analysis was used to obtain the content (%) of: moisture (M), volatile material (VM), carbon fixed (CF) and ash (A) of each biochar. The calorimeter analysis was used to obtain the high heating value (HHV). Using these variables we can to determine VM, CF, A and HHV in dry base (Eq. 1 – 4).

$$\%FC_{bs} = FC \times \left(\frac{1}{100 - M} \right) \times 100, \quad [1]$$

$$\%VM_{bs} = VM \times \left(\frac{1}{100 - M} \right) \times 100, \quad [2]$$

$$\%A_{bs} = A \times \left(\frac{1}{100 - M} \right) \times 100, \quad [3]$$

$$\%HHV_{bs} = HHV \times \left(\frac{1}{100 - M} \right) \times 100, \quad [4]$$

2.3 Analysis of products

The results of the proximate and calorimeter analysis provide data of fixed carbon (% FCbs), volatile material (% VMbs), ash content (% Abs) and calorific power surpluses (% HHVbs). Then the energy potential of the biochars will be calculated using equations [5] through [7].

$$FR = \frac{FC_{bs}}{VM_{bs}}, \quad [5]$$

$$CI(MJ/kg) = \frac{HHV_{bs}}{FR} \times (115 - \%A_{bs}) \times \frac{1}{105}, \quad [6]$$

$$VI(MJ/kg) = \left[\frac{HHV_{bs} - 0.338FC_{bs}}{VM_{bs} - M} \right] \times 100, \quad [7]$$

According to Conag et al., (2018) the FR (fixed carbon ratio for volatile material), CI (combustibility index) and VI (volatility of flammability) are indices that allow to evaluate the quality of the biochar, 0.5 and 3, IC values should be < 23 MJ/kg and VI should be > 14.5 MJ/kg, it should be noted that these indices are used in the evaluation of solid fossil fuels in thermoelectric plants.

3. RESULTS

3.1 Characterization of lignocellulosic biomass

On the Tab. 1 we can see that SCB and BSB have similar HHV_{db}. For the other side, of the proximate analysis we can see that SCB had the lower value of CF_{db} when compared with SSB and BSB, but the SCB have a VM content of approximately of 3% bigger than VM content of SSB and BSB.

When we calculate to relation between volatile material and carbon fixed (VM/CF), we can see that SCB and BSB have the higher values. When was seen the ash content, it was observed that BSB has the bigger content when compare with the other biomasses used.

Table 1 – Results of the proximate and calorimeter analysis from Braziliam lignocellulosic biomass

Bagaço	SCB		SSB		BSB
HHV_{db} (MJ/kg)	18.80		16.57		18.06
Proximate analysis (wt%, dry basis, db)					
Volatile matter (VM)	79.77		73.42		72.43
Fixed Carbon (CF)	11.95		19.27		16.25
Ash (A)	2.15		3.63		6.15
VM/FC	6.68		3.81		4.64

3.2 Torrefaction test

Tab. 2 shows the results of the mass loss (%W) and the biochar production yield (Y_P) after the torrefaction process for 20 min and 30 min respectively. As can be seen, SCB and BSB achieved maximum volatility elimination in 20 min of isotherm, so when the isotherm increased, mass loss (%W) for volatiles elimination was very similar for SCB and BSB. The results also suggest that the SCB had a more efficient devolatilization process than the pomace of both sorghums used in the research (i.e., SSB and BSB), consequently SCB had a greater mass loss of approximately 75%. The results of mass loss (%W) suggest that SSB and BSB were 22% and 12% less efficient in the devolatilization process when compared to SCB.

On the other hand, the yield results of biochar (Y_P) production suggest that a higher yield will be achieved when both sorghums are used. Because the rapid elimination of VM from structure SCB, the yield of biochar (Y_p) was reduced, thus, the Y_p for SCB was approximately 39.4% and 26.6% lower than Y_p of SSB and BSB respectively.

Table 2 – Yield of biochar for each biomass

Bagasse	SCB			SSB			BSB	
Isotherm (min)	**20**	**30**		**20**	**30**		**20**	**30**
ΔW (%)	75.29	75.32		53.22	63.94		66.87	66.27
Y_P (%)	24.71	24.68		46.78	36.06		33.13	34.15

Although these results are interesting, the biochars should be evaluated to determine their energy quality to be used in combustion processes in thermoelectric plants.

3.3 Combustion index

In order to determine the energy potential of the biochars produced to be used as alternative solid fuels, the combustion indexes FR, CI and VI were determined. The results are shown in Tab. 3.

Table 3 – Energy potential of *biochars* produced.

	SCB			SSB			BSB	
	B(20)	**B(30)**		**B(20)**	**B(30)**		**B(20)**	**B(30)**
FR (Kg/Kg)	1.78	1.72		1.76	1.71		2.06	2.13
IC (MJ/kg)	15.44	16.19		13.55	17.06		11.80	12.37
VI (MJ/kg)	12.50	11.26		16.96	13.66		14.22	18.91
$HHV_{Biomass}$	17.09	17.09		15.95	15.95		17.05	17.05
$HHV_{Biochar}$	25.79	25.54		24.81	26.90		24.66	26.52
R_{DE}	1.51	1.49		1.56	1.69		1.45	1.56

A low value of FR suggests that the solid would ignite rapidly due to the high volatile content (VM). However, a high content of the volatile material in the biomass can result in incomplete combustion due to the speed and difficulty in controlling the combustion. According to Conag et al. [9], the FR ratio for solid fuels should be between 0.5 - 3.0, however values above 2.0 may have ignition problems and flame stability. It is observed in Tab. 3 that the FR index was higher for the BSB biochar with an average value of 2.09 ± 0.04. In this work, the biochar with the most acceptable FR values (i.e. FR < 2.0) for use in the conventional combustion chambers were obtained from SCB and SSB. It should be pointed out, that this FR index does not invalidate the use of BSB in the pyrolysis process, it only indicates that this biomass was much more reactive in the torrefaction process, we can also indicate that when using the BSB, a ratio of FR, less than 2.0 could be obtained using lower temperatures and/or shorter residence times.

Sometimes solid fuels with a high FR ratio may not be adequate because this ratio can be greatly affected by the ash content, therefore an assessment of the solid fuel considering the ash content should be used in the selection of the solid fuel to in coal-fired power plants, the combustibility index (CI) is used. The combustibility index (CI) is used to characterize the combustion behavior of material, CI assesses the suitability of a solid fuel considering the ash content of the fuel. According to Ohm et al [13] an IC value lower than 12 MJ/kg and higher than 23 MJ/kg is inappropriate for combustion. After the torrefaction process, the IC values of all produced biochars were acceptable.

The volatile flammability index (VI) is used to measure the available energy of the volatile material, but the VI considers that some of the components of the volatile material may be inert and therefore, instead of promoting the ignition, may delay it [14]. According to Magasiner [14] when the volatile content of the solid fuel is < 20%, the ignition is unstable; therefore, it suggests that the VI index should be higher than 14MJ/kg, otherwise it will be necessary to consider some methods to improve the ignition. Recently Conag et al. [10] recommend that the volatile material has at least a heat capacity of 14 MJ/kg. In this study it was observed that of all the biochars produced using 20 min of isotherm, the only ones that present an acceptable VI value were both sorghum (i.e. SSB and BSB), it was emphasized that when the biochar derived from the SCB was used for combustion, precautions should be taken to improve the ignition.

It has also to be discussed that the energy density increased after the torrefaction process for this was used the ratio of the energy density between the biomass and the produced biochar (R_{DE}). All the biomass used in the study, i.e. SCB, SSB, and BSB, presented an HHV of 17.09 MJ/kg, 15.95 MJ/kg and 17.05 MJ/kg respectively, after the pyrolysis process the energy density increased between 45% and 69% for all produced biochar; and the largest increase was for the SSB with 69%.

4. CONCLUSION

The study of biochar production by torrefaction indicates that temperatures and isotherm time lowest than 300°C and 20 min could be applied when used SCB in order to increase o VI index. When BSB used to biochar production by torrefaction temperatures lower than 300°C also can be used. This study indicates more assessments must be realized using several temperatures lower than 300°C, even as, isotherm times lower than 20 min, in order to evaluate the best condition of torrefaction for biochar production using each lignocellulosic biomass, since the Brazilian lignocellulosic used have different characteristic and different roasting behaviors.

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6. RESPONSIBILITY NOTICE

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