

ENCIT-2018-0572 ENERGY ASSESSMENT OF TORREFACTION OF SUGARCANE BAGASSE

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Abstract. *In Brazil, sugarcane is an important biomass used to ethanol production. Sugarcane is an important resource for power generation, with a representation of 17.5% in the energy matrix. Despite of different studies about torrefaction of sugarcane bagasse there are few studies about the energy assessment of torrefaction process of sugarcane bagasse. In this work the torrefaction of sugarcane bagasse was studied. The effect of temperature and time on properties of torrefied biomass was studied. The preliminary results show an increase of High Heating Value (HHV) of torrefied sugarcane bagasse.*

Keywords: *Torrefaction, sugarcane bagasse, energy.*

1. INTRODUCTION

Currently, 80-85% of the world's energy demand is supplied mainly by fossil fuels such as coal, oil and natural gas. The constant use of fossil fuels generates large amounts of greenhouse gases (GHG) to the atmosphere (Abbasi and Yozgatligil 2014). Of the total GHG emitted, 3/4 corresponds to carbon dioxide (CO₂) which is the main anthropogenic emission responsible for global warming (Huaman and Jun 2014). According to the Intergovernmental Panel on Climate Change (IPCC, 2013), there is a direct correlation between rising GHGs and global warming.

To meet the high energy demand aiming at the reduction of GHG emissions, mainly CO₂, several alternatives were proposed, among them the use of biomass. Biomass is the fourth largest source of energy in the world and has been found to be a potential source of renewable energy, since it can simultaneously solve the problems of energy demand and chemical production (Tinwala et al. al., 2015, Kim et al., 2017).

The raw biomass presents undesirable indexes in the main properties of energy purpose, such as high values of moisture, hygroscopicity and heterogeneity, as well as low values of bulk density, carbon/oxygen ration and calorific value (Da Silva, et al. 2018). Among all thermochemical processes, torrefaction is a process that can improve the characteristics of biomass for energy purpose. Torrefaction is a mild pyrolysis process which thermochemically alters biomass structure by eliminating moisture and light volatiles. It also improves biomass structure through polymer alterations. It is a temperature sensitive process which is effective between 200°C and 300°C in an inert environment. It is carried out at near atmospheric pressure in the absence of oxygen and characterized by low particle heating rates (< 50°C/min). (Chen et al. 2015). The biomass partly decomposes during the process giving off various types of volatiles, which results in a loss of mass and chemical energy to the gas phase.

In Brazil, sugarcane is an important resource for power generation, with a representation of 17.5% in the energy matrix. The participation of sugarcane may increase due to the increase in sugarcane productivity or the increase in the efficiency of the combustion process. The efficiency of the combustion process can be increased by the integration of the biomass roasting process. Despite of different studies about torrefaction of sugarcane bagasse (Conag et al. 2017) there are few studies about the energy assessment of torrefaction process of sugarcane bagasse.

2. MATERIALS AND METHODS

2.1 Material: Sugarcane bagasse

Fig. 1 shows a sample of sugarcane bagasse used in the experimental test. The average granulometry used for torrefaction test was between $425\mu\text{m}$ - $500\mu\text{m}$ (ASTM 40 and ASTM 35). Before starting the torrefaction tests, sugarcane samples were dried for 24h at 105°C .



Figure 1. Sugarcane

2.2 Experimental setup

Fig. 2 exhibit the experimental setup used for test. A balloon of 500ml is used as reactor. A heating mantle is used to provide the heat necessary for torrefaction process. For experimental test were considered temperatures of 200°C e 300°C . The times of residence into reactor were of 0 and 45 minutes. A flow rate of 100ml of nitrogen gas (N_2) is used to carrier the material volatile to out of reactor. When torrefaction test is finalized, the reactor is removed from heating mantle.

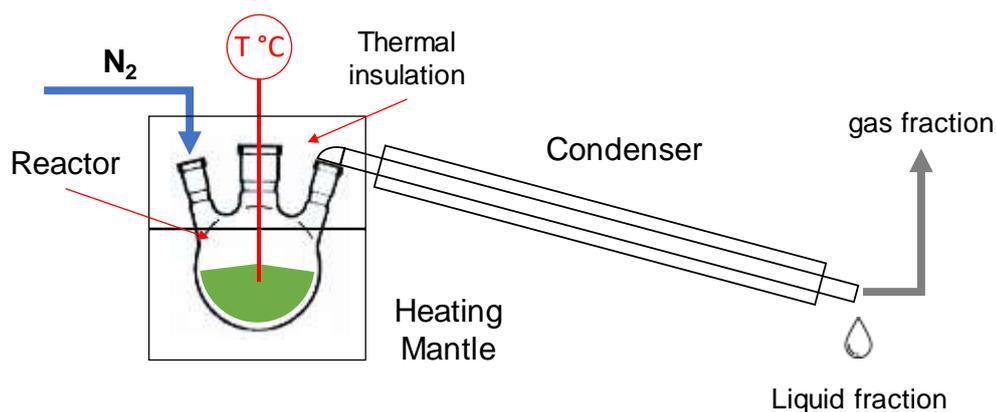


Figure 2. Experimental setup for torrefaction.

2.3 Characterization techniques

In this section is showed the techniques used for characterization of products, mainly the torrefied sugarcane bagasse was characterized by TGA analysis, proximate analysis and calorimetry analysis. TGA analysis was performed by TA Instruments (SDT Q600) in duplicate using a mass of $5\pm 0.5\text{mg}$, heating rate of $10^\circ\text{C}/\text{min}$ and an inert atmosphere of nitrogen (N_2). This analysis was realized for determine the initial temperature of thermal decomposition of the sugarcane bagasse.

The proximate analysis was realized to obtain moisture (M), volatile matter (VM), fixed carbon (FC) and Ash (A) content in the samples. To realize the proximate analysis was used a sample mass of 5 ± 0.5 mg in a thermogravimetric balance of the TA Instruments (SDT Q600). For this, heating was performed up to 110 °C at a rate of 10 °C/min, this temperature was kept constant for 30 min, and the mass loss referring to that region is the moisture of the material. Once the moisture is determined, heating is performed at a rate of 40 °C/min from 110 °C until 950 °C. This temperature is maintained for 7 min, and then, the sample was cooled at a cooling rate of 20 °C/min from 950 °C until 750 °C, the mass loss for this region refers to the volatile material into sample. The determination of fixed carbon and ash is carried out in an oxidizing atmosphere (or combustion atmosphere), therefore, once the sample reached 750 °C, the purge gas was exchanged for synthetic air and maintained at 750 °C for 30 min.

HHV was determined using a Calorimeter IKA C500. All tests are performed in duplicate using a mass of (0.5 ± 0.05) g. FTIR analysis was performed in a Perkin Elmer Spectrum 100 FTIR / ATR analyzer to measure the emission of absorption and diffusion of an infrared spectrum into sample.

3. RESULTS AND DISCUSSION

3.1 Sugarcane bagasse characterization

The Tab. 1 shows physical and chemical characteristics of the sugarcane bagasse. The sugarcane bagasse has an HHV_{db} of 18.80 MJ/kg, the content of volatile matter and carbon fixed is approximately 85.10% and 12.75%, respectively. The sugarcane bagasse is compounded of 22.2%, 33.3% and 40.7% of lignin, cellulose and hemicellulose, respectively. This sugarcane bagasse has low lignin content when compares with other compounds, consequently, the ash content is low too.

Table 1 – Physical and Chemical composition of sugarcane bagasse.

Analysis	<i>Sugarcane bagasse</i>
Calorimetry	
HHV _{db} (MJ/kg)	18.80
Proximate	
Volatile matter	85.10
Fixed Carbon	12.75
Ash	2.15
VM/FC	6.68
Chemical composition	
Extractive	13.83
Klasson lignine	22.22
Celullose	33.29
Hemicelullose	40.69

Fig. 3 shows the thermal decomposition behavior of sugarcane bagasse in inert atmospheres through TG/DTG curves. On TG curve can be seen three mass losses (Fig. 2). The three mass losses are overlapping with three peaks of DTG curves (Fig.2) related to thermal decomposition temperatures of the main components of sugarcane. The first mass loss event refers to the loss of moisture (approximately 53 °C). The second and third events refer to the decomposition of hemicellulose, cellulose, and lignin, and depending on the temperature each of these elements dominates the rate of decomposition. In the second event (293 °C) the hemicellulose decomposition is initially dominant, but the lignin also decomposes at this temperature. The third mass loss (354 °C) is mainly related to cellulose decomposition, and at the end of the event lignin begins to dominate the rate of mass loss and continues to decompose above 400 °C. With these results, can see that sugarcane bagasse will have an initial and final thermal decomposition temperatures in approximately 200 °C and 500 °C respectively.

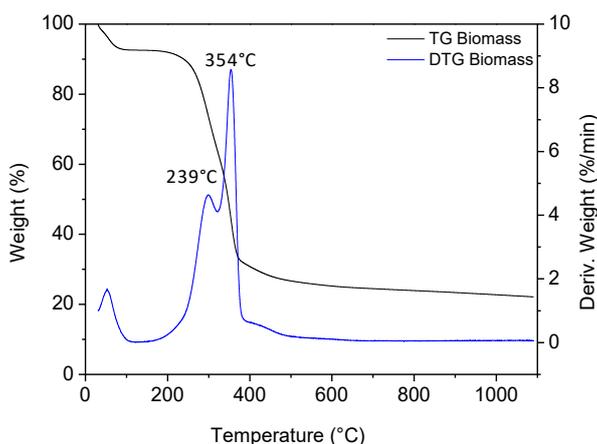


Figure 3. TG/DTG curves of sugarcane bagasse.

3.2 Experimental test

After of the experimental tests of torrefaction process using sugarcane bagasse was observed that when used a temperature of 200°C there are few qualitative changes on torrefied biomass produces when compares with sugarcane bagasse (Fig. 4a and 4b), and this is independent of residence time. Major quality changes are appreciated when used a temperature of 300°C (Fig. 4c and 4d). This behavior was expected to be realized on the torrefaction; due to thermal decomposition of sugarcane bagasse is started in 200°C, as shows the DTG curve from Figure 3. This means that hemicellulose, cellulose and lignin not yet decomposed. For the other hand, when observed the Fig. 3, can be seen the DTG curves in 300°C indicates that hemicellulose was decomposed totally, thus in the torrefied sugarcane bagasse produced was observed major changes in the structure when compares with sugarcane bagasse for both residence time used.

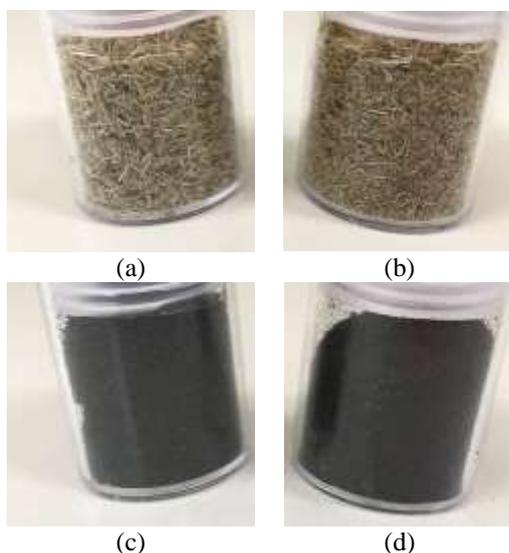


Figure 4. Torrefied sugarcane bagasse (a) 200°C and 0 min, (b) 200°C and 45 min, (c) 300°C and 0 min, and (d) 300°C and 45 min.

Tab. 2 shows the mass loss after experimental tests and the productivity of torrefied biomass production. Minimum mass losses (approximately $7.9 \pm 0.1\%$) are observed in torrefaction processes using 200°C, consequently, the yield of torrefied biomass was high with approximately 92%. These patterns changed when used temperature of torrefaction of 300°C. As seen in the Tab.2 the mass loss increases until 33.5%, this mass loss refers mainly to thermal decomposition of hemicellulose, consequently, the yield of torrefied biomass was reduce until 66.2%.

Table 2 – Mass loss (%W) and solid yield (Yp) after torrefaction test.

T°C	200		300	
time(min)	0	45	0	45
%W (%)	8.0	7.8	33.3	34.3
Yp (%)	92.0	92.2	66.7	65.7

3.3 Characterization of torrefied sugarcane bagasse

Once obtained the torrefied sugarcane bagasse, they were conducted to characterization by proximate and calorimetry analysis, the Tab.3 shows the results for that analysis. In Tab. 3 can be seen the moisture is low for all torrefied biomass produced, i.e. around 1.36%. When used 200°C for torrefaction process, the content of volatile matter reduced 4.80% and fixed carbon increase only 0.80% into of the torrefied biomasses of both residence time 0 min and 45 min. For other side when used 300°C for torrefaction process, the behavior was different, because the content of volatile matter reduced only 1.4% and fixed carbon increased 3.31% for both residence times used, respectively.

When observed the results of calorimetry analysis, i.e. HHV, can be seen that only torrefied biomass that increased 20% the HHV when compare with sugarcane bagasse was that produced with 300°C and 45 min of torrefaction temperature and residence times, respectively. This can be attributed of fixed carbon increased faster and volatile material decreased slowly when increase the residence times from 0 min until 45 min.

Table 3 – Results of proximate analysis and calorimetry analysis of torrefied biomass

tr (min)	T(°C)	Moisture	Volatile Matter	Fixed Carbon	Ash	HHV
0	200	1,22	84,37	13,40	1,01	17,45
	300	1,39	66,67	30,11	1,83	17,71
45	200	1,37	79,57	14,20	4,86	17,05
	300	1,25	65,29	33,42	0,04	20,40

4. CONCLUSION

Torrefaction of sugarcane bagasse increase the energy content and density. Although the torrefied biomass with 200°C had major productivity, the HHV is low, very similar to sugarcane bagasse. The results show that an increase in the HHV is only attained, when torrefaction temperature and residence time are 300°C and 45 min respectively. Besides that, the grindability of torrefied biomass is better than in natura biomass. However, more analysis is necessary, in order to evaluate others residence times and torrefaction temperatures.

5. ACKNOWLEDGEMENTS

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