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DRY TORREFACTION OF SUGARCANE BAGASSE USING CARBON DIOXIDE AS GAS CARRIER

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Abstract. *Emissions of greenhouse gases (GHGs), especially carbon dioxide (CO_2), have increased considerably over the past decades due to the continued use of energy derived from fossil fuels. This has led to problems and environmental impacts that motivate the use of clean and renewable energy sources and unconventional combustion processes. Biomass is a renewable source and has great potential for CO_2 neutral energy generation. Among all the alternatives for the use of biomass, thermochemical conversion processes are the most efficient. However, biomass has many disadvantages such as lower heating value, high moisture content, among others. These disadvantages can reduce the efficiency of these processes. Torrefaction is the process of heat treatment of biomass in an inert medium, which can improve these disadvantages. There are several studies in the literature on the torrefaction of biomass, demonstrating the significant improvement in the properties of biomass. There are several studies on the torrefaction of sugarcane bagasse that demonstrate a significant improvement in its properties, however, there are few studies on the use of other gases carriers such as carbon dioxide. Sugarcane bagasse is a resource available in Brazil, productivity tends to increase to satisfy the demand for ethanol. Thus, more bagasse is available. Sugarcane bagasse is currently used as a fuel to produce thermal and electrical energy, however up to 18% of the bagasse is lost through bacterial decomposition. The insertion of the torrefaction in the cogeneration plants could improve and preserve the properties of the biomass until the moment of its burning. In this work, the torrefaction of the sugarcane bagasse will be carried out between 200 and 300 °C, considering a time of 30 minutes and using carbon dioxide as the carrier gas. The results indicate that when using CO_2, the torrefaction temperature should be limited to 220°C, temperatures above present a significant reduction in the mass yield of torrefied biomass. In this condition, torrefied sugarcane bagasse can increase the value of HHV by 30%.*

Keywords: *Torrefaction, sugarcane bagasse, carbon dioxide.*

1. INTRODUCTION

Biomass is the fourth source of energy in the world and has been found to be a potential source of renewable energy, as it can simultaneously solve energy demand problems and reduce greenhouse gas (GHG) emissions (Saidur et al., 2011; Tinwala et al., 2015; Kim et al. 2017). The use of biomass can be carried out through biochemical and thermochemical conversion processes. However, thermochemical conversion (combustion, gasification, and pyrolysis) has received greater attention due to its speed and greater efficiency when compared to biochemical conversion (Tripathi et al., 2016). The thermochemical conversion of biomass presents some challenges due to some deficiencies inherent to biomass such as a high moisture content, low specific mass, heterogeneity, lower heating value and low carbon/oxygen ratio (Da Silva, et al. 2018). These deficiencies can be overcome through pre-treatment methods such as torrefaction. This process consists of heating biomass at a relatively low temperature (200–300°C) in an inert or partially oxidizing atmosphere and at a low heating rate (<50°C/min). Torrefaction is a pre-treatment process that can improve the characteristics of biomass for energy purposes (Chen et al. 2015; Bonassa et al. 2018), mainly because it increases the heating value. In Brazil, sugarcane is an important source of energy, with a representation of 17.4% (base year 2017) of renewable energy sources in the Brazilian energy matrix (EPE 2018). However, sugarcane bagasse exhibits some particularities such as a high moisture content (>50%), hygroscopic nature, low specific mass and relatively lower heating value (Conag et al. 2017). In addition, the current sugarcane bagasse management system promotes losses of up to 15% in mass due to deterioration caused by microbial action (Lima 2018).

Thus, the implementation of the sugarcane bagasse torrefaction process in the Brazilian sugar and ethanol sector's electricity generation systems could increase the efficiency of these systems, as well as the participation of sugarcane in the energy matrix. Despite the significant amount of work on biomass torrefaction processes, the literature presents some studies on sugarcane bagasse torrrefaction (Patel et al. 2011; Joshi et al. 2015; Conag et al. 2017). Furthermore, studies on the reactivity of torrefied sugarcane bagasse are scarce (Granados et al. 2017). Reactivity can be studied in terms of determining fuel properties and thus gaining knowledge of the material's performance in a burning condition.

The literature presents several works on the oxidative torrefaction of biomass. Li et al. (2015) They studied the influence of torrefaction with dioxide of carbon in the structure of bamboo. The research had as a result that an increase of temperature has an inverse relation with H/O and O/C ratios, also the hydrophobicity was enhanced with the increase of temperature. Saadon et al. (2014) They studied the effects of oxygen and carbon dioxide concentrations in the products yield of palm kernel shell torrefaction. As a result, they found that the solid yield decreases in 2 and 3 %, also in oxygen and nitrogen presence the liquid and gas fraction had a relation of 1:1 with oxygen and 1:2 with nitrogen. With the obtained results they comment that the difference between solid yield in inert and non-inert torrefaction is not much. Li et al. (2016) They studied the temperature torrefaction effects in the char structure and properties obtained from the pine and poplar torrefaction. The obtained results were that a mild temperature the reaction more meaningful was the decarboxylation, then the lignocellulose, cellulose and hemicellulose degraded from the solid, and to higher temperature the crystallinity index decrease because the degradation of crystalline cellulose increase, then the carbon dioxide is an alternative to use in the torrefaction, because enhanced hydrophobicity and reduce the moisture from the material. Li et al. (2018) They studied the effect of reaction conditions on the charcoal obtained from corncob after torrefaction under nitrogen and carbon dioxide. In this research the temperature showed more effect than the atmosphere in the charcoal properties. Besides, the results exposed a relation between an increase in the hydrophobicity and a decrease of the time of combustion. The temperature recommended for torrefaction was 260 °C. Uemura et al. (2015) They studied the effect of oxygen and carbon dioxide concentrations, temperature, and biomass size on the solid phase conversion, energy yield, and properties of torrefied palm kernel shell. The research showed that the heating value was enhanced, and the energy yield was decreased by both oxygen and carbon dioxide. Moreover, torrefaction in the presence of oxygen and CO_2 can be carried out at 220 and 300 °C. Despite the work on biomass torrefaction, there is little work on the torrefaction of sugarcane bagasse using carbon dioxide.

2. MATERIALS AND METHODS

2.1 Sugarcane bagasse

Figure 1 shows the sugarcane bagasse (SCB) used in this work. The sugarcane bagasse was dried, ground and sieved to obtain particles between 250 to 500 µm.

Figure 1. Sugarcane bagasse (250 - 500µm)

2.2 Experimental setup

Figure 2 shows the torrefaction experimental setup. To carry out the experiments, a round-bottomed flask in borosilicate with a capacity of 1000mL will be used as a reactor. The heating system consists of a muffle oven with temperature controller, which operates up to a maximum temperature of 1200°C. The liquid fraction will be obtained by the condensation system, formed by a set of Liebig condensers and a chiller, which keep the water cooled at 5°C, the water circulates through the condensers with the help of a pump. The gas fraction will be submitted to a burning test to verify the presence of any combustible substance.

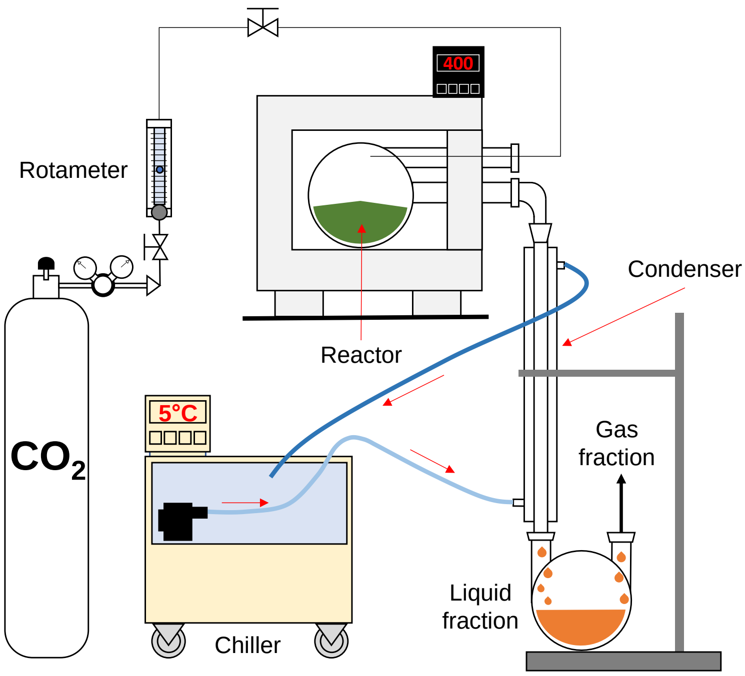

Figure 2. Experimental setup for torrefaction.

2.3 Torrefaction yield

Yields products were determined using equation 1. Gas fraction will be determined by difference.

$$m_{SCB} = m_{SCB\ torrified} + m_{liquid\ fraction} + m_{gas\ fraction} \tag{1}$$

3. Results And Discussion

Figure 3 shows the thermal behavior of SCB in an inert atmosphere. The decomposition temperature of each of the biomass components (Hemicellulose, Cellulose and Lignin) is observed. The TG curve shows a mass loss of 80.25%, which corresponds to the amount of volatile material that can be released from the SCB as a function of the increase in temperature during the thermal decomposition process in an inert medium. The value obtained is very similar to the volatile material content value determined by the proximate analysis of SCB.

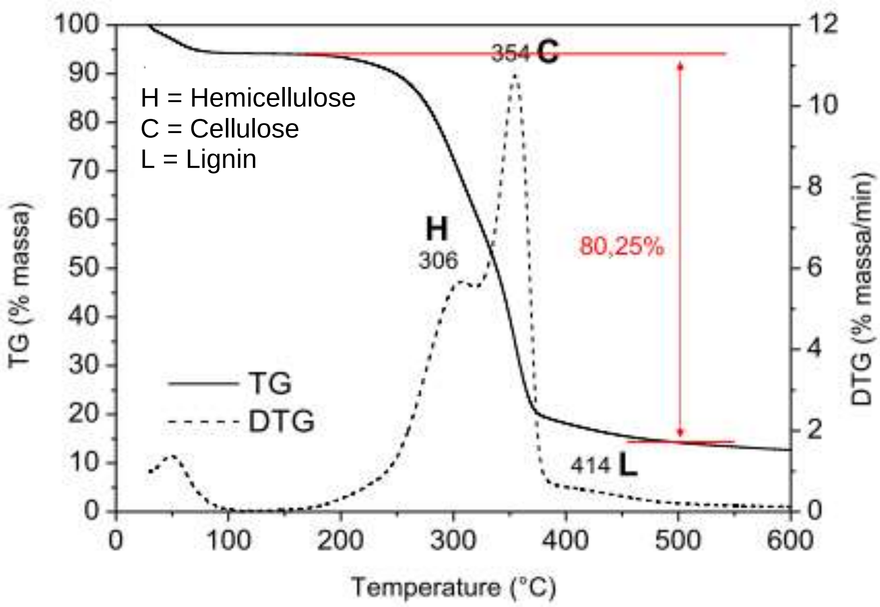

Figure 3. TG/DTG curves of SCB under carbon dioxide atmosphere.

Figure 4 shows the products obtained from dry torrefaction. Figure 4a shows SCB torrefied at 200°C, which is brown in color and has a characteristic odor. In all experimental tests, the liquid fraction (Figure 4b) obtained during dry torrefaction showed a dark color and a strong smell of volatile material. Finally, the gaseous fraction (Figure 4c) underwent a burning test to verify the presence of combustible substances (CH4; H2, light hydrocarbons, among others). Burning tests showed that the gaseous fraction has combustible characteristics. From the results, it can be said that, considering both the liquid and gas fractions as an energy source in the dry torrefaction process, these could make the process thermally self-sustainable, reducing process costs.

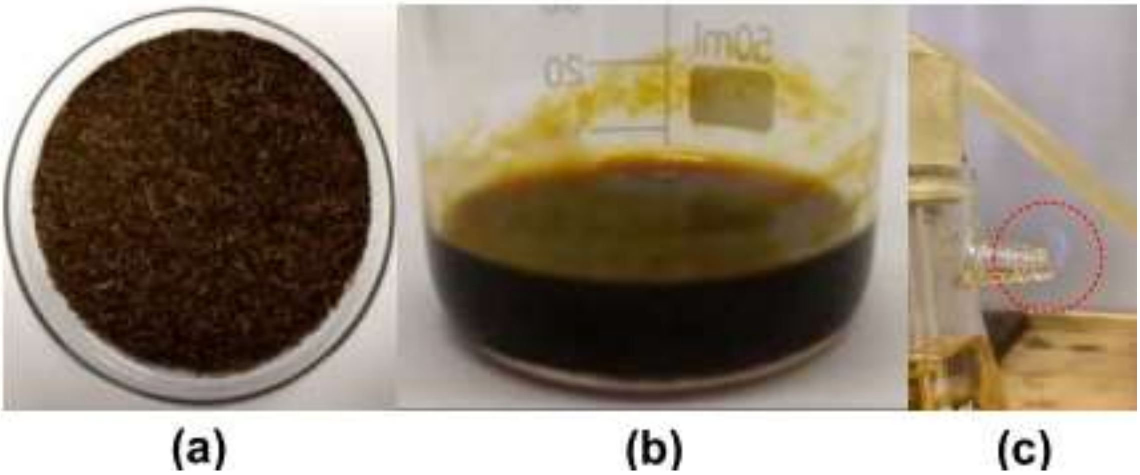

Figure 4. Products from torrefaction of SCB.

Table 1 shows the yield of products as a function of the temperature of the dry torrefaction. It can be seen in Table 1 that with the increase in the temperature, there was a progressive decrease in the solid fraction. On the other hand, there was a progressive increase in the liquid fraction in relation to the increase in the temperature. In addition, there is an increase in the gas fraction with the increase in the severity of the torrefaction. The increase in gas fraction is related to the decomposition of hemicellulose, which is completely decomposes at around 300°C. The reduction in the mass fraction of torrefied biomass and the increase in the liquid and gas fractions occur due to the increase in the temperature of the process, which causes the thermal decomposition of the structural components (hemicellulose, cellulose, and lignin) present in the SCB. The increase in temperature causes a greater thermal decomposition of the structural components, that is, a greater release of volatile material. Thus, water and other organic components are released into the liquid and gaseous fraction, reducing the O/C and H/C ratio present in the structure of the solid fraction and, consequently, improving the energy characteristics of the torrefied SCB. Comparing with the results of Manatura (2020) which torrefied sugarcane bagasse using nitrogen, the torrefied biomass yield was higher than shown in this work. This means the CO_2 has a higher effect on the decomposition of biomass components. This is interesting because it demonstrates the ability to be able to use CO_2-rich exhaust gases as a gas carrier in biomass torrefaction.

Table 1. Yield of products from torrefaction of SCB using CO_2.

Temperature (°C)	% Solid	% Liquid	% Gas
200	79,00	16,00	5,00
220	70,01	25,05	4,94
240	61,10	33,00	5,90
260	40,05	43,98	15,97
280	38,02	48,95	13,03
300	33,80	52, 03	14,17

Figure 5 illustrates the SCB samples obtained for each torrefaction temperature. A visible difference in sample color is observed when analyzing the extreme torrefaction temperatures of 200 °C and 300 °C. In addition, analyzing the intermediate temperatures, a progressive difference in the color of the SCB can also be observed, as the torrefaction severity increases, which varies from a brownish color for milder temperatures to a black tone for higher temperatures, similarly to the charcoal. The color change qualitatively indicates a change in the chemical composition of SCB. Furthermore, during the tests it was possible to identify a stronger smell for biomass that underwent a milder torrefaction process. This can be explained by the higher concentration of volatile material that was contained in the sample, while for the more severe torrefaction, the samples contained a weaker smell since there was a greater release of volatiles.

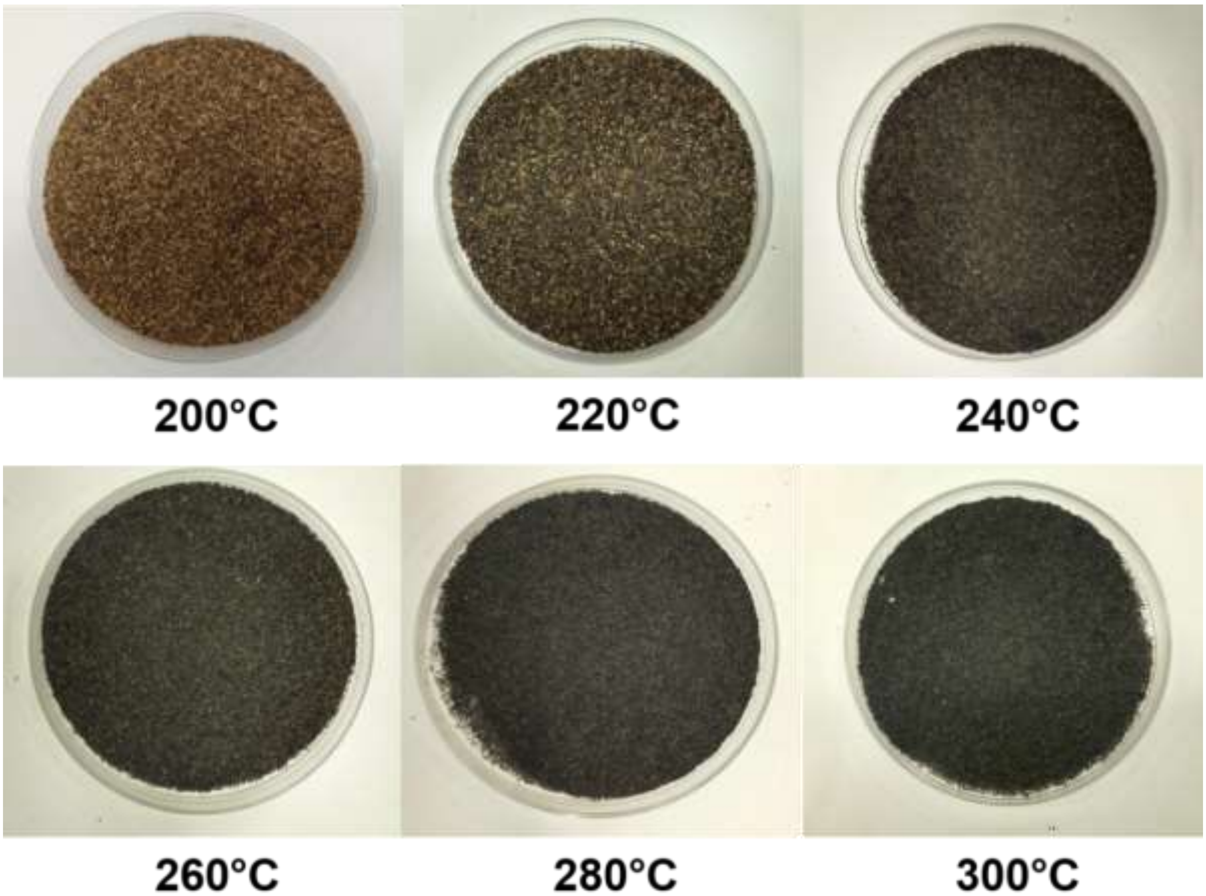

Figure 5. Torrefied SCB in different temperatures.

Table 2 presents the results of the proximate analysis and HHV of the torrefied SCB. Analyzing the results, it is possible to verify the reduction in the moisture content of torrefied SCB when compared to in nature SCB, thus minimizing biomass decomposition problems during storage. In addition, there is a small increase in moisture content for the 280 and 300°C samples, which is caused by the greater decomposition of volatile materials, promoting the release of hydrogen (H) and hydroxyl (OH) radicals, giving origin of water formation in the torrefied biomass. It is also possible to verify the great reduction in the volatile material content with the increase in the torrefaction severity. This reduction generates an increase in the contents of fixed carbon and ash contained in the structure of the torrefied SCB. It is important to emphasize that the sample torrefied at 300°C had a percentage of volatile material slightly higher than the samples at 260 and 280 °C. Furthermore, the lower fixed carbon content obtained at 300°C when compared to the other two was also due to the higher ash content present in the structure.

Table 2 shows the HHV of the torrefied SCB, showing that there was an increase of up to 64.41% for the 280°C sample, when compared to the HHV of the fresh SCB. In an experiment carried out by Conag et al. (2017), torrefaction the SCB at 300°C led to a HHV of approximately 26 MJ/kg, which shows that the values obtained are close to those reported in the literature. Through the results, it can be inferred a direct influence of the amount of fixed carbon present in the structure of the torrefied SCB with the increase of its heating value. This is since the volatile material fraction contains organic components that have a significant amount of oxygen and hydrogen. Thus, the reduction of volatile material and the consequent increase in fixed carbon in the structure, result in an improvement in the energy characteristics of the torrefied SCB.

Table 2. Proximate analysis and HHV of torrefied SCB using CO_2.

	in nature	200 °C	220 °C	240 °C	260 °C	280 °C	300 °C
Moisture (%)	5,50	4,28	1,92	1,91	1,10	2,24	2,87
Volatile material (%)	80,80	76,78	73,91	68,50	54,76	53,44	55,35
Fixed carbon (%)	11,20	13,28	19,12	21,74	33,42	34,93	29,95
Ash (%)	2,50	5,67	5,05	7,85	10,73	9,39	11,82
HHV (MJ/kg)	15,80	19,05	20,36	20,88	24,75	25,98	25,76

4. CONCLUSIONS

The torrefaction of sugarcane bagasse using carbon dioxide proved to be more intense, this can be seen by the biomass yields where, at torrefaction temperatures above 250°C, the yield of torrefied bagasse is less than 50%, making the process technically unfeasible. In this study, when using CO_2, the torrefaction temperature should be limited to 220°C, temperatures above present a significant reduction in the mass yield of torrefied biomass. In this condition, torrefied SCB can increase the value of HHV by 30%. Fraction gas from torrefaction has the potential to be used as a heat source for the process itself, this would help to reduce processing costs. Combustion studies of torrefied SCB are needed to evaluate its behavior during combustion and define the best condition on biomass torrefaction.

5. ACKNOWLEDGEMENTS

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