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SIMULATION OF TORREFIED SUGARCANE BAGASSE COMBUSTION

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Abstract

In Brazil, sugarcane has a fundamental role in energy generation. Sugarcane bagasse is used in thermal plants to produce energy, However, sugarcane bagasse exhibit high moisture content, low density, low heating value. To improve the sugarcane bagasse, the torrefaction process could be an alternative to improve the physical and chemical properties. The literature presents diverse studies about sugarcane residues torrefaction, however, few studies on the combustion of this torrified biomass. In this study, the combustion of torrified sugarcane bagasse was simulated using Aspen Plus software. The results show that the HHV value can be predicted using ASPEN software. The combustion of torrefied sugarcane bagasse shows an exhaust gas rich in CO_2 and water content was reduced. Torrefied sugarcane biomass at 200°C have a lower air fuel ratio, this condition shows a significant reduction in mass flow of exhaust gases.

Keywords: *Combustion, Simulation, torrefied biomass, energy.*

1. INTRODUCTION

The need for renewable energy increases due to factors such as the gradual reduction of fossil fuel reserves, the increase in global energy demand and the increase in greenhouse gas (GHG) emissions resulting from the use of fossil fuels (Abbasi and Yozgatlilgil 2014 ; Saidur et al. 2011). In order to satisfy the great energy demand aiming at the reduction of GHG emissions, several alternatives have been proposed, among them the use of biomass. Biomass is the fourth 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 reduce 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 more 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 typical biomass deficiencies such as a high moisture content, low specific mass, heterogeneity, low heating value and low carbon / oxygen ratio (Da Silva, et al. 2018). These deficiencies can be overcome through pre-treatment methods such as torrefaction. The torrefaction process consists of heating the 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. Sugarcane products represented 16.2% of primary energy production in the Brazilian energy matrix in 2019 (EPE 2020). The participation of sugarcane in the energy matrix may increase due to the improvement in its productivity and the insertion of other cultivars (sweet sorghum). However, sugarcane bagasse exhibits some particularities such as a high moisture content (> 50%), hygroscopic nature, low density and a relatively low heating value (Conag et al. 2017). In addition, the current system of sugarcane bagasse management promotes losses of up to 15% of the mass due to the deterioration caused by the microbial action (Lima 2018). Thus, the implementation of the sugarcane bagasse torrefaction in the cogeneration systems of the Brazilian sugar and alcohol sector could increase its efficiency, as well as the participation of sugarcane in the energy matrix. According to Granados et al. (2017) there is a significant amount of work on biomass torrefaction, however, the literature presents few studies on torrefaction sugarcane bagasse. Patel et al. (2011) studied the performance of the torrefaction process of cotton stalks, prosopis and sugarcane bagasse. The results showed that torrefaction performed at 300 ° C and within 1 hour significantly increased the heating value of the biomasses by between 27 and 41%. Joshi et al. (2015) investigated the torrefaction of sugarcane bagasse using a carrier gas stream with a percentage of oxygen simulating the use of an exhaust gas or air. The results obtained showed that oxygen promotes the formation of a gaseous product by increasing the concentration of carbon dioxide (CO2). Conag et al. (2017) investigated the effect of temperature and time of torrefaction sugarcane bagasse in a minimally oxidative atmosphere. The authors demonstrated that temperature and time have a significant influence on improving fuel characteristics. In addition to the few studies concerning the torrefaction of sugarcane bagasse, studies on its combustion are scarce.

2. MATERIALS AND METHODS

To estimate the higher heating value (HHV) of the torrified sugarcane bagasse using its compositional analysis, the software Aspen Plus v9.0 was used. The procedure was the same adopted by Patrocínio (2017), therefore, the bagasse was modeled as a nonconventional solid and the enthalpy and the density was estimated using the methods for coal, HCOALGEN and DCOALIGT. In the configuration of the HCOALGEN method, the Boie equation was used to determine the heat of combustion, the heat of formation was calculated based on the heat of combustion, the heat capacity was estimated using the Kirov relationship and the thermodynamics state of reference adopted was 298.15 K and 1 atm. The data for characterization of sugarcane bagasse are those reported by Manatura (2020). These data are presented in Tab1. The numbers after the sample names that start with T indicate the temperature in Celsius degrees at which the torrefaction took place for a period of 60 minutes. As the author presented the amount of sulfur along with the proximate analysis, it was necessary to recalculate the results of this analysis without considering this element and considering it in the ultimate analysis.

Table 1 - Proximate and ultimate analysis of raw and torrefied sugarcane bagasse.

Proximate analysis (%wt)					
Sample			FC(1)	VM(2)	Ash
Raw			14.28	83.55	2.17
T200			26.97	71.26	1.77
T225			25.55	71.95	2.49
T250			34.5	62.27	3.22
T275			44.11	51.93	3.96
Ultimate analysis (%wt)					
Sample	C	H	O	N	S
Raw	45.31	6.15	45.72	0.54	0.11
T200	41.14	4.13	52.64	0.23	0.1
T225	45.93	4.61	46.6	0.24	0.13
T250	50.93	3.67	41.77	0.27	0.14
T275	56.97	2.75	35.87	0.3	0.15

(1) Fixed carbon
(2) Volatile matter

The HHV was verified using the arrangement shown in Fig.1. The sugarcane bagasse (modeled as a nonconventional component) is separated into hydrogen (H2), nitrogen (N2), oxygen (O2), carbon (C), sulfur (S) and ash (a nonconventional component that only contains ash in the composition) in the SEP block. This block is a yield reactor (RYELD) type that allows the user specifies the quantity produced of each component at the exit based on the amount of bagasse entering. To determine how much of each component was produced, a routine was written using a calculator type block that allows determining the flow of these components according to the ultimate analysis. Then, in the COMBUST block, that is a stoichiometric reactor (RSTOIC) combustion of the components occurs. Hydrogen, carbon and sulfur are oxidized to form H_2O, CO_2 and SO_2, respectively. It was considered that the pressure inside the reactor is 30 bar, which is a typical value adopted in calorimeters (Annamalai and Puri, 2006), and that the reactor provides the necessary energy to separate the bagasse into its constituents in the SEP block. Moreover, it was simulated the combustion under 100% oxygen atmosphere and under air atmosphere (79% of and 21% oxygen), in both cases the amount of oxygen provided was the necessary to stoichiometric combustion. After combustion, the flue gases were cooled to 25 ° C and the rate of heat released during cooling divided by the bagasse mass flow at the entrance is equal to the HHV.

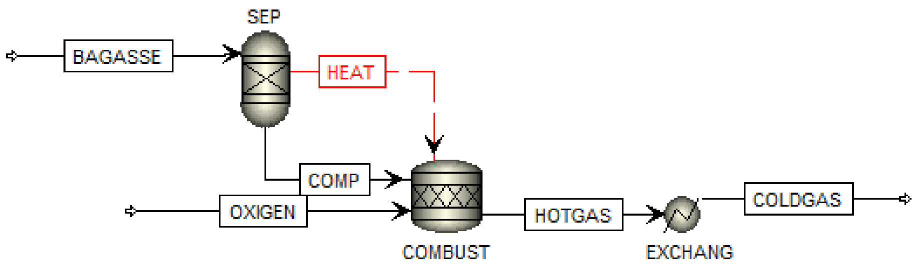

Figure 1 - Aspen Plus combustion simulation.

3. RESULTS AND DISCUSSION

A simulation was performed for each sample and the HHV was determined. To verify the validity of the results, the simulated HHV was compared with the value reported by Manatura (2020). This value was calculated using the enhancement factor (EF), which is the relationship between the HHV of torrified bagasse and raw bagasse. Table 2 shows the values for the EF of each sample. The HHV of raw sugarcane bagasse reported by the author was 14.33 MJ / kg. Table 3 presents the results of the HHV experimental and the predicted with Aspen. The program can satisfactorily predict the HHV using data from the elementary and immediate composition of the samples of torrefied sugarcane bagasse.

Table 2 - Enhancement factor of the torrefied bagasse (Manatura 2020).

Sample	Enhancement factor (EF)
T200	1.11
T225	1.19
T250	1.17
T275	1.28

Table 3 – HHV predicted using Aspen Plus for torrified sugarcane bagasse.

Sample	HHV Experimental (MJ/kg)	HHV under oxygen atmosphere (MJ/kg)	Error (%)	HHV under air atmosphere (MJ/kg)	Error (%)
Raw	14.33	17.76	23.94	17.74	23.80
T200	15.76	13.12	-16.75	13.10	-16.88
T225	17.05	16.05	-5.86	16.02	-6.04
T250	16.77	17.25	2.86	17.22	2.68
T275	18.34	18.95	3.33	18.92	3.16

Table 4 shows the composition of the exhaust gases and air fuel ratio (AF) from raw and torrefied sugarcane bagasse considering a stochiometric condition predicted using Aspen Plus. It can be observed that the CO_2 concentration increases significatively, and the H_2O concentration decreases as the value of the torrefaction temperature increases. This is due to during the torrefaction, the biomass components (hemicellulose, cellulose, and lignin) decompose thermally in volatile materials, this produce an increase to the carbon content, however, oxygen and hydrogen content are reduced significantly, causing a reduction in the formation of water during the combustion process of torrefied biomass. The reduction of water in the resulting exhaust gas is important as it could be used as a carrier gas during the torrefaction process. Air fuel ratio increase proportionally to carbon content, however torrified sugarcane bagasse at 200°C have a lower AF ratio and at 275°C have a value higher than the raw biomass. If we consider sugarcane bagasse torrefied at 200 °C as a potential solid fuel for the generation of thermal energy, there would be a significant reduction in exhaust gases, moreover, reduction in the power generation unit.

Table 4 – Composition of exhaust gas from combustion of torrefied sugarcane bagasse under air atmosphere.

Sample	CO_2 (% wt)	H_2O (%wt)	SO_2 (%wt)	N_2 (%wt)	AF
Raw	26.36	8.73	0.03	64.88	5.32
T200	31.14	7.63	0.04	61.19	3.86
T225	29.00	7.10	0.04	63.86	4.83
T250	29.83	5.24	0.04	64.89	5.29
T275	30.34	3.57	0.05	66.04	5.92

4. CONCLUSIONS

In this work the HHV was determined and the combustion of torrefied sugarcane bagasse was simulated of using ASPEN software. The results demonstrate that having data such as compositional, proximate, and ultimate analysis, the HHV of raw and torrefied biomass can be estimated with good precision. The burning of torrefied sugarcane bagasse indicates a significant reduction in the water content formed, this could bring some benefits, such as a reduction in mass flow of exhaust gas, and this gas could be used as a gas carrier in torrefaction process due to low water content.

5. ACKNOWLEDGEMENTS

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