EVALUATION OF THE POTENTIAL OF SUGARCANE BAGASSE FOR OBTAINING CHARCOAL, BIO-OIL, AND GAS THROUGH FAST PYROLYSIS PROCESS UNDER DIFFERENT OPERATIONAL CONDITIONS

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ABSTRACT

The increasing demand for renewable energy alternatives to reduce the use of energy from fossil fuel sources is occurring globally, as various environmental impacts are being caused by the use of these non-renewable sources, in addition to their limitations in nature. Among the forms of clean energy, the use of biomass stands out, given that Brazil is the largest producer of sugarcane in the world. Among the waste generated from this raw material, sugarcane bagasse has great potential to be used as clean energy through the transformation of the residue into biofuel. The fast pyrolysis process of biomass generates products such as charcoal, bio-oil, and gas, which can be used as an energy source with less environmental impact than fossil resources. In this study, the potential of sugarcane bagasse for obtaining charcoal, bio-oil, and gas through the fast pyrolysis process was evaluated by applying different operational conditions. It was concluded that the bagasse presents desirable physicochemical characteristics for the production of biofuels and that with different operational conditions employed in the fast pyrolysis process, it is possible to maximize a product of interest. The temperature range applied favored the production of liquids.

Keywords: Sugarcane bagasse. Fast pyrolysis. Biofuels.

1 INTRODUCTION

The climate changes occurring due to the intensification of fossil fuel usage raise concerns on a global scale. The increased use of fossil fuels, the reduction of global reserves, as well as the rise in the concentration of polluting gases (the so-called "greenhouse gases", GHGs) in the atmosphere, have led to the search for less climate-impacting energy sources. Therefore, renewable energy derived from biomass is one of the favorable options for reducing the environmental concentration of GHGs [1,2]. Sugarcane bagasse is a fibrous residue generated from the milling process for juice extraction. It exhibits desirable physicochemical properties for industry, such as low sulfur and ash content, with Brazil being the world's largest sugarcane producer [3,2].

There are various routes that can be used to convert biomass into products with higher added value, including chemical, physical, thermochemical, and biological routes. Among the thermochemical routes, pyrolysis stands out, which is a thermal decomposition process that occurs in the absence of oxygen, transforming biomass into products of interest, namely: charcoal, bio-oil, and gas. By employing different operational variables, it is possible to maximize the production of one of these three products [1,2]. Therefore, this study proposes the evaluation of charcoal, bio-oil, and gas production through the fast pyrolysis process and the potential of sugarcane bagasse for use as a clean energy source through physicochemical analyses.

2 MATERIAL & METHODS

2.1 Preparation and characterization of biomass

The sugarcane bagasse was subjected to characterization regarding moisture content, volatile matter, ash, and fixed carbon, with the latter three analyses conducted on a dry basis. Proximate analysis was performed in triplicate, following ASTM D 1762-84 standard. For sample standardization, the biomass underwent a milling process in an industrial mill, followed by particle size distribution analysis using a Bertel Mechanical Sieve Shaker.

2.2 Fast pyrolysis

Three experiments of fast pyrolysis were conducted in a temperature range of 300-520°C, with constant rates of biomass feed into the reactor, approximately 13 kg/h, the amount of sand, and the sum of the air fluidization rate and recycle rate employed, totaling 12m³/h. The variable used in this process was the air-to-recycle ratio. The conditions of each experiment are expressed in Table 1.

Table 1 Operational conditions employed in the fast pyrolysis process.

Experiment	Feed rate (kg/h)	Temperature (°C)	Air flow rate (m³/h)	Recycle flow rate (m³/h)
1	13	480	9	3
2	13	520	10	2
3	13	300-360	6	6

The solid product, referred to as "charcoal," is extracted from the cyclone and then quantified by its mass, while the non-condensable gases proceed to the heat exchanger, where, in indirect contact with water at ambient temperature, the acidic extract is collected. In the centrifuge, the droplets coalesce to obtain the bio-oil. Finally, before the remaining non-condensable gases are directed to the combustion chamber, they are collected in a bag for characterization. The mass yield of the pyrolysis products was calculated by the difference in the amount of biomass fed, as per equation 1.

$$y_i\ (\%) = \frac{m_i}{13_{kg}}\ x\ 100\% \quad (1)$$

2.3 Determination of gas composition

The percentage of each gas present in the sample from the fast pyrolysis experiments was determined by gas chromatography. The responses were obtained on a SCHIMADZU GC-2014 gas chromatograph containing a CARBOXEN-1000 packed column (15 ft x 1/8 in S.S. with a carbon molecular sieve 60/80 as the stationary phase). N2 was used as the carrier gas. The oven was programmed as follows: 5 minutes held at 35°C followed by heating to 225°C at a rate of 20°C/min and maintained at this temperature for 2 minutes, totaling 16.5 minutes of analysis. For each analysis, performed in triplicate, 300 μL of gas were used. By knowing the volumetric gas ratio and considering it in the ideal state, the molar composition is obtained.

3 RESULTS & DISCUSSION

3.1 Characterization of Sugarcane Bagasse

The sugarcane bagasse underwent a milling process, and from equation 2, the Sauter diameter was estimated.

$$d_{ps} = \frac{1}{\sum_{i=1}^{n} (\frac{xi}{dpi})} \quad (2)$$

Where xi represents the percentage corresponding to the mass fraction retained on sieve i

The obtained Sauter diameter was approximately 0.2 mm. In the study by El-Sayed & Mostafa (2014), a similar average particle diameter of 0.3 mm was reported after the bagasse had undergone a milling process [4].

Different particle sizes of bagasse can be explained by the type of milling used.

The results of the average triplicate measurements for moisture content, volatiles, ash, and fixed carbon of the sugarcane bagasse are presented in Table 2.

Table 2 Average Triplicate Results of the Proximate Analysis of Sugarcane Bagasse.

Moisture Content (%)	Volatiles (%)	Ash (%)	Fixed Carbon (%)
7,7 ± 0,1	83,4 ± 0,6	2,5 ± 0,2	14,1 ± 0,3

From Table 2, it can be noted that the biomass exhibited a volatile content of 83.4%, demonstrating potential for liquid fuel production. Similar values for moisture, volatiles, ash, and fixed carbon were reported in the studies by Sohaib et al. (2017) and Montoya et al. (2015), who conducted the fast pyrolysis process using sugarcane bagasse [5,6].

3.2 Yield of Products Obtained in the Fast Pyrolysis Process

Table 3 presents the operational conditions employed in the fast pyrolysis process and the mass yields obtained for coal, acidic extract, bio-oil, gas, and losses through Equation 1.

Table 3 Mass Yields of Products Obtained in the Fast Pyrolysis Process.

Experiment	Air:Recycle Ratio	Temperature (°C)	Char (%)	Acidic Extrac (%)	Bio-oil (%)	Gas (%)	Losses (%)
1	3:1	480	19	30	15	36	8
2	5:1	520	17	37	11	35	10
3	1:1	300-360	28	27	12	33	45

According to Table 3, it is observed that experiments conducted at lower temperatures resulted in an increase in char yield. However, the yield of acidic extract increases in experiments at higher temperatures. The optimal mass yield of bio-oil was 15% in the experiment conducted with an air-to-recycle ratio of 3:1 at 480°C. In the study by Sohaib et al. (2017), which conducted the pyrolysis process using sugarcane bagasse in a bench-scale reactor, a maximum bio-oil yield of 60.4% was observed at a temperature of 500°C. Warma & Mondal (2017) analyzed the effect of temperature on product yields and found a higher bio-oil yield at 500°C [5,7].

However, the operational conditions employed in experiments 1, 2, and 3 promoted the production of liquid products (acidic extract and bio-oil).

3.3 Composition of Pyrolysis Gas

Table 4 Molar Composition of Pyrolysis Gas.

Experiment	Temperature (°C)	H_2 (%)	O_2 (%)	CO (%)	CH_4 (%)	CO_2 (%)
1	480	1	75	2	2	21
2	520	1	75	3	3	18
3	300-360	0	81	8	1	10

The increase in temperature resulting from the increase in air flow led to a decrease in the oxygen content, which can be explained by combustion reactions generating CO, CO_2, and water vapor. Since the process occurred at moderate temperatures (below 520°C), minimizing the rates of H_2 and CO formation reactions, low levels of these gases were produced.

4 CONCLUSION

In this study, it can be concluded that sugarcane bagasse possesses attractive characteristics for conversion into higher value-added products, with a volatile content of 83.4% and moisture content of 7.7%. Lower temperatures favor the production of solid products in the fast pyrolysis process. However, the temperature range employed (300 – 550°C) favored the production of liquid products (acidic extract and bio-oil). Lastly, moderate temperatures (below 520°C) did not favor the production of H_2 and CO.

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ACKNOWLEDGEMENTS

The members of this study would like to express their gratitude to TECNORED Desenvolvimento Tecnológico S.A for the opportunity, to WXO for their assistance in conducting the experiments, and to FEQ-UNICAMP for their support in research and analysis. Finally, this study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.