

Gasification characteristics of sugarcane bagasse

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Abstract. Sugarcane bagasse is a residue that results from the crushing of sugarcane in the sugar industry. Among the various agricultural crop residues, sugarcane bagasse is the most abundant lignocellulosic material in tropical countries such as South Africa. Bagasse is a renewable feedstock that can be used for power generation and manufacturing cellulosic ethanol. In the sugarcane industries the bagasse is mainly burnt inefficiently in boilers that provide the heating for the industry. This project seeks to investigate the possibility of gasifying sugarcane bagasse as an efficient conversion technology. Proximate and ultimate analysis of sugarcane bagasse was conducted after which the results were used to conduct computer simulation of the mass and energy balance during gasification. This paper presents the proximate and ultimate analysis as well as the computer simulation results.

1 Introduction

The development of sustainable renewable energy technologies for their use in current and new power plants is of utmost importance now than ever before due to several reasons. Some of these reasons include energy security and availability, independence from foreign oils and reduction of greenhouse gas emissions to provide a cleaner environment for better health, plant and animal life. These reasons are precepts for the development of alternative and sustainable energy technologies. Among the various agricultural crop residues, sugarcane bagasse is the most abundant lignocellulosic material in tropical countries such as South Africa. Sugarcane bagasse is a residue produced in large quantities by sugar and alcohol industries. In general, 1 ton of sugarcane generates 280 kg of bagasse. About 54 million dry tons of bagasse is produced annually throughout the world [1].

In South Africa approximately 6 million tons of raw bagasse is produced annually [2]. Most large and medium sized mills can use up to 75% of this bagasse onsite to generate heat and electricity [3]. Epithelial cells, vessels, and parenchyma as well as fiber bundles are part of the structural elements contained in sugarcane bagasse [4]. Sugarcane bagasse holds promise as a fuel source since it can produce more than enough heat energy to supply the needs of a common sugar mill. Bagasse is a renewable feedstock that can be used for power generation and manufacturing cellulosic ethanol and if it is efficiently utilized, it could generate excess electricity that could be sold to the utility company or any other third party or even be exported [5].

Gasification of sugarcane bagasse provides part of the solution towards sustainable renewable energy sources. Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen, methane and carbon dioxide. This is achieved by reacting the material at high temperatures, usually above 1000°C, in the presence of a limited amount of oxygen and/or steam. The resulting syngas or producer gas has a heating value of 4-6 MJ/kg. The clean syngas from bagasse can be used in stationary gas turbines. The advantage of gasification is that using the syngas is potentially more efficient than direct combustion of the original fuel because it can be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher or not applicable [5]. Gasification of sugarcane bagasse produces the same amount of CO₂ as it consumes during its growth rendering it carbon neutral [6]. However limited data are available on the efficient

conversion of bagasse to clean syngas. The aim of this study is to investigate the possibility of gasifying sugarcane bagasse as an efficient conversion technology.

2 Research Methodology

Samples of sugarcane bagasse (SB) were obtained from TSB sugar, South Africa and were preserved to prevent contamination. The bagasse was dried at 105°C in a furnace for 4 hours. The dried sugarcane bagasse was ground using a cryogenic grinder to size range of 1.8 mm and was preserved in a sample container for analysis to be carried out. The characterization method involved proximate analysis, which gave the amount of fixed carbon, volatile and ash contents as well as moisture content of the SB. These were determined from the thermo gravimetric curves at two different heating rates (15°C/min and 20°C/min). The ultimate analysis of bagasse was determined using a CHNS analyzer. Three samples were analyzed using each of the latter techniques and an average value was calculated. The higher heating value (HHV) of the SB was measured using a bomb calorimeter (CAL2K Model). A downdraft biomass gasification program developed by Jayah *et al*, 2003 [7] was used to undertake computer simulation of the gasification of sugarcane bagasse. Table 1 show the parameters used during simulations. The moisture content of the material was varied between 2.14%, 7.14% and 15% respectively.

Table 1. Parameters used during gasification simulation

Fuel properties	Value	Gasifier operating conditions	Value
Carbon (%)	44.1	Throat diameter (cm)	25.5
Hydrogen (%)	5.7	Throat angle (°)	30
Oxygen (%)	47.7	Insulation thickness (cm)	17.5
Nitrogen (%)	0.20	Thermal conductivity (W/cm K)	2.8
Fixed carbon (%)	18.19	Temperature of input air (K)	300
Bulk density (g/cm ³)	0.178	Feed input (kg/hr)	40
Diameter of SB particle (cm)	14.3	Air input (kg/hr)	44.5
		Heat loss (%)	12.8

3 Results and Discussion

3.1 Sugarcane bagasse proximate and ultimate analysis

Table 2 presents the proximate analysis of sugarcane bagasse under study at 15°C/min and 20°C/min heating rates. No ash composition was observed for the 15°C/min heating rate due to the fact that the maximum temperature reached was not enough for complete combustion and determination of ash content.

Table 2. Proximate analysis of SB at 15°C/min and 20°C/min heating rates

Components	% Composition @ 15°C/min	% Composition @ 20°C/min
Moisture Content	2.4	3.62
Volatile Matter Content	58.02	68.40
Fixed Carbon	19.25	18.19
Ash	-	0.53

At 20°C/min heating rate, an ash content of 0.53% was observed which is typical of biomass materials. The ash content and its composition are important factors for biomass use in thermochemical processing due to its catalytic activity [8]. It is also evident from table 2 that the

heating rate influences the rate of volatile evolution from the material as volatile matter content increased from 58.02% at 15°C/min heating rate to 68.4% at 20°C/min heating rate. The ultimate analysis of SB is presented in table 3. It can be observed from the table that sugarcane bagasse contains more oxygen than carbon, which is typical of biomass materials.

Table 3. Ultimate analysis sugarcane bagasse

Chemical Components	Composition (%)
N	0.20
C	44.1
H	5.7
S	2.3
O	47.7

3.2 Thermogravimetric analysis

Figure 1 shows the TGA plot for sugarcane bagasse under study at 15°C/min and 20°C/min heating rates under nitrogen atmosphere. In general, three distinct mass loss stages could be noticed. In the first region (A), a reduction in weight at temperatures lower than 100°C is observed and can be attributed to loss of moisture content of the material at both heating rates. From the second region (B), the temperature range 100–260°C, a negligible weight loss is noticed which was followed by the beginning of devolatilization caused by rapid weight loss at 330°C. The insignificant weight loss prior to the start of devolatilization can be attributed to the removal of moisture and the start of hydrolysis of celluloses, hemicelluloses and lignin [9]. Biomass materials are composed mainly of cellulose, hemicelluloses and lignin [10]. The B region indicating weight loss as depicted in figure 1 is mainly due to the decomposition of these components [11]. The degradation of hemicellulose typically occurs in the temperature range 160-360°C while cellulose decomposes at a higher temperature range of 240-390°C (B). In region C there is a much lower rate of weight loss than in region B, which corresponds partly to the end of cellulose degradation and partly to the starting of degradation of heavier volatiles and formation of char. Lignin degradation also continues in this region [12].

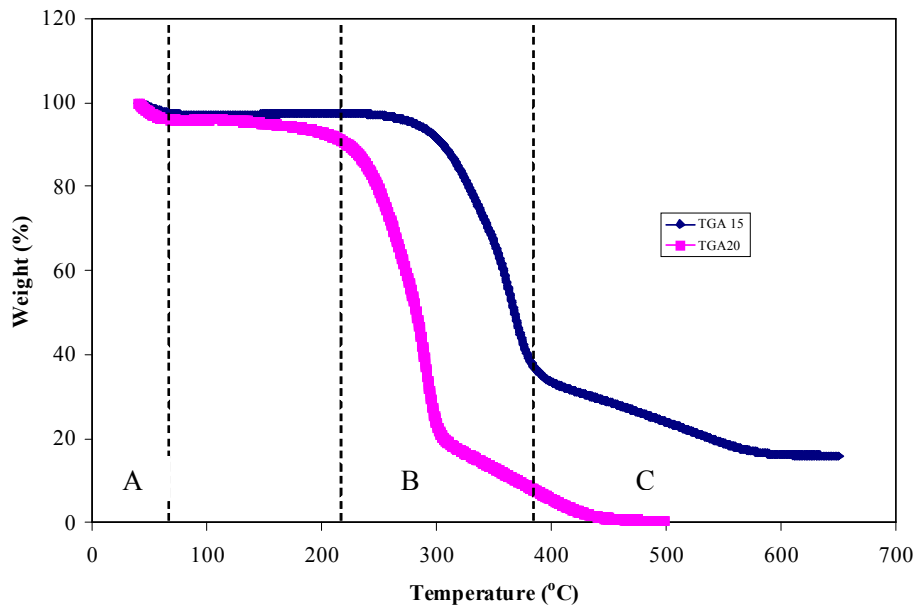


Figure 1. TGA curve of SB at 15°Cmin⁻¹ and 20°Cmin⁻¹ heating rates

3.2 Gasification simulation results

The higher heating value of the material was measured to be 17.8 MJ/kg, which was used during calculation of the conversion efficiency of the gasification process. Figure 2 shows the gas volumes and percentage difference obtained during gasification simulation using the gasifier operating parameters presented in table 1.

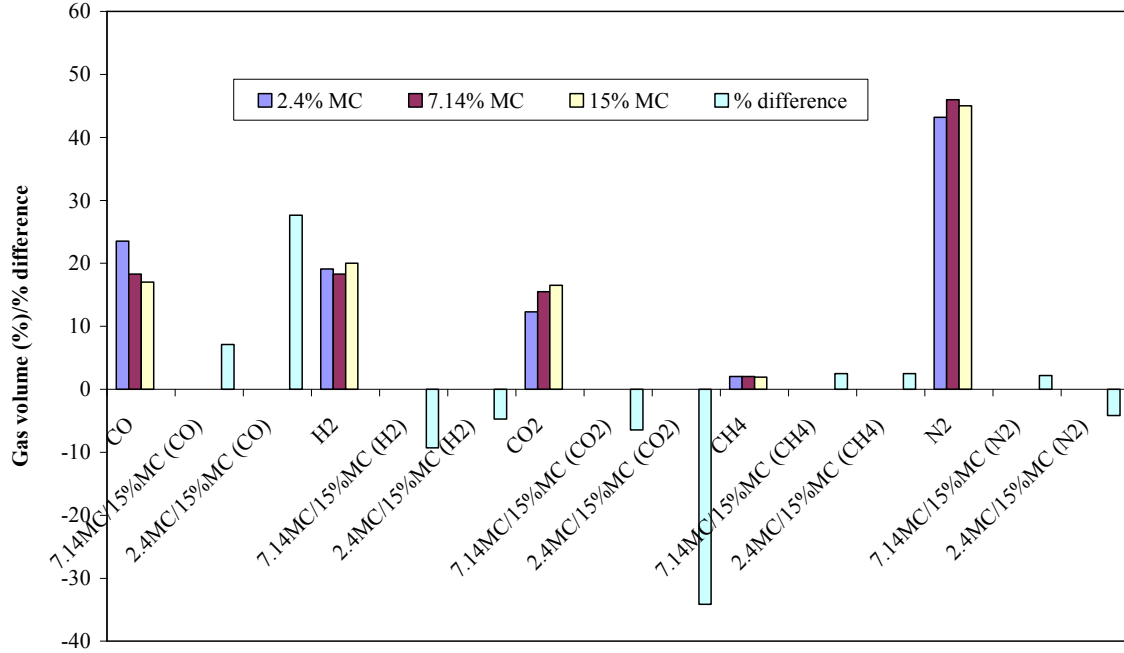


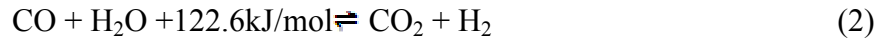
Figure 2. Gas volumes obtained through computer simulation

The major part of the syngas is formed through reduction reactions in the reduction zone of the biomass gasifier, most of these reactions are endothermic. The reactions are as follows [13]:

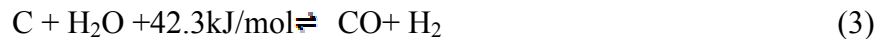
Boudouard reaction



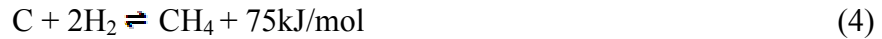
Water-gas reaction



Water shift reaction



Methane production reaction



The volume of carbon monoxide was found to be higher (27% by difference) when the moisture content of bagasse was low (2.4%) compared to when it was higher (7% and 15% respectively). This can be attributed to the fact that heat is not consumed during the drying of the feedstock; it is rather available for the reduction reactions to take place. The hydrogen content was found to be higher when the moisture content of the bagasse was assumed to be higher (15%). This is because of the availability of moisture for the water-gas reaction to take place. However the reduction in carbon monoxide implied a reduction in conversion efficiency and the gain in hydrogen could not compensate for the loss in CO content. The volume of the combustible gases

in the syngas largely influences the gas heating value. This in turn influences the conversion efficiency of the gasification process because the gas heating value is directly proportional to the conversion efficiency of the gasifier. Figure 3 shows the simulated gasifier conversion efficiency.

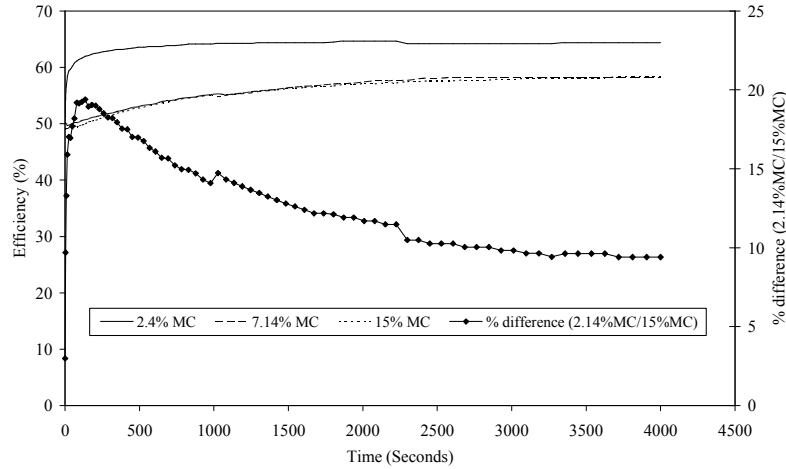


Figure 3. Computer simulation of the conversion efficiency of the sugarcane bagasse

The impact of gas heating value on the conversion efficiency of the gasifier is evident in figure 3. The implication for this is that the chemical reactions that favour the production of carbon monoxide during gasification of sugarcane bagasse should be optimized.

4 Conclusion

The paper investigated the possibility of gasifying sugarcane bagasse as an efficient conversion technology to establish the effect of various parameters on the thermal degradation behaviour of the material that will result in maximum conversion efficiency during gasification. It was established that the composition of sugarcane bagasse, as evident in table 2 cause the material to have high volatile matter content and low ash content and appears to be suitable for gasification. The oxygen composition in table 3 is about 8.16% more than the composition of carbon, as a result, higher reactivity of the material under much less severe operating gasification conditions is expected which is typical of biomass materials.

It was also established that high moisture content reduces the gas volume, which in turn reduces the gas heating value as the volume of combustible gases in the syngas largely influences the gas heating value. This also reduces the conversion efficiency of the gasification process because the gas heating value is directly proportional to the conversion efficiency of the gasifier.

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