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Structural analysis of sugarcane bagasse as a feedstock in downdraft gasifier system - A review

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Abstract

Sugarcane bagasse turns out to be a potential feedstock for utilization in gasification process. This has greatly influenced the selection of raw material and its maximum consumption in the gasifying industry. It involves the simple procedure of burning of bagasse and producing steam which on further process is converted to electricity with the help of an apparatus called gasifier. It proves to be a more efficient and high yielding renewable raw material in the production of renewable energy. This work presents the comprehensive review of the methods applied and the performance of sugarcane bagasse as a feedstock used in electricity generation specifically emphasizing on the usage of downdraft gasifier system. Sugarcane bagasse is used on a large scale in the production of renewable energy worldwide. In the past few years there has been observed a tremendous growth in the manufacturing of renewable energy from sugarcane bagasse with help of gasifying process.

Keywords: Sugarcane bagasse, Downdraft gasifier, pre-processing, biomass

1. Introduction

Sugarcane bagasse is a solid waste obtained after the crushing of the sugarcane in the sugarcane mills. It proves to be a very efficient raw material in the production of renewable energy. In comparison with the other agricultural crop residues sugarcane bagasse is the most high yielding and abundant material. 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]. Sugarcane bagasse proves to be a great source of fuel for the downward gasifier for the production of electricity. Sugarcane bagasse is one of the most important lignocellulosic or plant biomass material utilized in the field of power generation. Lignocellulosic material do not contain readily accessible monosaccharaides and chemicals but rather polymers which need to be hydrolyzed to release the desired compounds [4]. Lignocellulosic material is determined by its fibrous nature by which structural framework of the plant cell is composed. Downdraft gasifier proves to be an efficient source of renewable energy due to its small scale production and affordability and also due to its small scale applications for the domestic as well as low power consuming factories. Many studies have been carried out in order to determine the maximum utilization of sugarcane bagasse in downdraft gasifier. In order to look to the basic definition of gasification of, it mainly refers to the conversion of energy from one form to another i.e. from the heat that is liberated during the burning of solid waste into useful source of energy for the small scale utilization. The proper conversion and right utilization of wasteful energy into useful energy is the main aim of the concerned process. In order for the appreciable optimization of the sugarcane bagasse its composition plays an important role for which many studies have been carried out. Mill-run bagasse contains approximately 50% fiber, 48% moisture and about 2% sugar [4–7]. The bagasse is converted into small tablets or pellets before it can be used in the gasifier. Along with its advantage of being cheaper it also produces less amount of tar during its functioning. If on considering the case of India, renewable energy plays an important role in many lives of rural areas where the use of non-renewable resources like coal, wood is done on a large scale due to the non-availability and scarcity of knowledge regarding the other forms of energy

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resources and their production. The process is based on a series of complex reactions that are influenced by many factors including the composition of the feed material to be converted, the pre-processing conditions of the feed and the operating conditions of the gasifier [9]. Among the gasification technologies, the downdraft gasification has an increased interest among the researchers worldwide due to its suitability to produce mechanical and electrical power at affordable price even in small scale applications [10]. The components of bagasse like carbohydrates, protein, moisture, etc. plays an essential part in the performance and proper functioning of the gasifier. Environmentally, Biomass Gasification is a clean technology free of CO_2 emissions, if well designed. Utilization of renewable energy sources makes it a sustainable energy system [11].

Figure 1: Experimental setup of gasifier [8]

2. Sugarcane Bagasse: The feedstock

The selection of feedstock for energy production purposes is dependent upon certain criteria such as potential yield per hectare, feedstock properties and the potential uses [12]. Sugarcane proves to be a rich feedstock for the downdraft gasifier due to its potential behavior and the excess of its production and usage. However, the value of Sugarcane Bagasse as a fuel for energy production largely depends on its calorific value, which in turn depends on its composition, especially with regard to its moisture content and to the calorific value of the sugarcane plant, which mainly depends on its content of sucrose [13]. There are several pathways by which sugarcane bagasse can be converted into energy and some of those pathways include gasification, pyrolysis, liquefaction, fractionation, fermentation and hydrolysis [14]. Although the availability of other methods for the conversion of sugarcane bagasse into electricity, this review is mainly centered with the gasification process with the use of downdraft gasifier. In sugar mills, bagasse is usually combusted in furnaces for steam production, and the steam in turn is used for power generation; but the challenge of this process is related to the net electrical efficiency, which is extremely low (between 10–20%) when compared with the gasification process, which can have an efficiency as high as 67–80% [15,16]. Another limitation of the use of the boiler technology for bagasse combustion is the duration of startup, which is usually up to 8 h as well as the use of auxiliary fuels as startup fuels, which results in SO_2 and NO_x emissions including particulate emissions due to poor conditions of combustion in the boiler while it is cold during the startup period [16].

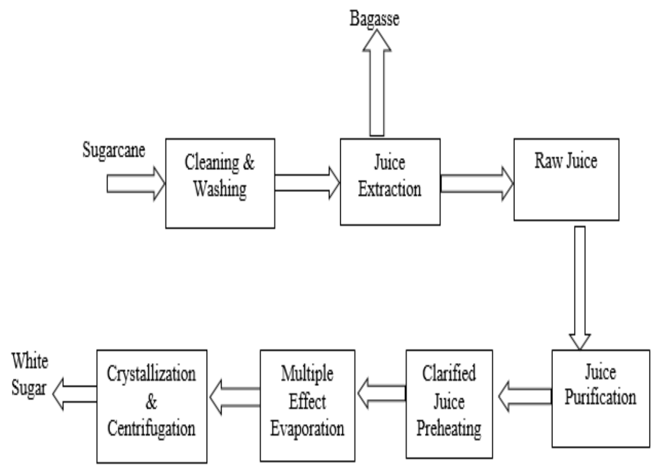


Figure 2: A simplified process diagram for the generation of sugarcane bagasse [17].

3. Composition of sugarcane bagasse

Sugarcane bagasse is a fibrous material consisting of framework of plant cell wall. The main components or the composition of sugarcane bagasse consists of carbohydrates obtained from two types of polysaccharides namely cellulose and hemicellulose, lignin, protein and moisture.

3.1 Carbohydrates

The major source of carbohydrates in sugarcane bagasse is cellulose and hemicellulose.

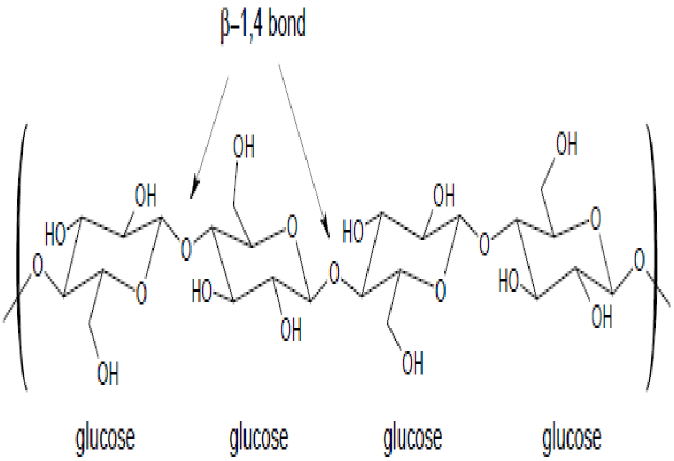
3.1.1 Cellulose

It is the most abundant constituent and is a homo – polysaccharide composed entirely of β-1, 4 - glucosidic linked glucose monomers [4]. There is the formation of hydrogen bonds between and within the molecules i.e. inter and intra-molecular hydrogen bonds due to the presence of linearity in the structure of cellulose. Approximately 50-90% of the total cellulose is crystalline, depending on the biomass source [18].

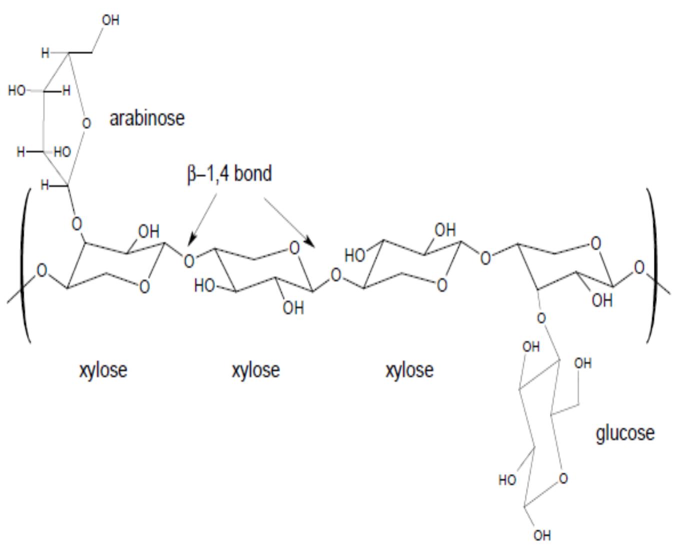
3.1.2 Hemicellulose

It is the heterogeneous polysaccharide composed of D – xylose, D – glucose, D – mannose, D – galactose, D –

arabinose, D – glucuronic acid and 4 – O – methyl – D – glucuronic acid [4]. Bagasse hemicellulose is composed of a backbone of xylose, branched with glucose and arabinose units [19] (Figure 2).



(a)



(b)

Figure 3: (a) Simplified structure of cellulose, (b) bagasse hemicellulose [4].

3.2 Lignin

Lignin is a three dimensional polymer three different phenyl – propane precursors monomers: p – coumaryl, coniferyl, and sinapyl alcohols [20].

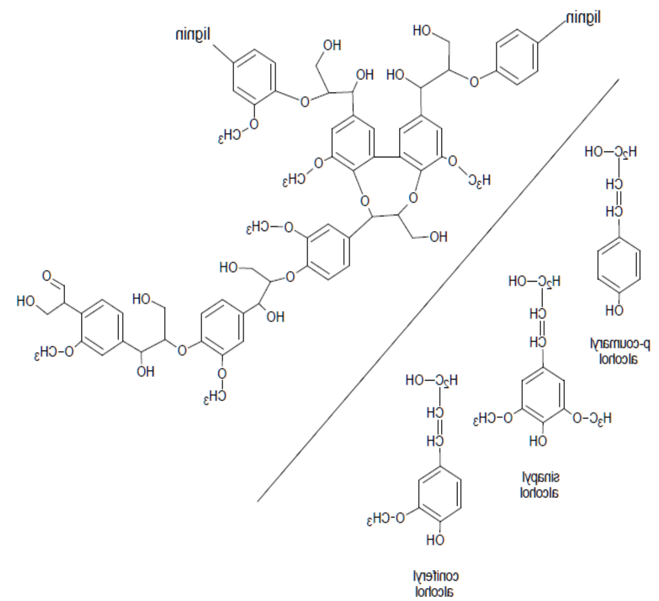


Figure 4: Phenyl - propane precursors (left) and a model lignin structure (right) [4].

3.3 Protein

The protein is determined as a nitrogenous compound.

3.4 Moisture

It is one of the main contents of the sugarcane bagasse on which the performance of gasifier depends.

4. Properties of sugarcane bagasse

The properties of sugarcane bagasse vitally influence the performance of the gasifier which thereby led to the variation in the production and right analysis of the results obtained during the process. The composition and the inherent properties of the source of biomass determine both the choice of the conversion process and any subsequent processing challenges that may arise, as the biomass choice is equally influenced by the form in which the energy is required, with the interplay between these two aspects enabling the introduction of flexibility into the application of biomass as an energy source [5].

4.1 Analysis of the sugarcane bagasse

The composition and properties of biomass can be described in terms of proximate and ultimate analyses, which are normally the first steps taken to evaluate the suitability of any biomass material for conversion into energy [21]. Fuel properties of the bagasse is obtained by the analysis called proximate analysis. The rate of decomposition and the released gas composition is dependent upon temperature and the heating rate of the decomposition reaction [21]. Generally, the proximate analysis of biomass provides a measure of the ease with which the biomass can be ignited and subsequently gasified or oxidized, depending on how the material is to be utilized as a source of energy [22]. Pre-processing of SCB has significant effects on all downstream processes and would ultimately influence the overall yield of the gasification process and cost [23]. It has been experimentally determined that the main components of sugarcane bagasse are carbon and oxygen along with a small amount of hydrogen. The high O2 composition is due to the alcohol (OH) and carboxylic acid (COOH) groups in the main constituents of bagasse which are cellulose, hemicellulose and lignin, and which also accounts for the high reactivity and high ignition stability of SCB when used as fuel in thermochemical conversion systems such as the gasification systems [24]. The conversion process of SCB or any biomass material begins with the knowledge of the energy content of the biomass, measured in the units of MJ/kg [25].

4.2 Calorific value of sugarcane bagasse

The conversion of sugarcane bagasse or any biomass material in the presence of excess amount of oxygen or air such that it releases energy in the form of heat is known as the calorific value and also the heating value. This is usually measured using a bomb calorimeter; however in the absence of equipment for measuring the heating value of biomass, two common equations are used to estimate this value [26]. These are the Dulong equation and the Boie equation [27, 28]. The Dulong equation can be written as follows [25, 27].

$$HV(MJ/Kg)= 33,823\text{x}C + 144,250 \left(\frac{H-O}{8}\right) + 9419\text{xS} \qquad (1)$$

Where HV is the heating value of the material in MJ/kg, and C, H, O and S are the elemental mass fractions of the material. The Boie equation is given by the following [25].

$$HV\ (MJ/Kg) = 35,160\text{x}C +116225\text{x}H - 11090\text{x}O+6,280\text{x}N+ 10465\text{x}S \qquad (2)$$

Where, C, H, O, N and S are the elemental mass fractions of the biomass material.

SCB is known to have a low heating value between 17 and 20 MJ/kg [22]. Feedstocks with high heating values are always better for gasification, and the conversion efficiency of a gasification process is based purely on energy in the feedstock [29, 30]. A high heating value material is beneficial as it leads to improved functionality and reduced energy use of feedstock conveyor at power plants [31].

4.3 Microstructure of sugarcane bagasse

SCB is highly complex in structure as well as in chemical ma- keup, so to better understand and describe thermochemical con- version processes using bagasse as feedstock for energy production, examination and analysis of the microstructure and macro- structure as well as the chemical makeup of bagasse are necessary [32]. The microstructure of bagasse is linked to its low molecular weight substances which include the organic and inorganic sub- stances present in its structure, while its macrostructure are related to the cellulose, hemicellulose, and lignin present [33]. The formulae for the cellulose and the hemicellulose are $(C_6H_{10}O_5)_m$ and $(C_5H_8O_4)_n$ respectively. These two compounds are polysaccharides with degree of polymerization represented by m and n, and with degrees of polymerization that are less than10000 and 50–300 for cellulose and hemicellulose respectively [21]. It also consists of lignin which is structurally irregular. However, the fraction of these three main components of SCB varies among the species of sugarcane as well as its origin; therefore, the composition of SCB is usually written in empirical form as CH_xO_y, which is based on the molar fraction of the elements present in bagasse [32]. Lignin also helps to form pellets or briquettes without binders because of its thermosetting properties at working temperatures of >140 °C [34]. Adhesion in the structure of lignocellulosic plant material is per- mitted by the lignin content of that material, acting as a bulking and rigidifying agent; and the strength characteristics of briquettes made from lignocellulosic biomass materials are attributed to the adhesive properties of thermally-softened lignin [35, 36]. The reaction behavior of hemicellulose is similar to that of cellulose, while lignin decomposes at a much wider temperature range forming CO_2 and CH_4 during gasification, due largely to the dealkylation of the side chain of the alkyl phenols in the lignin structure [37].

5. Methods for the pre-processing of sugarcane bagasse

Biomass, including SCB is difficult to work with when compared with conventional fuels like coal, which are used by a variety of energy conversion systems, with their benefits making them almost the exclusive source of energy for most industrial systems [38]. However, the process of gasification is the most demanding among all thermal conversion processes in terms of product end-use, which can be affected by pre-processing of the feedstock to be converted [39]. The quality of a pre- processed material depends on the pre-processing methods applied [23]. In addition, microbial reaction can lead to spontaneous combustion due to the burning properties of SCB [17].

5.1 Densification

Densification is one pre-processing method usually applied to achieve uniform properties and to increase the densities of biomass materials [23]. A densified material is easy to handle, transport and store and densification can be achieved with most biomass materials including SCB, provided that they attain the correct moisture content and particle size [38]. The commonly used methods for the densification of sugarcane bagasse are pelleting and briquetting. The use of biomass pellets or briquettes for energy production purposes depends largely on the type of conversion system employed [23]. Even though biomass pellets have specifications, there are various sizes, densities and composition of pellets produced depending on how the biomass material is to be utilized [38]. Pelleting may be a viable option for most biomass conversion systems because of the ease of handling of pellets, however, a major limitation in using biomass pellets is the energy requirements and associated cost of producing them [26]. The power consumption of the pellet mill is in the range of 15–40 kWh/t of biomass [40]. Briquetting is a high-pressure compaction technology used to increase the densities of biomass materials and remains a viable and attractive solution to biomass utilization as a potential feed- stock for energy production. The process of briquetting is usually carried out with a hydraulic, mechanical or a roller press type of briquetting machine [26]. The technologies for briquetting are classified according to the method used to compress the material. These include the piston press, the screw extruder and the pellet mill [26]. The piston press densification technologies include the hydraulic piston press, the mechanical piston press and the roller press [41].

6. Gasification process

Gasification is one of the most flexible technologies that can be used to produce clean energy. It is a thermo-chemical process that breaks down virtually any carbon-containing material into its basic chemical constituents, collectively known as synthetic gas (syn- gas) [26]. This process consists of a number of physical and chemical processes including rate-determining steps, and takes place under limited supply of O2 so that partial oxidation can increase the efficiency of the entire process [42]. The location of the chemical processes depends on the type of gasification technology, and the three major types are the fixed bed, fluidized bed and the en- trained flow gasification systems [43]. The mechanisms of heat and mass flows vary in magnitude according to the physical and chemical processes characterized by each zone, which include temperature, air moisture, heat losses, mass flow rate of air and gas, solid phases, feed rate, feed size, and moisture content [43].

7. Result and Discussion

The performance of a gasifier is based upon the effectiveness and the efficiency of the raw material that has been utilized which works according to the advantageous properties of the material. Pre-processing of the sugarcane bagasse is mainly done to overcome the limitations that arises in the processing of the raw material. The structural fundamentals of the sugarcane bagasse reveals the internal study of the material and also fulfills the fact about its suitability of working as a raw material which can be thus use for the gasifying process. The method of pelleting results in the decrement of the transportation cost and also requires less storage.

8. Conclusion

It can be concluded from the article that the advantageous properties of the sugarcane bagasse and its supporting structural composition makes it a good raw material for gasification process. The advantages of the downdraft gasifier like ease and simplicity in the controlling systems, operational comfort ability, very less wear and tear which thereby reduces the maintenance cost. Downdraft gasifier is not advantageous but also has some disadvantages like it can only be implemented in small scale production of energy and the gasifier cannot handle the raw material having moisture content. On the grounds of better understanding of the process and in-depth study of the process more basic and fundamental studies need to be done.

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