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A Comparative study of Sugarcane Bagasse gasification and Direct Combustion

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Abstract

Anaerobic digestion and gasification are two of the main ways to convert biomass into gaseous fuels. Both pathways generate a combustible gas: biogas and synthetic gas (syngas), respectively. Biomass gasification generates syngas, which is attractive for energy applications because of its H_2, CO, and CH_4 contents. Syngas composition varies by reactor operating conditions and can be tailored to specific applications. The two main syngas applications are power generation and fuel synthesis.

Gasification is almost as ancient as combustion, but it is less developed because commercial interest in it has not been as strong as in combustion. Thus the main aim of this paper to provide a comparison of Bagasse (Sugar mill waste) direct combustion and gasification for sugar mill power production. This study is focused on the modelling, simulation and performance analysis of Bagasse gasification processes using Aspen plus Simulation software.

Keywords: Life cycle analysis, gasification, syngas thermo Economic analysis of sugar Industry etc.

INTRODUCTION

Sugarcane is the highest yielding and most fecund crop in the world and having major byproducts of the sugar industry (Islam et al., 2010a). The sugar industry produces mainly four major types of wastes products: cane residue left in the field after harvesting, bagasse, press mud and spent wash. (Gupta et al., 2011).

Bagasse is the remainder left after cane crushing operation and is the fuel resource of that industry (Rasul et al, 1999). Pressmud is the compressed sugar industry waste produced from the filtration of the cane juice. It is a good source of fertilizer. (Gupta et al., 2011).

Bagasse is a lignocellulosic residue of the sugar industry, which consists of around 40–50% cellulose, 20–30% hemicellulose, 20–25% lignin and 1.5–3% ash or generally it can be say that it contains 50% fiber, 48% moisture and 2% sugar which couldn't be extracted (Chauhan et al., 2011). It has high energy content (Drummond and Drummond, 1996). It assumes an imperative part to satisfy the vitality prerequisite for creating nations like India, Brazil and so forth., where huge measure of sugarcane are delivered. After Brazil, India is second significant producer of sugarcane on the planet. In year 2011–2012 around 330.36 million metric tons of sugarcane was produced on 4.71 million hectares of land, with an average yield of 70.07 tons/ha (USDA Gain Report). Generally, one ton of raw sugar-cane produces around 100 kg of sugar, 270 kg of dry bagasse and 35 kg of molasses (Garcı`a-Pèrez et al., 2002a). For the most part, bagasse is utilized as a fuel hotspot for boiler in sugar plants. Be that as it may, this isn't completely utilized as a wellspring of vitality in sugar factories, since it makes the waste administration issue at process site. In addition, the direct combustion of bagasse in boilers has efficiency of only 26%, as well as the burning of bagasse in the boilers form airborne fly ash, which is responsible for major health hazard. [2-5]

Conversion of biomass into energy is undertaken using three main process technologies: Thermochemical, biochemical/biological and mechanical extraction (with esterification/ trans esterification) for biodiesel production, within thermochemical conversion four process options are available: combustion, pyrolysis, gasification and liquefaction. Bio-chemical conversion encompasses two process options: digestion (production of biogas, a mixture of mainly methane and carbon dioxide) and fermentation (production of ethanol). The figure 1 is explaining, the intermediate energy carriers and the final energy products to each type of thermo-chemical conversion.

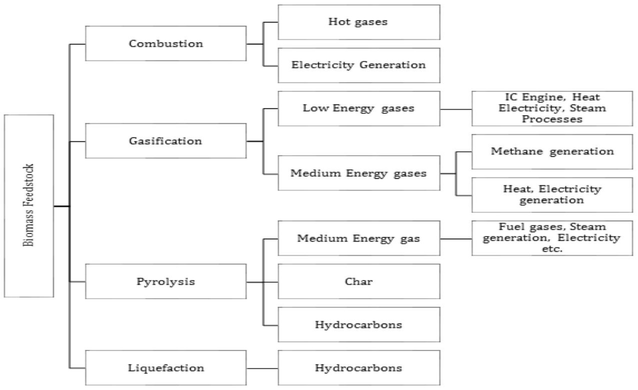


Figure 1: Thermochemical conversion of Biomass Feedstock [3]

There are numerous routes to convert the chemical energy in biomass into heat or electric power. Direct combustion releases heat that can be used in Stirling engines or Rankine steam power cycles. [5] Alternatively, thermal treatment with low-oxygen concentrations yields intermediate materials with varying energy properties. Carbonization and slow pyrolysis produce a charcoal material with high-carbon concentration. Biomass gasification results in a combustible gas. Fast pyrolysis generates mostly a liquid fuel.

Gasification is a thermal process characterized by an oxygen-deficient environment and temperatures above 750°C. In this environment, most carbonaceous material converts into a flammable gas consisting of CO, hydrogen (H_2), CH_4, CO_2, and smaller quantities of heavier hydrocarbons. Gasification may take place with either air or pure oxygen input. [6] Air gasification yields gas with high N_2 content commonly known as producer gas; gas from oxygen gasification is known as synthetic gas or syngas. Steam may also be introduced into the gasification environment as an oxygen carrier. [7] Gasification requires heat input that is delivered either internally from partial combustion of the feed input or via external heaters. Gasification performance depends on the ability to introduce oxygen and heat into its environment. Residual material from biomass gasification includes unconverted carbon (char) and ash. [9]

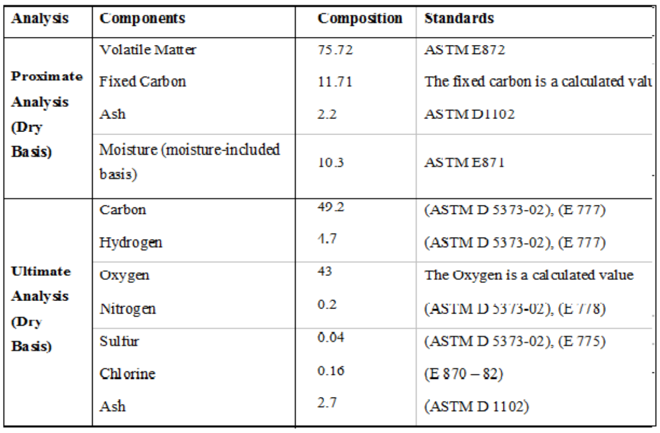
The gasification process involves four primary steps [10]: heating and drying, pyrolysis, gas–solid reactions, and gas–phase reactions. As in combustion, heating and drying evaporates all feed moisture before the particle temperature increases to gasification temperatures. Pyrolysis occurs once the thermal front penetrates the particle, resulting in the release of volatile gases via pores of increasing number and size. [13] The volatile gases include all gasification final products as well as tar. Tar consists of heavy and extremely viscous hydrocarbon compounds. After the pyrolysis step, these gases react with the particle surface, which is now primarily char, in a series of gas–solid endothermic and exothermic reactions that increase the yield of light gases. Finally, released gases continue to react in the gas–phase until they reach equilibrium conditions. [11] The heating and drying, and pyrolysis steps during gasification are similar to those of combustion. However, in the case of gasification, pyrolysis yields a larger quantity of tarry material because of insufficient oxygen and/or temperature to decompose the heavier compounds. Much of this tar elutriates from the particle and accumulates upon condensation. Where gasification differs from combustion is in the gas–solid and gas phase reactions. [12]

SUGARCANE BAGASSE GASIFICATION

Proximate and Ultimate Analysis

It is necessary to understand the composition of biomass before its application in energy conversion systems [1]. Proximate and ultimate analysis of biomass are usually used to describe the composition of biomass and different indicators are often used to quantify these components. Standards were followed for the analysis. [ASTM E871 - 82(2013); ASTM D1102 - 84(2013); ASTM E872 - 82(2013)] Samples of sugarcane bagasse were obtained from the Sugar Mill operated in Central India. The dried sugarcane bagasse was milled to size using a cryogenic grinder. The results of the proximate and ultimate analysis of sugarcane bagasse are presented in Table 2.

Table 2: Ultimate and Proximate Analysis of Sugarcane Bagasse

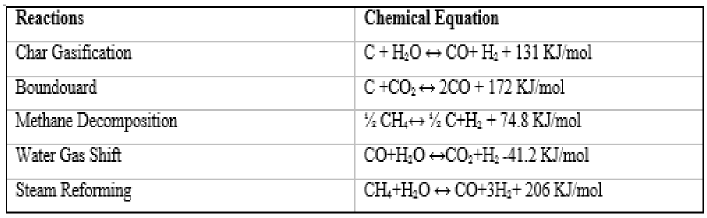


Analysis	Components	Composition	Standards
Proximate Analysis (Dry Basis)	Volatile Matter	75.72	ASTM E872
	Fixed Carbon	11.71	The fixed carbon is a calculated valu
	Ash	2.2	ASTM D1102
	Moisture (moisture-included basis)	10.3	ASTM E871
Ultimate Analysis (Dry Basis)	Carbon	49.2	(ASTM D 5373-02), (E 777)
	Hydrogen	4.7	(ASTM D 5373-02), (E 777)
	Oxygen	43	The Oxygen is a calculated value
	Nitrogen	0.2	(ASTM D 5373-02), (E 778)
	Sulfur	0.04	(ASTM D 5373-02), (E 775)
	Chlorine	0.16	(E 870 – 82)
	Ash	2.7	(ASTM D 1102)

Gasification Reactions

Table 3 shows the gasification reactions taking place during the gasification process in a gasifier

Table 3: Reactions taking place during the Gasification Process



Reactions	Chemical Equation
Char Gasification	$C + H_2O \leftrightarrow CO + H_2 + 131$ KJ/mol
Boundouard	$C + CO_2 \leftrightarrow 2CO + 172$ KJ/mol
Methane Decomposition	$\frac{1}{2} CH_4 \leftrightarrow \frac{1}{2} C + H_2 + 74.8$ KJ/mol
Water Gas Shift	$CO + H_2O \leftrightarrow CO_2 + H_2$ -41.2 KJ/mol
Steam Reforming	$CH_4 + H_2O \leftrightarrow CO + 3H_2 + 206$ KJ/mol

Assumptions

The following assumptions were considered in modeling the gasification process

- Process is steady state and isothermal;
- H_2, CO, CO_2, CH_4, H_2O, tar and char are considered the product of devolatization;
- Spherical and uniform size particle of average diameter throughout the process;
- Char contains carbon and ash;
- Pressure drops are neglected;

- Heat loss from the reactors and Tar formation are not considered during the process;
- Char is considered as impurity free as 100 % carbon and Ash comes from the biomass is considered as inert, it does not react with other components.

Model Simulation in a dual fluidized-bed gasifier using Aspen Plus

The objective of the model was to study the energy potential of Bagasse in a biomass fed fluidized bed gasifier. ASPEN PLUS software is used for the simulation analysis. In these models, the zero-dimensional and time independent reactions were considered. As thermodynamic equilibrium model is considered for the simulation than there is no need of reaction kinetics and the reactor hydrodynamics. [15]The stoichiometric and nonstoichiometric methods are used. Minimization of the Gibbs free energy method is considered. The nonstoichiometric strategy is specific appropriate for biomass gasification reproduction as the correct compound formulae of biomass is obscure and the gasification response instruments are exceptionally confounded. [16]

The diverse stages considered in ASPEN PLUS reproduction, so as to demonstrate the general gasification process, are decay of the encourage, unstable responses, singe gasification, and gas – strong Division.

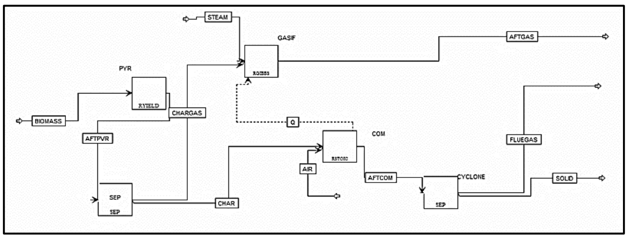
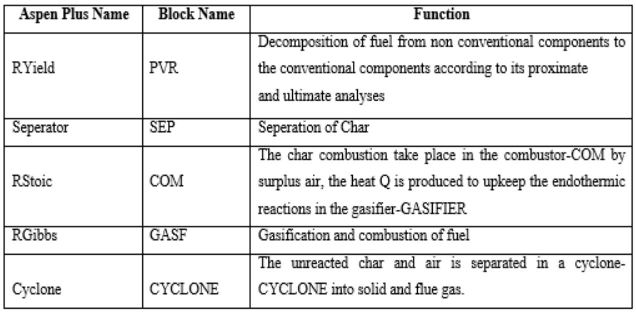


Figure 1: ASPEN PLUS Simulation Model used for the Study. [Ke Sun et al]

A Dual Fluidized Bed Gasifire is considered for the study for the gasification process of Bagasse Gasifire in Aspen Plus model simulator.The whole process is seperated in different blocks as shown in figure 1 and depictated in Table 4.

Table 4: Description of the unit operations of the Aspen blocks

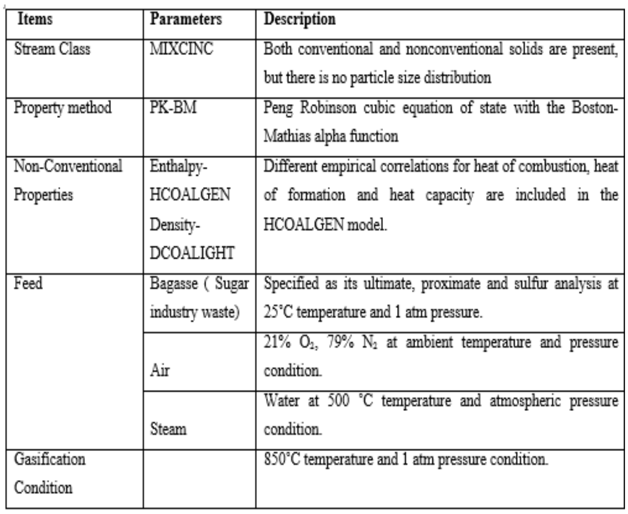


Aspen Plus Name	Block Name	Function
RYield	PVR	Decomposition of fuel from non conventional components to the conventional components according to its proximate and ultimate analyses
Seperator	SEP	Seperation of Char
RStoic	COM	The char combustion take place in the combustor-COM by surplus air, the heat Q is produced to upkeep the endothermic reactions in the gasifier-GASIFIER
RGibbs	GASF	Gasification and combustion of fuel
Cyclone	CYCLONE	The unreacted char and air is separated in a cyclone-CYCLONE into solid and flue gas.

For the purpose of analysis, the reaction zones are represented by a number of blocks. Fig. 1 shows the flow chart of biomass gasification simulation using Aspen Plus and Table 4 gives the brief descriptions of the unit operations of the blocks. The stream BIOMASS was specified as a nonconventional stream and it was defined in terms of proximate and elemental analyses. When BIOMASS was fed into the system, the first step was the devolatilization stage was performed in the block PYR in which the RYield reactor was used. In PYR, the feedstock was transformed from a non-conventional solid into volatiles and char. The volatiles consisted of carbon, hydrogen, oxygen, and nitrogen, and the char was converted into ash and carbon, based on the ultimate analysis. The yield of volatiles was equal to the volatile content in the fuel according to the proximate analysis. [18-19]

Moreover, the actual yield distributions in PYR were calculated by a calculator block which was controlled by FORTRAN statement in accordance with the component characteristics of the feedstock. [20] The combustion and gasification of biomass were simulated by a block called GASF in which the chemical equilibrium was determined by minimizing the Gibbs free energy.

Table 2: Operating condition and gasification parameters



Items	Parameters	Description
Stream Class	MIXCINC	Both conventional and nonconventional solids are present, but there is no particle size distribution
Property method	PK-BM	Peng Robinson cubic equation of state with the Boston-Mathias alpha function
Non-Conventional Properties	Enthalpy-HCOALGEN Density-DCOALIGHT	Different empirical correlations for heat of combustion, heat of formation and heat capacity are included in the HCOALGEN model.
Feed	Bagasse (Sugar industry waste)	Specified as its ultimate, proximate and sulfur analysis at 25°C temperature and 1 atm pressure.
	Air	21% O_2, 79% N_2 at ambient temperature and pressure condition.
	Steam	Water at 500 °C temperature and atmospheric pressure condition.
Gasification Condition		850°C temperature and 1 atm pressure condition.

Simulation Results

To find out the effect on syngas composition the four parameters are considered for the analysis i.e. Steam temperature, Air Temperature, Steam to Biomass ratio and Gasification Temperature. The sensitivity analysis has been carried out for the study to find out the optimized gasification condition with respect to heating value of the fuel.

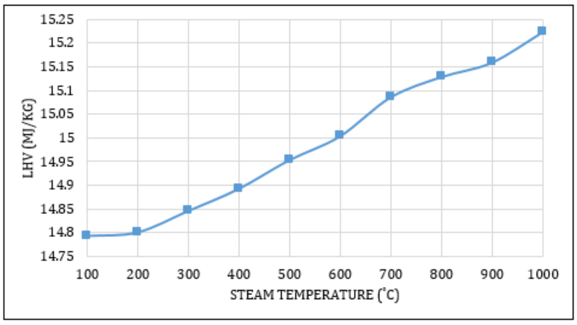


Figure 2: LHV corresponding to Steam Temperature

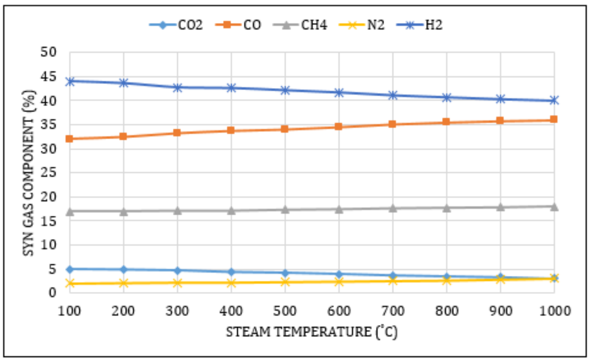


Figure 3: Syn Gas Composition corresponding to Steam Temperature

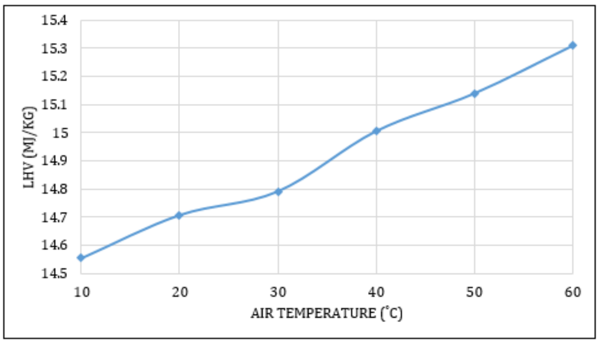


Figure 4: LHV corresponding to Air Temperature

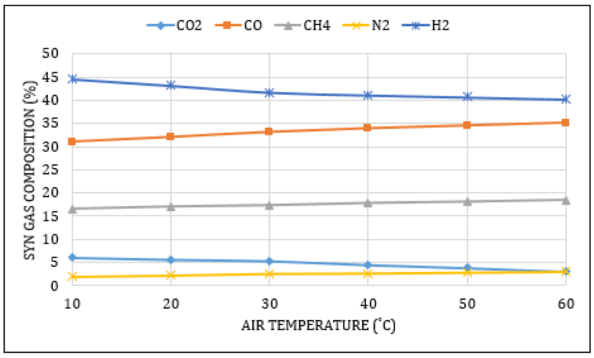


Figure 5: Syn Gas Composition corresponding to Air Temperature

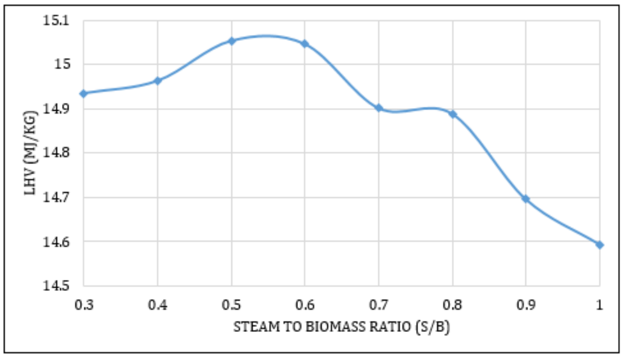


Figure 6: LHV corresponding to Steam to Biomass Ratio

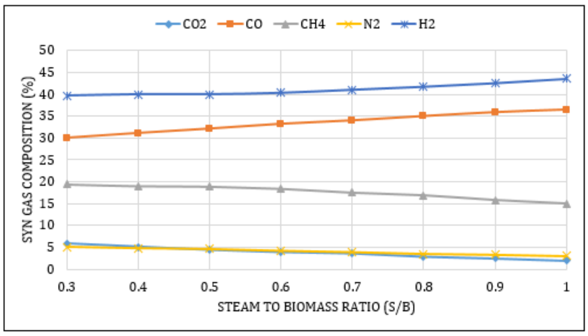


Figure 7: Syn Gas Composition corresponding to Steam to Biomass Ratio

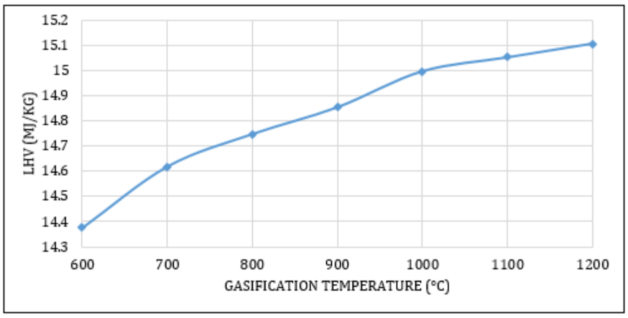


Figure 8: LHV corresponding to Gasification Temperature (˚C)

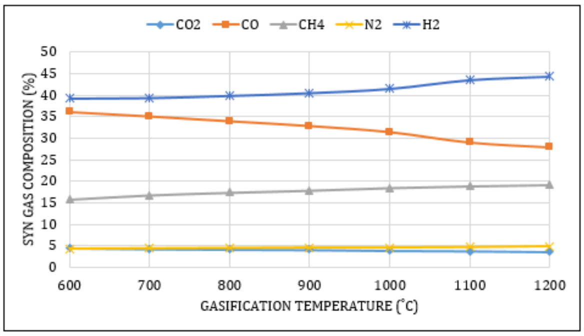
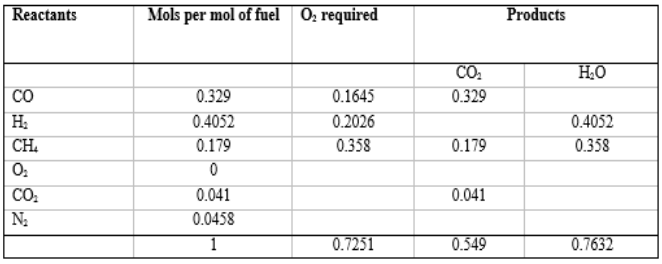


Figure 9: Syn Gas Composition corresponding to Gasification Temperature (˚C)

The Lower heating value is greatly influenced by the all four parameters i. e. Steam Temperature, Air Temperature, Steam to Biomass Ratio and Gasification Temperature. It is increases with increment of steam, air and gasification temperature but it is maximum with steam to biomass ratio about 0.5-0.6.

While considering the Syn Gas composition H_2 is the main constituent having the higher composition while N_2 and CO_2 shows the lower value. About the average of 14.8 to 14.9 MJ/kg of bagasse of lower heating value can be achieved by gasification process.

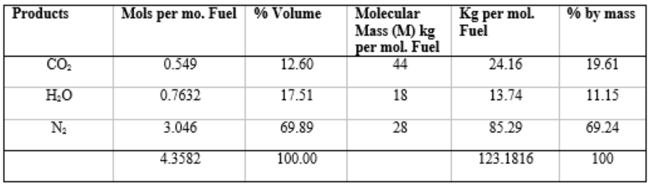
Table 4: The percentage composition of product of Syn Gas Combustion.



Reactants	Mols per mol of fuel	O_2 required	Products	
			CO_2	H_2O
CO	0.329	0.1645	0.329	
H_2	0.4052	0.2026		0.4052
CH_4	0.179	0.358	0.179	0.358
O_2	0			
CO_2	0.041		0.041	
N_2	0.0458			
	1	0.7251	0.549	0.7632

The analysis of product by mass and by volume is given in Table 5

Table 5: The percentage composition of dry flue gas after Syn Gas combustion



Products	Mols per mo. Fuel	% Volume	Molecular Mass (M) kg per mol. Fuel	Kg per mol. Fuel	% by mass
CO_2	0.549	12.60	44	24.16	19.61
H_2O	0.7632	17.51	18	13.74	11.15
N_2	3.046	69.89	28	85.29	69.24
	4.3582	100.00		123.1816	100

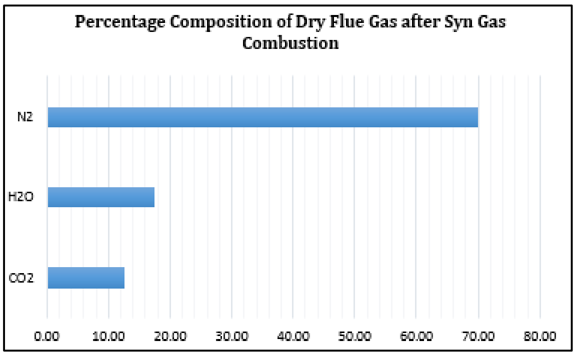


Figure 10: Percentage Composition of Dry Flue gas after Syn Gas Combustion

Table 4 and 5 shows the calculation for find out the percentage composition of dry flue gas produced after combustion of Syn Gas produced after gasification process. The Product after combustion are N_2, H_2O and CO_2. About 12.6 % (by volume) CO_2 is generated which can affect the environment.

DIRECT COMBUSTION OF BAGASSE IN BOILER

Combustion converts chemical energy directly into heat via rapid oxidation of the fuel. Primary products from combustion of carbonaceous products include carbon dioxide (CO_2) and water. Secondary products result from incomplete combustion or reactions with fuel-bound nitrogen (N2), sulfur, and other impurities. This part of paper is for calculation of amount of energy that can generated by direct combustion of Bagasse in Boiler for power production.

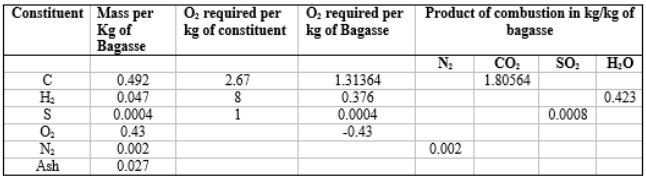
The calorific or heating value of fuel may be obtained approximately from a chemical analysis of a dried sample (Ultimate and proximate analysis)

The LHV of fuel is given by Dulong's Formulae

$$LHV = \frac{33800\,C + 144000\left(H - \frac{O}{8}\right) + 9270S - (9 \times 2442 \times H)}{100}\ KJ/Kg \qquad \ldots\ldots\ldots..(1)$$

With the calculation by using equation (1) the lower heating value obtained is about 15.66 MJ/Kg.

Table 6: The product of direct combustion in kg/kg of bagasse



Constituent	Mass per Kg of Bagasse	O_2 required per kg of constituent	O_2 required per kg of Bagasse	Product of combustion in kg/kg of bagasse			
				N_2	CO_2	SO_2	H_2O
C	0.492	2.67	1.31364		1.80564		
H_2	0.047	8	0.376				0.423
S	0.0004	1	0.0004			0.0008	
O_2	0.43		-0.43				
N_2	0.002			0.002			
Ash	0.027						

Total O_2 required per kg of bagasse combustion: 1.26004 kg

Mass of minimum air required = $\frac{1.26004 \times 100}{23}$ = 5.478 kg

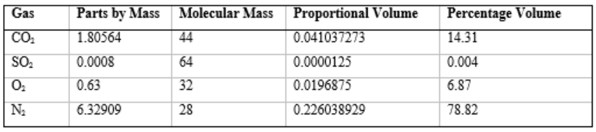
Nitrogen in actual air supply = 5.478 ×1.5×0.77 = 6.32709 kg

Total Nitrogen in Flue gas = 6.32709 + 0.002 = 6.32909 kg

Excess oxygen in flue gas = 5.478 ×0.5×0.23 = 0.63 kg

The percentage composition of dry flue gas is given in Table 5

Table 7: The percentage composition of dry flue gas after direct combustion



Gas	Parts by Mass	Molecular Mass	Proportional Volume	Percentage Volume
CO_2	1.80564	44	0.041037273	14.31
SO_2	0.0008	64	0.0000125	0.004
O_2	0.63	32	0.0196875	6.87
N_2	6.32909	28	0.226038929	78.82

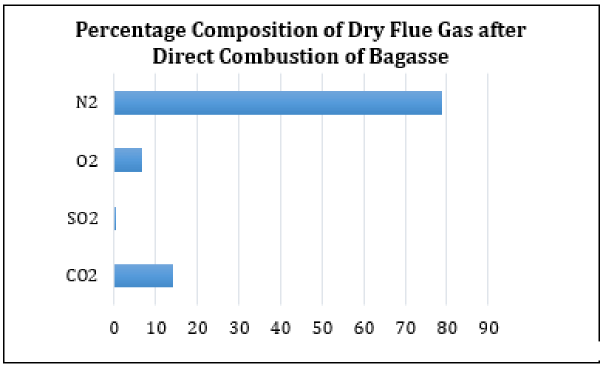


Figure 11: Percentage Composition of Dry Flue gas after Direct Combustion of Bagasse

Table 6 and 7 shows the calculation for find out the percentage composition of dry flue gas produced after direct combustion of Bagasse. The Product after combustion are N_2, O_2, SO_2 and CO_2. About 14.31 % (by volume) CO_2 is generated which is about 2 % more than the Syn Gas combustion. In addition SO_2 is also produced.

DISCUSSION

The effect of four parameters i.e. Steam temperature, Air Temperature, Steam to Biomass ratio and Gasification Temperature are also discussed for optimization of gasification process.

The environment is a major issue, and it has been a major driver for gasification for energy production. Low energy density and high moisture content are two key disadvantages of using biomass as a solid fuel. Regulations for making biomass economically viable are in place in India. For if gasification replaces direct combustion in a sugar plant, the plant earns credits for CO_2 reduction equivalent to what the direct combustion was emitting. These credits can be sold on the market for additional revenue.

Gasification of bagasse compare then direct combustion has an edge in certain situations. In combustion systems, sulfur in the fuel appears as SO_2, which is relatively difficult to remove from the flue gas without adding an external sorbent. In a gasification process 93 to 96% of the Sulfur appears as H_2S with the remaining as COS, which can easily extract Sulfur from H_2S by absorption. Even after gasification of Bagasse there are neglected amount of Sulfur produced as discussed earlier. Furthermore, in a gasification plant we can extract it as elemental Sulfur, thus adding a valuable by-product for the plant.

A direct combustion system oxidize the nitrogen in fuel and in air into NO, the acid rain precursor, or into N_2O, a greenhouse gas. Both are difficult to remove. In a gasification system, nitrogen appears as either N_2 or NH_3, which is removed relatively easily in the syngas-cleaning stage.

CONCLUSION

This work presents a comparative study regarding the modeling and simulation of Bagasse gasification processes with direct combustion in a boiler in a sugar plant. A Simulation is carried out for bagasse gasification in order to study the effect of primary parameters on the production of Syngas.

The complete study is carried out for comparison of both the alternatives i.e. either gasified Bagasse or combust it directly in the boiler for production of energy to run the plant. Almost same amount of energy can be generated by both the process but the environment is a major issue that forces the plant to adopt the gasification technology.

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