

# Fabrication and Performance Analysis of Downdraft Biomass Gasifier using Sugarcane Industry Waste

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**Abstract**— The process by which biomass can be converted to a producer gas by supplying less oxygen than actually required for complete combustion of the fuel is known as gasification. It is a thermo-chemical process and it is performed by a device known as gasifier. For executing the gasification experiments nowadays single throated gasifier uses sugarcane industry waste. In the present study we get to know that sugarcane briquettes are manufactured from residue of sugarcane which is used as a biomass material for the gasification process. Briquettes are formed by extruding the sugar which is extracted from the residue of sugarcane (bagasse) dried in the sun. Equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate and cold gas efficiency are certain grounds for estimating the performance of the biomass gasifier. The experiential results are compared with those reported in the literature.

**Key words:** Gasifier; sugarcane; biomass; producer gas; production rate

## I. INTRODUCTION

In present era, biomass is the most effective renewable energy sources and it is present in large quantity in many parts of the world [1,2]. Because of its large quantity and features like energy content and eco-friendly, it could play a vital role in fulfilling the energy demand of the world. It came into existence because of the effective technologies for its thermo-chemical conversion known as Biomass gasification. The reaction between a feed gas and a feed stock makes this conversion possible. We get a combustible gaseous product known as producer gas by the optimal energy conversion of the solid biomass which is the basic target of biomass gasification. The drying zone, pyrolysis zone, combustion zone and the reduction zone are the four major thermal conversion layers present in a gasifier. The biomass undergoes drying, pyrolysis, combustion and reduction, one after the other in a single throated downdraft biomass gasifier.

In the presence of limited quantity of air/oxygen by the process known as thermo chemical conversion we get a producer gas; a combustible fuel which is converted by down draft gasifier from biomass fuels. This producer gas can now be used for thermal applications like boilers, drying units, chemical heating, cooking, ceramic kilns etc. through gas combustion making use of non-woody fuels for gasification avoids deforestation. The moisture content in waste biomass is ranges from 50 to 90% [3]. In India, for energy generation there will be n problem as crop residues are present in abundant manner. Biomass fuels play a beneficial role in the domestic and industrial sectors in India as it is an economy based on agriculture. The transposition of formal fossil fuels with biomass for energy production

leads to net reduction in emission of greenhouse gases and in the replacement of non-renewable energy sources.

The power produced by coal and petroleum being non-renewable resources are going to exhaust because of their limitation in nature. Further, the rising process of petroleum products necessitates searching and developing renewable energy sources like solar, wind and biomass, which are abundantly present in India. Biomass is a pure and safe energy source. There are two processes through which energy can be obtained from biomass. They are bio-chemical reaction or thermo-chemical reaction. Both the process is practically viable. Therefore, the entire process of utilizing biomass to produce producer gas through thermo-chemical process is known as gasification. In other words, gasification is the conversion of any carbonaceous fuel to a gaseous product with a usable heating value. This definition does not contain combustion, because the product flue gas has no residual heating value. It does consider the technologies of pyrolysis, partial oxidation and hydrogenation. The most common process is partial oxidation, which produces the fuel producer gas consisting of carbon monoxide and hydrogen in varying ratios, by which the oxidants may be pure oxygen, air, and/or steam. Partial oxidation can be applied to solid, liquid, and gaseous.

In India, the gasifier technologies are supported by downdraft gasification and designed chiefly for woody biomass. Therefore, biomass in the form of briquette can be converted into a useful gaseous fuel to meet the growing demand of energy.

Zainal et al. [4] have executed experimental investigation of a downdraft biomass gasifier using wood chips and charcoal with a different comparable ratio. By using furniture wood waste, Sheth and Babu [5] have also performed experimental study on a downdraft biomass gasifier. Hazel nutshell has also been used in studying gasification by Dogru et al. [6] with varied equivalence ratios. Guo et al. [7] carried out experiments of BMF air-stream gasification by the gasifier, with energy for BMF gasification produced by partial combustion of BMF within the gasifier using a hypostoichiometric amount of air. The effects of ER (0.22-0.37) and S/B (0.15-0.59) and biomass particle size on the performances of BMF gasification and the gasification temperature were studied.

Cheng et al. [8] developed all thermal biomass gasification system using biomass micron fuel (BMF) as external heat source was and heat supplied to gasifier was generated from combustion of BMF. Biomass feedstock was gasified with steam and then tar in the produced gas was decomposed in a catalytic bed with NiO/ $\gamma$ -Al<sub>2</sub>O<sub>3</sub> catalyst. Producer gas was employed as a substitute for domestic fuel gas and overall energy analysis of a complete system was investigated.

The results of the performance analysis of a downdraft biomass gasifier are stated further in this present paper.

## II. MATERIALS AND METHODS

Drying, pyrolysis, combustion/oxidation and reduction are the four distinct reaction zones present in a single throated downdraft gasifier. Pyrolysed gas and moisture is released in pyrolysis and drying zone respectively and flows downward in a downdraft gasifier. There is continuous supply of air from the air nozzles when biomass is fed to the gasifier and oxidized in the zone. The temperature of the particles lying above the oxidation zone gets raised and gets pyrolysed when heat is released from the biomass combustion. After that the particles of biomass are separated into volatiles and charcoal in the pyrolysis zone flows downward in the packed pyrolysis bed. The tar of the pyrolysed gas mixture changes into non-condensable gases and water because of the high temperature of the combustion zone. Because of the combustion the cracked pyrolysed gases mixes with the carbon dioxide and the inert N<sub>2</sub> is present in the air. Now it undergoes endothermic reduction reaction when this gaseous mixture passes over the hot bed of charcoal. The total height of the gasifier is 1150 mm and the diameter at the pyrolysis zone is 250 mm and 200 mm is the diameter at the reduction zone. 110 mm is the height of the reduction zone and 100 mm is of the oxidation zone given. The photograph of the downdraft gasifier is shown in Fig.1 and the block diagram of gasifier is shown in Fig.2.



Fig. 1: Photograph of Downdraft Gasifier

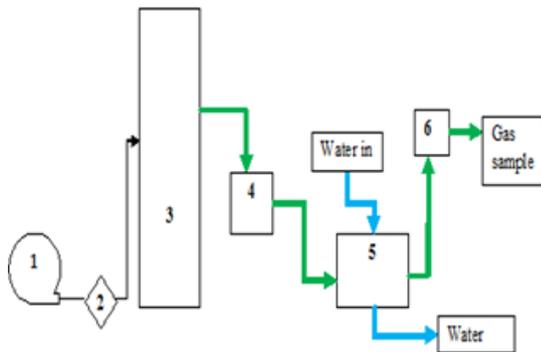


Fig. 2: Block Diagram of Gasifier Unit.

Sr. No.	Description	Sr. No.	Description
1.	Blower	4.	Gas filter
2.	Flow control valve	5.	Heat exchanger
3.	Gasifier	6.	Gas flow meter

Downdraft gasifier, gas filter, heat exchanger and a flow meter are present in the unit [9]. To initiate the process of gasification about 200 g of coal was fed into the gasifier and then it was ignited. For inducting the air blower was used and flow was maintained as per the requirement [10]. About 15 kg of sugarcane briquettes are fed into the hopper with the starting of coal ignition. For biomass to be burnt partially and generates producer gas, the blower supplied air in such a manner. Now this producer gas passed through the gap between the gasification zone and casing of a gasification zone. In this process, most of the bulky particles get stuck and tar gets creaked which is present in the producer gas. After this, producer gas is allowed to pass through the dry filter. Further, the temperature of the producer gas gets reduced when it was allowed to pass through a heat exchanger.

## III. PROCEDURE

### A. Preparation of biomass:

Briquettes machines are used for preparing briquette which works on piston-press technology where dried bagasse is punched or pushed into a die of 80 mm by reciprocating ram by high pressure. These briquettes are further splitted in the length of 60-100 mm manually. For the generation of producer gas these briquettes came into use in Fig.3.



Fig. 3: Sugarcane Briquette Sample Used for Experiment

### B. Analysis of biomass:

Proximate and ultimate analysis were used to determine the physical and chemical properties such as moisture content, overall length and diameter, bulk density, C, H, N and S of briquettes and are listed in Table 1 and 2 respectively. Proximate analysis is the determination of moisture content, volatile matter, ash content and fixed carbon in the biomass sample whereas ultimate analysis is the determination of volumetric percentage of total carbon, hydrogen, nitrogen, oxygen and sulphur percentages.

Length (mm)	Diameter (mm)	Bulk density (kg/m <sup>3</sup> )
50	80	1100

Table 1: Physical Properties of Biomass.

Proximate analysis (% by weight on dry basis)			
Fixed Carbon (FC)	Volatile matter (VM)	Ash	
10.26	85.78	3.96	
Ultimate analysis (% by volume on dry basis)			
Carbon	Hydrogen	Nitrogen	Sulphur
45.45	5.26	0.23	0.05

Table 2: Chemical Properties of Biomass

C. Determination of HHV of biomass:

Empirical formula is used for calculating the HHV of biomass given by Eq.1 reported in the literature [11].

$$HHV(MJ/kg) = 0.356FC + 0.1559VM - 0.0078ASH = 16.97 MJ/kg \quad (1)$$

D. Flow measurement:

Digital anemometer (Model AM4201) is used to measure the flow of air supplied to the combustion chamber of gasifier and producer gas flow rate at the exit.

$$\text{Flow rate} = \text{Area} \times \text{velocity} \quad (2)$$

E. Temperature measurement:

To measure the temperature distribution inside the oxidation zone of the gasifier K-type thermocouples were used. The samples of gas were collected at a temperature range of 600 to 900 °C.

IV. RESULT AND DISCUSSION

A. Biomass Gasification:

Table 3 shows all the details of the range of parameter varied in the present experimental analysis. Biomass consumption rate varies from 4.61 to 5.55 kg/h for an air flow rate varying from 3.921 to 5.016 m<sup>3</sup>/h respectively. Combined effect of the air flow rate, rate of biomass supply and duration of the sum is clearly characterized by an equivalence ratio. From Eq. 3, we can calculate equivalence ratio for each run. For ideal or theoretical gasification, the equivalence ratio should be in the range (0.19-0.43) given by Zainal et al. [4]. For each run, there is calculation of equivalence ratio. The equivalence ratio was found in the range (0.26-0.33), for gasifier which is within the range for ideal and theoretical gasification. A/F ratio for  $\phi = 1$  was calculated 5.141 kg/kg of fuel. Table 3 provides the values of equivalence ratio and details of biomass experimental run.

$$ER = \frac{\text{flow rate of air supply} \times \text{duration of run}}{\text{mass input of biomass} \times \frac{A}{F} \text{ ratio for } \phi = 1} \quad (3)$$

B. Performance evaluation of biomass gasifier

Each producer gas compositions have mentioned in Table 4.

Run	Fuel input (kg)	AFR (Nm <sup>3</sup> /h)	Time (h)	FCR (kg/h)	PGFR (Nm <sup>3</sup> /h)	ER
1.	15	3.921	3.25	4.61	5.92	0.29
2.	15	4.560	2.7	5.55	6.384	0.28
3.	15	4.195	2.75	5.45	6.385	0.26
4.	15	4.469	3	5.00	6.840	0.30
5.	15	4.742	2.85	5.26	7.114	0.31
6.	15	5.016	2.95	5.08	7.387	0.33

Table 3: Biomass Experimental Run Details

Run	ER	CO <sub>2</sub>	CO	H <sub>2</sub>	CH <sub>4</sub>	C <sub>n</sub> H <sub>m</sub>	N <sub>2</sub>
1.	0.29	12.62	24.16	17.83	3.05	1.92	40.42
2.	0.28	12.55	21.77	21.12	3.21	1.32	40.03
3.	0.26	15.63	18.26	17.15	3.86	2.32	42.78
4.	0.30	18.16	19.01	24.80	2.58	1.33	34.12
5.	0.31	17.62	18.92	21.98	3.21	2.04	36.83
6.	0.33	16.16	17.22	20.13	2.17	2.37	41.95

Table 4: Producer Gas Compositions for Each Experimental Runs.

C. Composition of producer gas:

Non-permeable gas sampling bags with 1 litre capacity were used to collect sample gases at temperature ranging between 600 to 900 °C using syringes and TCD gas chromatograph was used to analyze it. Effect of equivalence ratio on composition of producer gas is shown in Fig.4. from figure we can say that with an increase in ER up to a value of ER= 0.29, the molar fraction of nitrogen and carbon dioxide decreases, and with an increase in values of ER, the molar fraction of nitrogen and carbon dioxide increases. There is showing an increasing and decreasing trend in the fraction of carbon monoxide and hydrogen which is absolutely opposite to that of nitrogen and carbon dioxide. Higher air flow rate for a specific biomass consumption rate is represented by a higher value of ER which makes the production of CO<sub>2</sub> is more amount in combustion zone and also more amount of nitrogen entry followed with air flow.

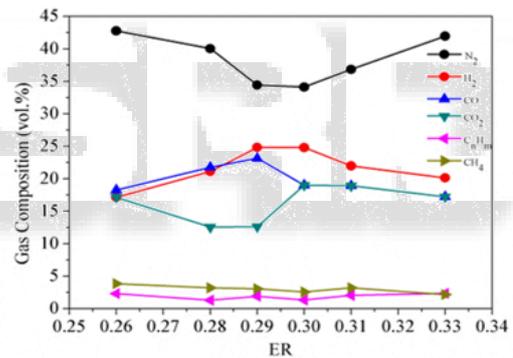


Fig 4: Effect of Equivalence Ratio on Producer Gas Compositions

The rate of reactions happening in the reduction zone and the length of the reduction zone is a big factor for the conversions of CO<sub>2</sub> to CO. The decreased CO<sub>2</sub> gets changes into carbon monoxide and hydrogen in combustion zone when there is increase in ER from 0.26 to 0.29 and because of that the fraction of CO<sub>2</sub> and H<sub>2</sub> increases with ER=0.29 and fraction of CO<sub>2</sub> and N<sub>2</sub> decreases. Equivalence ratio higher than 0.29 shows that CO<sub>2</sub> produced in combustion zone is higher to that of the conversion capacity of reduction bed and it is marked with the increase in CO<sub>2</sub> and decrease in CO and H<sub>2</sub> fractions. Due to more amount of N<sub>2</sub> entry along with air flow, there is increase in N<sub>2</sub> fractions for the ER value varying between 0.29 and 0.33.

D. LHV of producer gas

Concentration of each individual gas and its corresponding heating value is needed for the calculation of lower heating value of producer gas. Eq. 3 is used for calculating LHV of fuel gas [9].

$$LHV(kJ/Nm^3) = 4.2(30CO + 25.7H_2 + 85.4CH_4 + 151.3C_nH_m) \quad (4)$$

where CO, H<sub>2</sub>, CH<sub>4</sub> are the molar percentages of components of the product gas, and C<sub>n</sub>H<sub>m</sub> represents the sum of the molar percentages of C<sub>2</sub>H<sub>2</sub>, C<sub>2</sub>H<sub>4</sub> and C<sub>2</sub>H<sub>6</sub>. Fig.5 shows the effect of equivalence ratio on LHV of producer gas.

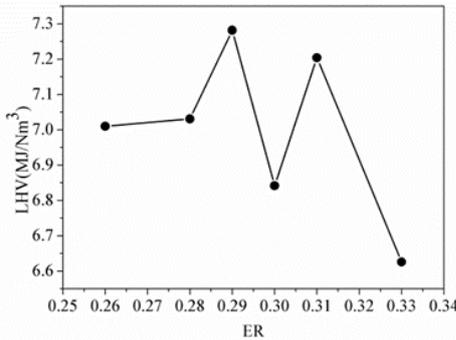


Fig. 5: Effect of Equivalence Ratio on LHV of The Producer Gas

To get higher calorific value carbon monoxide and hydrogen are needed which are also the major components of producer gas. The calorific value is least (6.626 MJ/Nm<sup>3</sup>) at an equivalence ratio of 0.33. By little increasing the equivalence ratio to 0.29, the calorific value goes to a maximum of 7.282 MJ/Nm<sup>3</sup> due to increases percentage of CO and H<sub>2</sub> and then follows the decreasing trend. Again the calorific value decreases to a high speed with just an increase in equivalence ratio from 0.29. There is a same trend of increasing and decreasing in the calorific value variation as it was in the carbon monoxide variation with equivalence ratio, as given in Fig.4. For most power applications the gas must have energy content greater than 4 MJ/Nm<sup>3</sup> [12].

#### E. Gas production rate:

The producer gas production rate per unit weight of biomass is given by Eq. 5.

$$\text{Gas production rate} = \frac{\text{Fuel consumption rate (kg/h)}}{\text{Producer gas flow rate (m}^3\text{/h)}} \quad (5)$$

From Eq.5, we can get the producer gas production rate per unit weight of biomass. The rate of production of producer gas increases with an increase in the equivalence ratio, from 0.26 to 0.33, is given in Fig.6. It shows the effect of equivalence ratio on the producer gas production rate per unit weight of biomass (m<sup>3</sup>/kg). Fig. 7 shows that the calorific value of the producer gas deteriorates due to higher amounts of carbon dioxide, while the production rates of producer gas continue to increase after a certain value of the equivalence ratio.

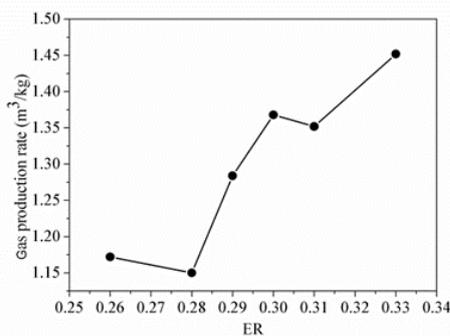


Fig. 6: Effect of Equivalence Ratio on the Producer Gas Production

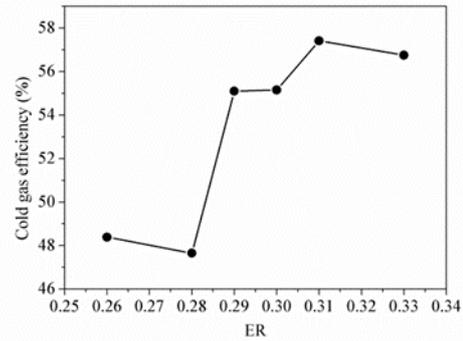


Fig. 7: Effect of Equivalence Ratio on Cold Gas Efficiency

#### F. Cold gas efficiency

The ratio of energy of the producer gas per kg of biomass to the HHV of the biomass material is known as Cold gas efficiency.

$$\text{Cold gas efficiency} = \frac{\text{LHV of gas} \times \text{gas producer rate}}{\text{HHV of biomass}} \quad (6)$$

Fig. 7 shows the variation of cold gas efficiency with equivalence ratio. Calorific value and the amount of producer gas released at a constant HHV of biomass are needed or responsible for cold gas efficiency. At an equivalence ratio of 0.28, there is lowest value of (47.65%) cold gas efficiency while the maximum value is 57.41% at an equivalence ratio of 0.31. higher the values of equivalence ratio, lower is the effect of ER on cold gas efficiency, where the cold gas efficiency increase from 47.65% to 57.41% on changing the equivalence ratio from 0.26 to 0.33. Table 5 shows the calculated values of lower heating values, gas production rate and cold gas efficiency of producer gas.

ER	LHV (MJ/Nm <sup>3</sup> )	Gas production rate (Nm <sup>3</sup> /kg)	Cold gas efficiency (%)
0.26	7.01	1.172	48.39
0.28	7.031	1.15	47.65
0.29	7.282	1.284	55.10
0.3	6.842	1.368	55.15
0.31	7.204	1.352	57.41
0.33	6.626	1.452	56.75

Table 5: Calculated Values of LHV, Gas Production Rate and Cold Gas Efficiency

#### V. CONCLUSION

Biomass is one of the nearly all utilized environmentally friendly sources around the world. Its significance for your power and substance industrial sectors is actually anticipated to boost make it possible for your changeover by fossil energizes to environmentally friendly, in order to meet different local climate aims and to generate an additional sustainable community eventually [13]. The best performance of the downdraft biomass gasifier is achieved at equivalence ratio of 0.29, which is optimum and the variation of the calorific value, gas production rate and cold gas efficiency with equivalence ratio shows a peak value (0.29). We can get the maximum calorific value of producer gas at ER of 0.29 at 7.82 MJ/Nm<sup>3</sup>. We found in other researcher papers that with increase in ER from 0.26 to 0.33 the gas production per unit weight of the fuel gets increased.

We also came to know that with an increase in ER from 0.26 to 0.33 the cold gas efficiency also increases and it is maximum at ER of 0.33 at 57.41% which is also greater than other published literature listed in Table 7. From the above studies we came to know that the quality of gas is suitable for power generation as lower heating value of producer gas is found to be 7.282 MJ/Nm<sup>3</sup> which is greater than 4MJ/Nm<sup>3</sup> actual required for power generation [12]. Dogru *et al.* [4] used Hazel nutshell as a biomass for the process of gasification has come from the above studies. Equivalence ratio varies from 0.262-0.314 and between 1.44 and 1.47 Nm<sup>3</sup>/kg of air to fuel ratios at the values of 4.06 and 4.48 kg/h of wet feed rate is optimum operation of the gasifier which also produces the producer gas having a 5MJ/m<sup>3</sup> calorific value. Wood chips and charcoal were used for performing experimental study on a downdraft gasifier with a varied equivalence ratio from 0.259 to 0.46 by likewise, Zainal *et al.* [4]. Calorific value increases with equivalence ratio and reaches a peak value of 0.388 for which the calorific value is reported to be 5.62 MJ/Nm<sup>3</sup> is found from the above study. The wood waste generated during making of furniture in the carpentry section of the institute's workshop were used by Sheth and Babu [5] for performing experimental study on a downdraft biomass gasifier and their equivalence ratio varied from 0.1673 to 0.354. When compared other researchers the wide range of equivalence ratio (0.26-0.33), the singularity of this work is distinguished from earlier studies. Choosing the operating conditions of the downdraft biomass gasifier becomes easy and simple from the results of the present study. The present study is compared with the published literature. We get to know that in present study highest calorific value is obtained, i.e. 7.282 MJ/kg.

Research group	Biomass used	Optimum ER	Gas production rate (Nm <sup>3</sup> /kg)	LHV (MJ/Nm <sup>3</sup> )	Cold gas efficiency (%)
Sheth and Babu (2009)	Furniture waste of Dalbergia sisoo	0.205	1.62	6.34	56.87
Zainal <i>et al.</i> (2002)	Furniture wood + charcoal	0.388	1.08	5.62	33.72
Dogru <i>et al.</i> (2002)	Hazel nutshell	0.276	2.73	5.15	80.91
Present study	Sugarcane briquettes	0.29	1.368	7.282	57.41

Table 6: Comparison with Published Literature

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