

# Performance Evaluation of a down draft Gasifier using Agricultural Waste Biomass

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**ABSTRACT:** In today's global fuel usage scenario the need for fossil fuel is very high, and is depleting. The pollutions caused by the fossil fuel are as high as the demand. The threat of energy depletion and greenhouse gas effect prove that fossil fuels are no longer sustainable for wide use. As a result of environmental and policy considerations as well as dwindling oil resources, there is increasing interest in using renewable energy sources. An alternative energy resources that is sustainable for use, environmental friendly as well as regionally available has been laid a challenge for researchers. The use of biomass to generate heat power, fuels and chemicals is crucial in achieving energy independence and increasing our use of renewable energy sources. The availability of bio-residues from various agricultural activities has been estimated to be around 300 million tons per year in India. A considerable portion of this quantity is getting wasted. Gasification promises to play a major role in large part because its products can make use of existing infrastructure and equipment associated with fossil fuel use. In the present work, a biomass gasifier of downdraft type is designed and tested with the feedstock of corn plantation wastes blended with suitable agents to provide continuous burning. This research investigated gasification and corresponding thermal conversion efficiency of corn biomass fuel. As a result, it was found that the thermal conversion efficiency was around 65% with a heating value of fuel to be 4.2MJ/m<sup>3</sup>. It was observed that the biomass having light weight was better for feeding in the gasification system. Much fewer bridging and clogging issues occurred than pure wood.

**KEYWORDS:** Biomass, Corn cobs, Gasification, down draft gasifier, Heating value, Thermal conversion efficiency.

## I. INTRODUCTION

Fazil Hassan P et al [1] proposed sustainable energy resources for waste disposal technique as Gasification. With the high coconut production, the production potential per ton of waste is calculated to be 4408 kWh/ton and Energy from waste is calculated to be 2858 MW. After the experimentation they found that the composition of combustible species in the producer gas from coir waste is 6 to 20% less due to the low carbon content and heating value. All the biomasses have higher conversion efficiency when the equivalence ratio is close to 0.2. Mohamed Ali et al [2] carried out an experiment using a pilot scale throated downdraft gasifier to study the conversion of almond shell into a combustible gas. After a transient period of three hours, a pseudo steady state regime was established in the reactor. The gas generated from the almond shell contained about 23% syngas (hydrogen and carbon monoxide) with a LHV of about 4MJ/m<sup>3</sup>, which could be considered as low to medium value. K. R. Dhurai et al (2012) [3] studied about the feasibility of a biomass gasifier for burner system with coconut shell as fuel. The activated carbon is a waste product in this process, which is highly in demand for water purification system. The operating temperature of the gasifier they constructed is in the range value of 900°C to 1000°C. It was also suggested to develop biomass gasifier for using in any

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thermal heating application. V. Wilk et al (2011) [4] investigated about the successful conversion of biomass wastes, such as waste wood, bark and reed. Waste wood and bark have been gasified successfully and first results of these experiments were promoting. The reed is an interesting feedstock for gasification plants too, but agricultural circumstances require an infrastructure for its use.

H Roesch et al (2010) [5] has produced a model predicting the composition and heating value of producer gas made from a small scale (20-250 kWh), down-draft gasifier. Eight biomass feed stocks were gasified and analysed for this study (alfalfa, algae, field grass, hemp, miscanthus, peanut shells, pine, and municipal solid waste). The experimental data was used to develop an adjusted model of the equilibrium model which showed significant improvement in estimating the heating values and composition of the syngas. Significant improvement was shown by the adjusted model over the equilibrium model. Anil K. Rajvanshi et al (1986) [6] published a detailed report on the gasification of the biomass and expressed his thoughts about the effective utilization of the waste materials. It is often advantageous to convert the solid waste into more readily usable fuel form like producer gas. They have listed few property values of various gasification feedstocks along with their disadvantages. Finally they concluded that only some knowledge has been gained on the part of gasification and further more research must be done in order to obtain the highest potential of the process and various feed stocks. E. M. H. Khater et al [7] discussed the behaviour of a downdraft gasifier of 30 cm diameter and 140 cm height using rice hulls as a fuel. Feeding rates of 1.3-5.1 kg/h and airflow rates of 2-4.44 m<sup>3</sup>/h, which corresponds to 26- 55 % of the Stoichiometric amount needed for complete combustion, were used. The maximum temperature attained was found to lie between 570°C and 820°C. At an air to fuel ratio of 55 % of that of Stoichiometric case, the maximum yield of combustible constituents in the producer gas was attained. The obtained gas had a composition including 13.67% CO, 5.13% H<sub>2</sub> and 2.42% CH<sub>4</sub>. Valentino M. Tiangco et al [8] have explained the experimental determination of the optimum specific gasification rate for static bed rice hull gas producers which was conducted for reactor diameters of 16-30 cm. All experiments were performed with reactors under suction from a throttled centrifugal blower. Cold-gas efficiency was observed to increase as specific gasification rate increased from 100 to 200 kg/h m<sup>2</sup>, and then begin to decline as gasification rate was increased further. The decline in efficiency at higher gasification rates was due to decreasing gas heating value which could not be compensated by increasing gas flow.

## II. DESIGN OF EXPERIMENTAL SETUP

A scaled biomass gasifier for a micro scale application which is to produce mechanical power of about 2kW is designed. The design of the reactor is empirical and is implied from the charts based on the previous literatures [9]. In the present work, downdraft gasifier using corn cobs as feedstock is used for producer gas generation, because it produces less tar compared to updraft gasifier. Main components of downdraft gasifier and their design are described below.

### 2.1. Hopper

The purpose of a hopper is to store the biomass for continuous feed to reaction chamber. It is mounted above the reactor of gasifier. The height of the hopper is decided on the basis of the feedstock which it will be required to hold within the period of operation. The period of operation is taken to be 2 hours. Therefore, given the biomass consumption rate as 3.74 kg/h, the total biomass consumption estimated to be consumed in 2 hours is 8 kg (app).

$$P_g = \frac{P_m}{\eta_e}$$

The fuel storage hopper is made up of 2mm thick mild steel. The diameter and height of fuel hopper is chosen to be 420mm and 500mm respectively. However the actual height of the hopper required is almost less than half of the value being chosen. Round shaped hopper has been chosen to prevent the problem of biomass being stuck. The bulk density of corn stoves is between 300 and 550 kg/m<sup>3</sup> depending on the moisture content. Assuming the value of the bulk density is taken to be 300kg/m<sup>3</sup>,

$$P_T = \frac{P_g}{\eta_T}$$
$$\text{Minimum hopper height} = \frac{\text{Feedstock volume}}{\text{Cross sectional area}}$$

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$$= \frac{0.02493}{0.1385} = 180\text{mm (Required)}$$

## 2.2. Gasification Zone

This is the main component of gasifier. The main reaction of gasification like oxidation, reduction and distillation takes place in this zone. It is in the shape of vertical convergent and divergent nozzle (from top to bottom direction) and made by 2mm thick mild steel. Upper diameter of divergent section is 420mm and the lower diameter is of 210mm with 150mm height. A cylinder of 210mm diameter and 150mm height is welded at the top of divergent section. 5 holes of 21mm diameter are drilled in the inner side of circular pipe in inclined downward direction as shown. Air is inducted in the reactor through the holes in round shaped pipe with the help of external source like blower. A convergent section with 210mm upper diameter and 350mm lower diameter with 80mm height is welded at the top of the round circular pipe. The whole convergent and divergent gasification zone is welded at the top of these two coupled round strips.

### 2.2.1. Power consumption of the gasifier:

An engine with an efficiency of about 25% is considered for the present work, thermal power in the gas can be estimated to be,

$$\begin{aligned} BCG &= \frac{P_T}{HV} \\ &= (2 / 0.25) &&= 8 \text{ kW} \end{aligned}$$

The thermal efficiency of the gasifier is taken to be around 70%, then the thermal power consumption

$$= (8 / 0.70) = 11.43\text{kW}$$

### 2.2.2. Biomass Consumption of the Gasifier

It is defined as the thermal power consumption to the heating value of the biomass. Here the feedstock is the corn stoves and corn cobs are used as the biomass with a heating value of about 11,000 kJ/kg.

$$\begin{aligned} &= (11.43 / 11000) &&= 0.001039 \text{ kg/s} \\ &= 0.001039 \times 3600 = 3.74 \text{ kg/hr} \end{aligned}$$

### 2.2.3. Throat diameter

It is defined as the amount of producer gas reduced to normal conditions divided by the surface area of the throat at the smallest circumference. It is usually expressed in  $\text{m}^3 / (\text{cm}^2 \text{ h})$ .

$$\begin{aligned} Bg &= 2.3 \times Bs \\ Bs &= Bg / 2.3 \end{aligned}$$

where, the value of the hearth load falls in the range of  $0.3 \leq Bg \leq 1$ . Take  $Bg = 0.3$  (least value)

$$\begin{aligned} Bs &= \frac{BCG}{A_t} \\ (0.3 / 2.3) &= (3.74 / A_t) \\ A_t &= 0.03486 \text{ m}^2 \end{aligned}$$

The throat diameter can be determined from the total area value required for the throat section in the design.

$$\begin{aligned} A_t &= (\pi / 4) \times D_t^2 \\ D_t &= 0.2107 \text{ m} \approx 210 \text{ mm.} \end{aligned}$$

After comparison of the design characteristics of a number of gasifiers, the throat inclination should be round 45 to 60°. A throat angle of 60° is used.

### 2.2.4. Diameter of the hearth

It is a function of throat diameter and can be estimated as,

$$\begin{aligned} \frac{Dh}{Dt} &= 2 \\ D_h = 2 \times D_t &= 2 \times 210 = 420 \text{ mm} \end{aligned}$$

2.2.5. Height of the nozzle throat is a function of throat diameter and can be estimated as,

$$\begin{aligned} \frac{hnt}{Dt} &= 0.7 \\ h_{nt} = 0.7 \times D_t &= 0.7 \times 210 = 147.49 \text{ mm} \\ &= 150 \text{ mm (app)} \end{aligned}$$

Total area of the nozzle is given as a function of throat diameter and is estimated,

$$\frac{Ant}{At} = 0.05$$

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$$A_m = 0.05 \times 0.03486 = 0.001743 \text{ m}^2 \quad (\text{for 5 no. of nozzles})$$

$$= 0.0003486 \text{ m}^2 \quad (\text{for 1 nozzle})$$

And the diameter of the nozzle is determined from the above value of area as ( $D_n$ ) 21mm, with a chosen inclination of  $15^\circ$ . The nozzles are placed at the tip ring diameter of 367mm. This is estimated as a function of throat diameter.

$$\frac{D_n}{D_t} = 1.75$$

$$D_n = 367\text{mm}$$

### 2.3. Gas outlet

A flat round strip of 250mm internal diameter, 380mm external diameter and 2mm thick with 8 equally spaced hole of 80mm diameter is designed to cover the gap between gasification zone and outer casing of gasification. A hole of 20mm diameter is made in this round flat strip at a radius of 270mm from the same centre. This hole is made to provide outlet to producer gas. Another strip of 380mm external diameter, 330mm internal diameter and 3mm thick with 8 equally spaced hole of 80mm diameter is welded over the other one so as to fix it with bottom cylinder with the help of nut and bolts. The air blast velocity ( $V_b$ ) can be estimated by equating the volumetric flow rate of the producer gas through the throat to the volumetric flow rate of air through the nozzle.

$$Q = A \times V_b$$

The volumetric flow rate of producer gas through the throat is estimated using this flow rate as the flow of air through the nozzle,

$$Q = (2.3 \times 3.74) / (3600) = 0.001743 \times V_b$$

$$V_b = 1.3737 \text{ m/s}$$

### 2.4. Air Inlet and Outlet

The general range for air inlet velocity is 6 m/s to 10 m/s. The dimensions for the air inlet can be obtained using the continuity equation.

$$Q = A_i \times V_i$$

$$(8.620 / 3600) = A_i \times 6$$

$$A_i = 3.99 \times 10^{-4} \text{ m}^2$$

And the air inlet diameter is determined from the above value as 21 mm (app).

## III. EXPERIMENTAL RESULTS

The down draft gasifier suitable to the power demand which uses agricultural corn cobs as feed stock was fabricated as per the dimensions determined from the above calculations and is shown in figure 1. Wood blocks & coconut choir were used to initiate the gasification process, some pieces were placed inside the gasifier and it had been ignited. Air was inducted with the help of a variable speed blower; the flow of air was regulated as per the requirement. When wood reached its red hot level, the crushed corn cobs were poured into the hopper. Upon operation it generated a producer gas suitable to be used for later combustion. This gas has to be analysed for the suitability of the fuel in the lab, by estimating its composition & calculating the heating value.

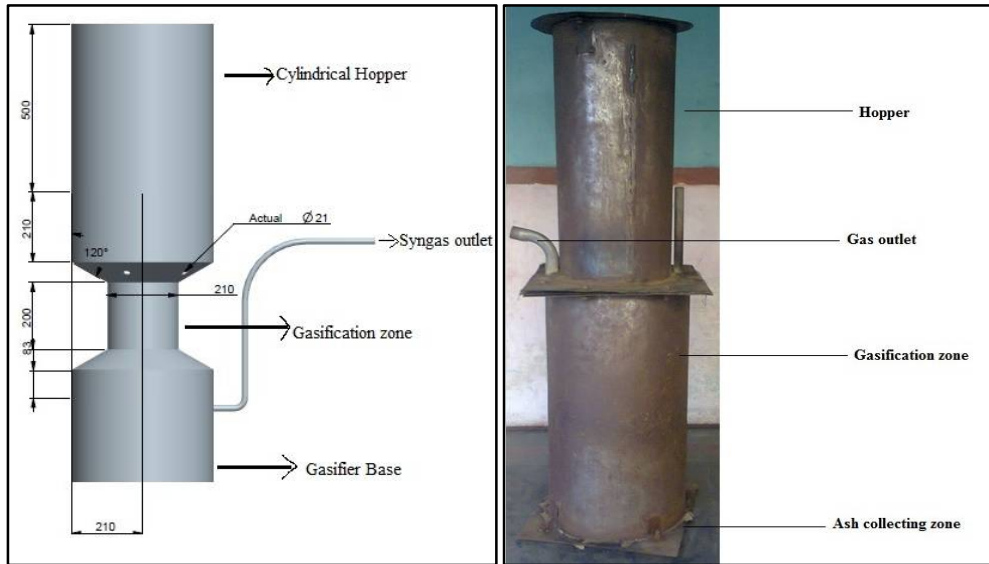


Figure 1 - Schematic layout & actual model of the proposed gasifier model

The modeled view along with dimensional details of the proposed gasifier is shown in the figure 1. The actual fabricated view is shown as well. In the prepared experimental set up, the outer cover is paced in order to reduce the unwanted air current flowing into the equipment. The outer cover is air tight. The gasifier is operated and the ashes are removed only after the entire processing is completed.



Figure 2 - AVL 444 DiGas Analyzer

The producer gas sample was analyzed by a 5 gas analyzer shown in figure 2, (Make: VL India, Model: 444) fitted with a DiGas sampler, confirming to RAI certification: ARA/TA (4G-RV)/AVL/DiGas 444/0910 – 12. The principle for measuring the CO, HC, CO<sub>2</sub> was the NDIR, and for the NO and O<sub>2</sub>, it was electrochemical. The Co, CO<sub>2</sub>, O<sub>2</sub> were measured in volume percentage, while the total unburned hydrocarbon HC was measured in ppm (vol.) of n-hexane equivalent, and the NO content was measured in ppm (vol.) during each run of the operation.

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Table 1 - Detailed specification of the gas analyser

Measured quantity	Measuring range	Accuracy
CO	0-10%	< 0.6% vol: ±0.03% vol ≥ 0.6% vol: ± 5% of initial value
CO <sub>2</sub>	0-20%	< 10% vol: ±0.05% vol ≥ 10% vol: ± 5% of vol
HC	0-20000 ppm vol	< 200 ppm vol: ± 10 ppm vol ≥ 200 ppm vol: ± 5% of initial value
O <sub>2</sub>	0-22% vol	< 2% vol: ±0.01% vol ≥ 2% vol: ± 5% of vol
NO	0-5000 ppm vol	< 500 ppm vol: ± 50 ppm vol ≥ 500 ppm vol: ± 10% of initial value
Voltage	11-22 V DC	
Power consumption	≈25W	
Warm up time	≈7 min	
Operating temperature	5-45 <sup>0</sup> C	
Dimensions (W X D X H)	270x320x85	
Weight	4.5 kg (net weight) without accessories.	

The detailed specification of this gas analyzer model is given in the table 1. The measuring range of each gas component is specified for the equipment used in the research. Also the accuracy level for each measurement is mentioned. The physical dimension and its electrical demand details for smooth operating are given below. The gasifier is operated and three trials of readings were taken at different time period in order to identify the better performance of the gasifier. During all the experimentation the producer gas composition is measured by using the DiGas analyzer.

The composition of the various components present in the gas is listed in the table 2. From the table, it can be seen that the hydrogen concentration is higher during the first and third trial of the experimentation. This may be the effect of atmospheric or environmental conditions prevailed during the gasification process. Similarly the methane content also shows an increased value in relation to the hydrogen.

Table 2 – Composition of producer gas from experiments

S. No	Component		Volume Fraction (%) of gas from Corn cobs		
			Trial 1	Trial 2	Trial 3
1	Hydrogen	H <sub>2</sub>	12.28	10.89	12.98
2	Oxygen	O <sub>2</sub>	0.77	0.71	0.77
3	Carbon dioxide	CO <sub>2</sub>	09.49	8.47	10.10
4	Carbon monoxide	CO	15.16	16.16	14.49
5	Hydrocarbon	CH <sub>4</sub>	1.91	1.32	2.17
6	Nitrogen	N <sub>2</sub>	60.39	62.45	59.49

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## IV. RESULTS & DISCUSSION

### 4.1. Heating Value of the producer gas

The amount of heat energy produced by combustion of unit mass or volume of fuel is called its calorific value (CV). For the solid and liquid fuels, unit mass are considered and the unit of CV will be kJ/kg. For gaseous fuel, unit volume is considered under NTP and the unit of CV will be in MJ/m<sup>3</sup>. Most of the fuels contain hydrogen. During combustion process H<sub>2</sub> combines with O<sub>2</sub> and forms steam (water vapour). If this water vapour is condensed at constant temperature, large amount of heat is released. On account of this, two types of calorific values are defined.

The higher calorific value is defined as the total heat liberated by combustion of unit mass of fuel when the water vapour formed by combustion is completely condensed at constant temperature releasing its latent heats. The lower calorific value of fuel is defined as the net heat liberated by combustion of unit mass of fuel when the water vapour formed by combustion exists completely in vapour phase.

### 4.2. Calculation of high heating value

With the results of producer-gas composition, the HHV of gaseous fuel produced from the fuel can be calculated. Only H<sub>2</sub>, CO and CH<sub>4</sub> in the gas have combustion value. The HHV of producer-gas is calculated only based on the concentration of H<sub>2</sub>%, CO% and CH<sub>4</sub>%. Energy value of H<sub>2</sub> = 12.745 MJ/m<sup>3</sup>; CO = 12.633 MJ/m<sup>3</sup>; CH<sub>4</sub> = 39.819 MJ/m<sup>3</sup> [12]. The heating value of the producer gas is calculated using the following equation,

$$HHV_{\text{Producer gas}} = ((HV \text{ of } H_2 \times \% \text{ of } H_2) + (HV \text{ of } CO \times \% \text{ of } CO) + (HV \text{ of } CH_4 \times \% \text{ of } CH_4)) / 100 \quad \text{eqn(1)}$$

### 4.3. Calculation of density of producer gas (ρ)

The volume fraction of each constituents of the gas is known from the readings obtained from the gas analyser. Using the gas mixture method, the density of the producer gas is equivalent to the sum of density of individual gases present in the mixture. Thus the density can be estimated by using the following equation.

$$\rho_{\text{gas}} = (\rho_{H_2} \times y_{H_2}) + (\rho_{CO_2} \times y_{CO_2}) + (\rho_{CO} \times y_{CO}) + (\rho_{N_2} \times y_{N_2}) + (\rho_{CH_4} \times y_{CH_4}) + (\rho_{O_2} \times y_{O_2}) \quad \text{eqn(2)}$$

### 4.4. Calculation of Gasification Efficiency (η)

The gasification efficiency or thermal conversion efficiency depends on the type of biomass used, its particle size, the ER value and the reactor's design. The gasification efficiency is usually determined on the lower heating value basis, can be calculated in two different ways and is defined as the hot or cold efficiency. The hot efficiency is calculated as the ratio of the total energy in the producer gas (sensible and chemical) and the chemical energy in the feedstock (the heating value). The cold efficiency calculations account only for the heating value of the producer gas and neglect the value of the sensible heat.

In order to compare the gasification efficiencies, the majority of authors consider the cold efficiency value in order to avoid the uncertainty related to the calculations of the sensible heat of producer gas discharged from the reactor since the high temperature of this gas is very often not the objective in the gasification process. Typical values of the cold efficiency for biomass gasification in a downdraft reactor are between 50 - 80%.

Equivalence ratio (ER) is the ratio of actual air-fuel ratio to the Stoichiometric air-fuel ratio. Usually, the ER range for gasification lies between 0.19-0.43 theoretically, but 0.25 is identified to be the optimum. ER is directly related to the pressure, and thus affects the performance of the gasification process. The ER is taken as 0.2 approximately. That is, the amount needed for an ideal gasification is approximately 20% of what is needed for a complete combustion. Therefore, the amount of producer-gas produced from gasifying 1kg fuel can be calculated.

$$\text{Gasifier efficiency} = \frac{HHV_{\text{gas}} \times V_{\text{gas}}}{HHV_{\text{biomass}} \times M} \quad \text{eqn(3)}$$

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Where

$$\begin{aligned}
 M_{gas} &= M_{air} + M_{feedstock} \\
 ER &= 0.2 \\
 M_{air} &= ER \times HHV_{gas} \\
 V_{gas} &= M_{gas} / \rho_{gas}
 \end{aligned}$$

The property values of three trial runs were calculated following the above procedure and are listed in table 3. The table contains High heating value, density, mass of air required, mass of gas produced, volume of the producer gas and the gasification efficiency. The higher efficiency is achieved at the third trial as the hydrogen and methane content produced in that particular experiment is high compared with the others.

Table 3 - Comparison of calculated property values of the producer gas

Trial	High Heating Value (MJ/m <sup>3</sup> )	Density of gas (kg/m <sup>3</sup> )	Mass of air (kg)	Mass of gas (kg)	Volume of gas (m <sup>3</sup> )	Gasification efficiency (%)
1	4.2408	1.0890	0.8482	1.8482	1.6971	65.43
2	3.955	1.0999	0.791	1.791	1.62836	58.55
3	4.3489	1.0845	0.8698	1.8698	1.72414	68.16

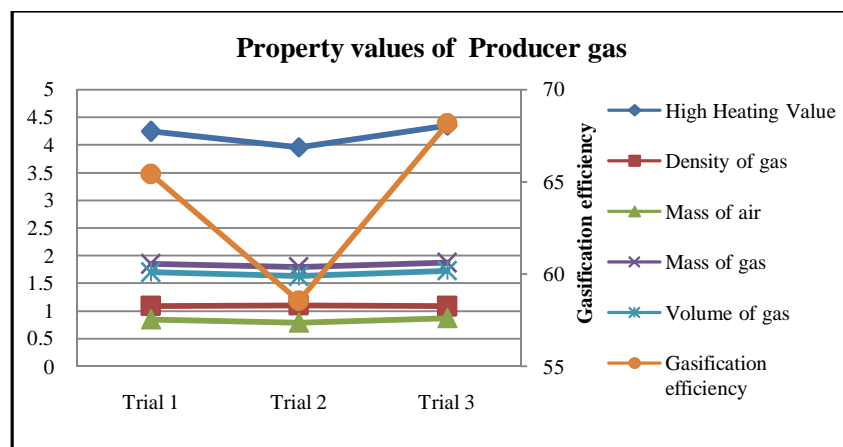


Figure 3 - Comparison of property values of the producer gas during all trials

The various property values tabulated are shown graphically in the figure 3. The x-axis represents various trials and the y-axis represents the range of multiple properties. A secondary y-axis has been introduced to represent the gasification efficiency as its range is higher than the rest of the properties. Thus the designed gasifier operates at an average efficiency of 65% for the corn feedstock used. The average heating value of the producer gas formed from the corn cobs was found as 4.1814 MJ/m<sup>3</sup>. This value lies close to the heating value of wood.

## V. CONCLUSION

Global problems that are associated with the use of fossil fuels are strong incentives for a transition to renewable energy and materials. While sun, wind, water, geothermal resources and biomass are renewable sources for energy, biomass is the only renewable source for (transportation) fuels and materials. In this research work, a downdraft gasifier was designed and developed. The identification of appropriate fuel sources for biomass gasification facilities in a particular region is significant from both energy and economic efficiency perspective. This research investigated gasification and corresponding thermal conversion efficiency of corn biomass fuel. As a result, it was found that the thermal conversion efficiency was around 65% with a heating value of fuel to be 4.2 MJ/m<sup>3</sup>. It was observed that the



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biomass having light weight was better for feeding in the gasification system. Much fewer bridging and clogging issues occurred than pure wood. It is concluded that the chosen gasifier system is one of the best suited methods for utilizing the biomass to the full potential and reducing the cost involved in the fuelling and waste disposal at the same time.

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