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Performance of Open Core Gasifier with Briquette of different Crop Residues

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Abstract

The open core gasifier was designed for loose agricultural residues like soybean briquette, pigeon pea briquette and mix briquette of (soybean + pigeon pea). In this experiment using air in gasification as supplementation mode there result found better as air suction mode there was less tar and gas quality. The gasifier performance was evaluated in terms of fuel consumption rate, calorific value of producer gas and gasification efficiency. Optimum value of specific gasification rate for gasification of briquette of mix biomass in open core gasifier reactor is 252 kg/h- m^2. The lower heating value of producer gas under the optimum operating conditions is about 4.10 - 4.57 (MJ/m^3).The pigeon pea briquette has show the maximum temperature in oxidation zone was 1397 ˚C.which as higher the ash fusion temperature increase. The flame Temperature of soybean briquette, pigeon pea briquette, and mix briquette is 624, 634, and 619 ˚C respectively is attained at the burner. Gasification efficiency of soybean briquette, pigeon pea briquette and mix briquette of (soybean + pigeon pea). 56%, 51%, 53%, respectively. The gas produced from the briquette could used to replace the coal and wood.

Keywords: Open core gasifier, Gasification efficiency, Pyrolysis, Biomass, Crop residues briquette.

Introduction

Biomass is one of the most promising renewable energy sources. Biomass is in various forms and it is abundant in many areas of the world. Due to its abundance, its energy content, and the low emissions to the atmosphere, it could play a major role in meeting world energy demand. Biomass gasification is one of the effective technologies for its thermo chemical conversion. The conversion is achieved by reactions between a feed gas and a feedstock. The primary goal of biomass gasification is optimal energy conversion of the solid biomass into a combustible gaseous product known as producer gas. In a gasifier, there are three main thermal conversion layers: the combustion zone, the pyrolysis zone and the reduction zone. In a downdraft fixed bed, the biomass undergoes combustion,pyrolysis and gasification, one after the other.

down draft gasifier, which can convert biomass fuels into a combustible fuel gas called producer gas, by a process involving thermo chemical conversion with a limited quantity of air (SPRERI 1995). The producer gas can be used for thermal applications like boilers, drying units, chemical heating, cooking, ceramic kilns etc. through combustion of the gas in a burner. General need to use non-woody fuels for gasification is to avoid deforestation. Crop residues are most abundantly produced in India. As per the estimates, about 249.78Mt of surplus biomass was available in 2001 from all sources like agro-processing residues, grasslands, forests, roadsides, agro-forestry and degraded habitats. Their availability is likely to increase to about 384.51 Mt by 2015 (Pathak et al. 2004) Substantial quantity of this surplus biomass could be utilized for energy generation. Generally, crop residues are seasonal so there must be a unique system that can work on multi-fuels. Biomass fuels continue to play an important role in the domestic and industrial sectors in India, as it is an agricultural-based economy. The substitution of conventional fossil fuels with biomass for energy production results both in a net reduction of greenhouse gases emission and in the replacement of non-renewable energy sources (Dasappa et al.2004).

The power produced from non-renewable sources like coal and petroleum are not going to last for a long period due to their exhaustive nature. Further, the high price of petroleum products compels

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to search and develop renewable energy sources like solar, wind and biomass, which are available in abundance in India. Nuclear energy production being a highly costly process, deter its use in daily activities. The installations of dams for hydel energy are not always possible. Tidal energy is a much localized energy source. Biomass is a clean and safe energy source. The energy from biomass may be obtained either through biochemical reactions (biomethanation) or thermo- chemical reaction. Both the processes are practically feasible. The process for utilizing biomass to produce producer gas through thermo- chemical process is called gasification. The term gasification, in its widest sense, covers the conversion of any carbonaceous fuel to a gaseous product with a useable heating value. This definition excludes combustion, because the product flue gas has no residual heating value. It does include the technologies of pyrolysis, partial oxidation, and hydrogenation. The dominant process is partial oxidation, which produces the fuel producer gas (otherwise known as synthesis gas or syngas) consisting of carbon monoxide and hydrogen in varying ratios, whereby the oxidant may be pure oxygen, air, and/or steam. Partial oxidation can be applied to solid, liquid, and gaseous.

However, at present, generating energy from biomass is rather expensive due to technological limits related to lower conversion efficiency (Caputo et al.2005). As per the estimates, about 249.78 Mt of surplus biomass was in India in 2001 from all sources including agro-processing residues, grassland, forests, roadside, agro forestry and degraded habitats. Their availability is likely to increase to about 384.51 Mt by 2015 (Pathak et al.2004). Biomass has high but variable moisture content and is made up of carbon, hydrogen, oxygen, nitrogen, sulphur and inorganic elements. In comparison to fossil fuels, biomass contains much less carbon, more oxygen and a lower heating value in the range of 12–16 MJ kg−1 (Pathak 2005). Biomass gasification is the thermo chemical conversion of solid biomass into combustible gas mixtures. Gasification is carried out in a reactor which converts biomass into combustible gases by controlled-temperature oxidation with ambient air and subsequent reduction of the products of combustion with the char (Sasidharan et al. 1995; Fassji 2006). The gas produced by gasifier can be utilized to produce process heat for thermal application. To disseminate the gasification technology in actual uses, Ministry of New and Renewable Energy (MNRE) has taken initiative to develop research group within India for technology and man power development, as a consequence Indian premier institute like Indian Institute of Science, Bangalore (IISc) (Dasappa et al 2004). The Energy and Resource Institute (TERI), Sardar Patel Renewable Energy Research Institute (SPRERI) have been involved in the field of biomass combustion and gasification technology. More than 350 TERI gasifier systems have been successfully installed in the field throughout India with a cumulative installed capacity of over 13 MWth (Palit and Mande 2007). The gasifier technologies available in India are based on downdraft gasification and designed primarily for woody biomass (Chawla and Kishore 1993). In order to meet energy demand in some extent. In which biomass in the form of briquettes can be converted into a useful gaseous fuel. A briquette based open core gasifier system was developed at Central Institute of Agricultural Engineering at Bhopal. Selected to evaluate with briquettes produced from different crop residues suitability of gasifier using agricultural residue based fuel such as soybean briquette, pigeon pea briquette and mix briquette of (soybean + pigeon pea).

Material And Methods

Properties of crop-residue briquette

Physical and Chemical properties of crop residues briquette are obviously the most vital parameter which decides the consistent and efficient operation of the gasifier. Following properties will be determined.

Physical properties of crop residues briquette

The physical properties such as moisture content, overall length and diameter, bulk density, tumbling resistance, and resistance to water penetration of crop residue briquettes were determined. The briquettes selected for determine physical and chemical properties of three type of briquette i.e. soybean briquette, pigeon pea briquette, Mix briquette of (soybean + pigeon pea).

Chemical Parameter of crop residues briquette

Chemical properties are very important to determine the fuel quality**.** Study of proximate analysis of biomass was carried out for determination of volatile matter, fixed carbon, ash content, Ash fusion temperature and Calorific value, in the biomass briquette of soybean briquette, pigeon pea briquette, Mix briquette of (soybean + pigeon pea).The ASTM D 3172, ASTM D 3177, ASTM D 3175, ASTM D 1875, ASTM D 3286 (ASTM 1983) was used for the study.

Gasifier

Gasifier is a chemical reactor where various complex physical changes and chemical reactions take place. Any variety of biomass like wood, agricultural wastes, roots of various crops, maize cobs, etc. can be gasified in the gasifier. Biomass gets

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dried, devolatilized, oxidized and reduced, as it flows through the gasifier. The exit producer gas has a heating value of about 4000-5500 kJ/m^3.

System description of Open core Gasifier

The open core down draft gasifier developed at CIAE Bhopal, is shown in (fig. 1).The system consists of a Gasifier reactor shell, manual rotating type grate, ash pit, electric blower and burner. A brief description of different units is given in following sections.

Table 1 Technical specification of open core gasifier

Type	Downdraft, throat less, closed top
Capacity	biomass 75 kg
Diameter	30 cm internal diameter
Material used	Mild steel
Ash removal unit	Manual- rotating type
Biomass consumption rate	16.7 kg/h

Component of open core gasifier

Gasifier reactor

The gasifier developed is open core downdraft gasifier.It consists of a well insulated co-cylindrical reactor whose inner diameter is 30 cm. with rotating type stainless steel grate .the grate was fabricated from stainless steel (310) and was mounted with a shaft in the ash pit. The water sealing is provided at the bottom of the gasifier with the help of a trough. Ash is removed manually whose handle is provided at the bottom of the trough. The ash fall into the trough containing water, this was fabricated from a mild steel of 3 mm thickness.

Fig. 1. Photograph of open core down draft gasifier design at energy enclave CIAE, Bhopal

Blower

The blower used in the supplementation mode. The air distribution unit that positive air supply through the air tuyers. Circular pipe connected to air tuyers around the reactor, air supply by blower is made TawdePollutech India Pvt. Ltd, having a capacity of 1000 m^3/h. The air supply is regulated with the help of a valve during the operation. The rated power of blower is 746 W and rated speed is 2880 rpm.

Burner

A burner of 20 cm diameter has been designed at C.I.A.E. Bhopal, for the study whose flame shows a successful operation.

Raw materials

Raw material of crop residues i.e. soybean and pigeon pea stalk available at energy and power division CIAE Bhopal, Briquettes were prepared using a briquetting machine based on piston-press technology in which soybean residues and pigeon pea residues are punched or pushed into a die of 60 mm by a reciprocating ram by high pressure. These briquettes are broken in the length of 6-10 cm manually and are fed to the Gasifier from the top lid which is later closed during the operation.

Experimental procedure

The fuel was loaded up to top of the gasifier. The blower was started, air supply for gasification through the air tuyere with connected to circular pipe by electric blower. By holding a flame at the air tuyere one by one ignited the fuel bed, after some time, the producer gas obtained becomes combustible

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and was ignited at the burner. Finally, the biomass feeding port and air tuyere of the gasifier were closed.

Performance measurements were taken after the stable operation of the system was observed, the grate was operated at regular interval to remove ash accumulated on the grate. Chromel– Alumel type K thermocouples and a digital multichannel temperature indicator were used to measure temperature.

Performance of Gasifier measured different Parameter

The gasifier was operated according to the procedure prescribed by the ministry of non-conventional sources of energy (MNES) . Proximate analysis of fuel was carried out before the test by using the method suggested by (ASTM 1983). A bomb calorimeter (Advance Research Instruments Company) was used to measure the gross heating values of biomass fuel Initially 10 kg charcoal pieces (10–50mm long) were loaded up to the air nozzle level, then fuel was loaded up to the top of the gasifier. Firstly, the wood feeding port and air tuyeres of the gasifier were closed. The blower was started, drawing air for gasification through supplementation mode through the air tuyeres. By holding a flame at the air tuyeres one by one ignited the fuel bed, which supplied air in the flame to ignite the bed. After some time, the producer gas obtained becomes combustible and was ignited at the burner. At the end of the test, first the air control valve was closed and thereafter the blower was turned off. A globe valve was provided with the blower to control gas flow rate. A stand with ladder was provided with the system for facilitating the manual fuel feeding and other operations. Proximate analysis was done to analyze the feedstock.

Fixed carbon (FC) was determined using material balance ASTM. Analysis of the different feedstock is given in (table 2) Performance measurements were taken after the stable operation of the system was observed, i.e., constant raw gas temperature. Generally, this took 1.5–2 h from ignition.

Fuel consumption rate

This is the amount of briquette fuel used in operating the Gasifier divided by the operating time. It was measured by recharging hopper after one hour of Continuous Testing and measured by using electronic balances this is computed using the formula,

$$\mathrm{FCR(kg/h)} = \frac{\text{weight of briquette fuel used(kg)}}{\text{operating time (hr)}}$$

Specific gasification rate

Specific gasification rate (kg/h-m^2) was calculated using the weight of crop residue briquettefor a run, net operating period and the cross sectional Area of the reactor using the following relation.

$$\text{Specific gasification rate} = \frac{\text{Weight of feed material (kg/h)}}{\text{Crossectional area of the reactor (m}^2\text{)}}$$

Specific gas production rate

Specific gas production rate (m^3/h-m^2) is the rate of gas production at standard temperature and pressure per unit cross-sectional area of the gasifier.

$$\mathrm{SGPR} = \frac{\text{Rate of gas production } (m^3/h)}{\text{Crossectional area of the gasifier (m}^2\text{)}}$$

Gasification Efficiency

Gasification efficiency is the percentage energy of briquette fuel converted in to cold producer gas (free from tar). The following expression was used to compute the gasification efficiency (A. Jain 2006)

$$\text{Gasification efficiency } (\eta) = \frac{\text{Heating value of gas X Volume flow of gas}}{\text{Heating value of gasifier fuel X Gasifier solid fuel consumption}} \times 100$$

Temperature profile

Temperature. The temperature at reactor of gasifier was measured by using chromel alumel with Data logger .“K” type and R type thermocouple having diameter 8mm, 6mm and length 1meter respectively. With connected data taker used to recording temperature at 1 min interval, Thermocouples were inserted through the probe, for measure the temperature profile at 120 mm and 220 mm above the grate.

Flame temperature

The flame temperature was measured by holding the chromel alumel “J” type thermocouple with digital temperature indicator, temperature attained at burner of different heights in the flame.

Quantity of gas flow

$$Q_g = A \text{ X } V_g$$

Where,

A = Area of pipe through which gas flow, m^2

V_g = Velocity of gas flow, m/s.

Gas analysis

The volumetric percentage of all the composition of producer gas like CO, H_2, CH_4 etc. living the gasifier was collected in the sampler and analyzed using gas chromatograph (Plate 4.11). Microprocessor based Gas Chromatography (Model 2010) fitted with columns and valves was used for

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analysis of producer gas. The equipment was manufactured by M/s Chromatography and Instruments Company, Gujarat, India has computer controlled Data workstation based with digital and analog output for detector. It was designed for High temperature analysis up to 500ºC and fitted with a forced air auto cooling system.Producer gas was analyzed by Gas chromatography for carbon monoxide, hydrogen, methane, Carbone dioxide, and nitrogen.

Calorific value of producer gas

Gas analysis data obtained on gas chromatography for each run was used to compute the lower heating value of producer gas. The lower heating value of different constituent at standard temperature and pressure used in calculations is

Carbone monoxide - 13.1 MJ/m^3
Hydrogen - 11.2 MJ/m^3
Methane - 37.1 MJ/m^3
Propane - 46.35 MJ/kg
Butane - 45.75 MJ/kg

The following expression was used for calculating the lower heating value of producer gas:

$$CV_G = \Sigma X_1 H_1$$

Where,

CV_G = Calorific value of gas, MJ/m^3
X_1= Volume fraction of gas constituent
H_1 = lower heating value of the gas constituent, MJ/m^3

Result And Discussion

The system was operated at an average air flow rate for all type fuel. The variations in the temperature of different zones of the gasifier with respect to time were noted for all fuels and it was observed that temperatures were almost constant for all three types of briquettes. It was also observed that there was large variation in the temperatures at 250mm above the grate resulting in very poor quality of producer gas. To maintain uniform fuel flow poking/ramming at a regular interval (30 min) was required. This may be due to improper flow of fuel because of its low bulk density. The result was encouraging and variation in temperatures and gas flow. It shows that flow of material in the gasifier can be improved by the addition of dense biomass. The measured values of the some physical and chemical properties are shown in (Table 2) The gasifier performance with different fuels show that in (Table 3) for certain biomass.

Table 2 Physical and chemical properties of different crop residues briquette

Characteristics	Soybean	Pigeon pea	Mix biomass (Soybean + Pigeon pea)
Diameter (mm)	60	30	60
Length (mm)	60-85	65-90	65-80
Bulk density (kgm_3	618	675	598
Moisture content (% (wb))	8.75	9.12	8.9
Volatile matter (% (db))	76.96	77.07	79.14
Fixed carbon (%)	16.46	15.88	13.52
Ash content (%)	6.58	7.05	7.34
Calorific value (MJ/kg)	18.92	17.19	17.50

Start of Gasifier

Evaluation of the gasifier system was carried out to study the feasibility of soybean briquette, pigeon pea briquette, and briquettes of mix biomass were used as feedstock for open core gasifier. The gasifier was operated with positive air supply through air nozzle with the help of a starting blower; ignite fuel bed with ignition torch. The starting time of gasifier with different type of briquette are given in (table 5.8). The results indicate that there is no significant effect in starting time with change in briquette material. It took around 12–16 min to generate flammable gas, which was burnt using a self-aerated type burner.The performance parameters included the fuel consumption rates, specific gasification rates, temperature profile within gasifier, temperature of raw gas at the gasifier exit, flame temperature at burner, gas composition, were measured. To maintain uniform fuel flow rotating of grate at a regular interval (30 min) was required. Higher the temperature inside the reactor helps in better tar cracking. **Performance of Gasifier with Briquette of Crop Residues**

The physical and chemical analysis was carried out to analyze the feed stocks suitable for gasification. The parameters studied included bulk density, moisture content, volatile matter, ash content, Fixed carbon, ash fusion temperature was determined using material balance. Analysis of the feedstock of different crop residues briquette showed (Table 2 and 3).

Table 3 Performance gasifier with briquette of crop residues

Sample	Fuel consumption rate (kg/h)	Specific gasification rate, (kg/h- m^2)	Specific gasification production rate (m^3/h-m^2)	Gasification efficiency (%)
Soybean briquette	16.7	238	40.1	56
Pigeon pea briquette	14.1	203	34.3	51
Mix briquette	17.7	252	45.3	53

Performance of gasifier with soybean briquette

The gasifier was evaluated with briquettes prepared from soybean straw. the biomass

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consumption of soybean briquette was observed that 16.7 kg/h. The specific gasification rate, with soybean briquette was 238 kg/h-m^2. The specific gasification production rate were observed to be 40.1 m^3/h-m^2.The temperature of profile of gasifier of oxidation and reduction zones were measured and the variation of temperature .The maximum temperature observed at oxidation zone temperature was 1319˚C.which was consider high and resulted in to clinker formation. The flame temperature of gasifier was also measured to assess the quantity of gas produced. The average flame temperature of soybean briquette was observed 624˚C attained with burner developed by C.I.A.E, Bhopal. Calorific value of producer gas generated for soybean briquettes were calculated 4.47MJ/m^3.The gasification efficiency with briquette of soybean was observed to be 56%.

Performance of gasifier with pigeon pea briquette

The gasifier was evaluated with briquette of pigeon pea having 60 mm diameter. The biomass consumption of Pigeon pea briquette was found to be 14.1 kg/h. In the present study specific gasification rate with briquettes of Pigeon pea was observed to be 203, kg/h- m^2. The specific gasification production rate were also observed that 34.3 m^3/h-m^2**.**The temperature profile of gasifier at oxidation zone and reduction zone were measured. The maximum temperature of oxidation zone of gasifier was observed to be 1397 ˚C. The variations in the temperature of different zones of gasifier with respect to time. It was also observed that there was large variation in the temperature at 120 mm above the grate. The flame temperature of producer gas was also measured. The flame Temperature of pigeon pea briquette was observed to be 634˚C.Calorific value of producer gas generated for pigeon pea briquette was calculated as4.57 MJ/m^3. The gasification efficiency with briquette of pigeon pea was observed to be 51%.

Performance of gasifier with briquette of mix biomass

The gasifier was tested with briquette of mix biomass. The biomass consumption of Mix briquette was found to be 17.7 kg/h. In the present study specific gasification rate with briquette of mix biomass was observed to be252kg/h- m^2. Specific gasification production rate were observed to be 45.3 m^3/ h-m^2.The variations of temperature profile at different zones of the gasifier with respect to time were measured. The variations of temperature inside the reactor. The temperatures of oxidation zone was observed 1297˚C,. The observed temperature was higher than the ash fusion temperature resulted in to clinker formation.The flame temperature may be taken as indication of Calorific value of the fuel and quantity of gas produced. The flame Temperature of producer gas generated for briquette mix biomass was observed to be 619˚C.The Calorific value of producer gas generated for biomass of mix biomass was 4.10 MJ/m^3.The gasification efficiency with briquette of pigeon pea was observed to be 53%.

Effect of briquette on SGR of gasifier

The variation in specific gasification rate with briquette of different biomass as shown in (fig.2). The maximum gasification rate was observed with briquette of mix biomass followed by soybean briquette and pigeon pea briquette. The mix briquette has helped in gasifier of biomass

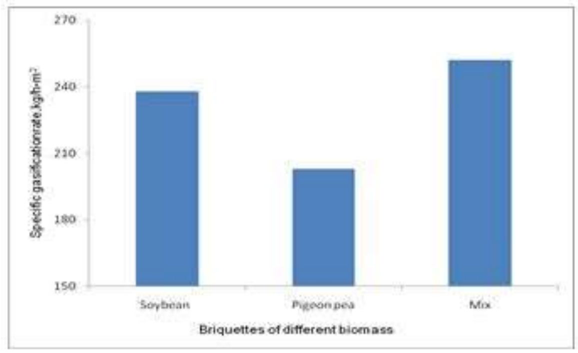

Fig.2 Effect of different biomass briquettes on SGR of gasifier

Effect of different biomass briquette on SGPR of gasifier

The variation in specific gasification production rate with briquette of different biomass as shown in (fig.3) the maximum specific gasification production rate was observed with briquette of mix biomass followed by briquette of soybean and pigeon pea respectively.

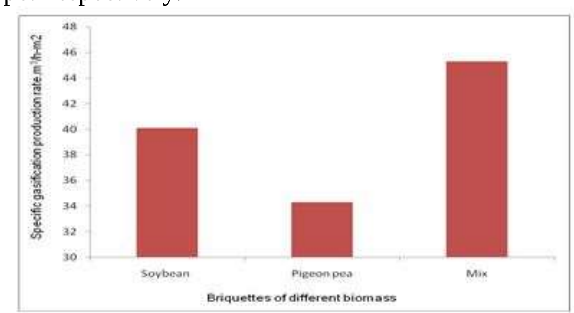

Fig. 3 Effect of different biomass briquettes on SGPR of gasifier

Effect of briquette on efficiency of gasifier

The gasification efficiency of gasifier with different type of biomass is shown in (fig.4). The maximum gasification efficiency was achieved with briquettes of soybean straw followed by pigeon pea and mix biomass.

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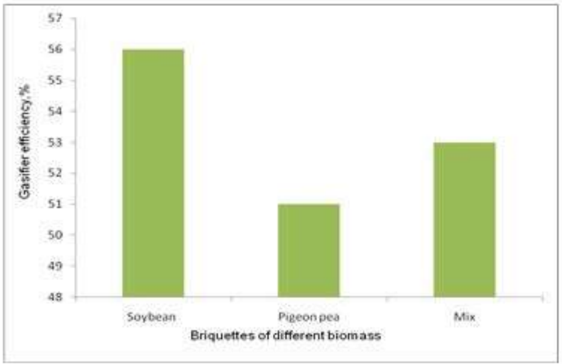

Fig.4 Effect of briquettes on efficiency of gasifier

Effect of briquettes as quality of producer gas

The volumetric percentage of composition of producer gas for CO, H_2, CH_4 , CO_2, N_2 were analyzed used gas chromatograph .The variation in producer gas composition generated from briquettes of different biomass of producer gas detected during the operation conducted at different crop residues briquette are given in (Table 4). The variation of gas composition may be due change in chemical composition of biomaterial and gasifier developed in the gasifier reactor.

Table 4.Gas composition of producer gas during operation

Type of biomass briquette	CO (%)	H_2 (%)	CH_4 (%)	CO_2 (%)	N_2 (%)	Calorific value of gas (MJ/m^3)
Soybean	16.2	15.5	1.66	11.1	57.54	4.47
Pigeon pea	17.3	16.1	1.35	10.5	55.75	4.57
Mix biomass	15.12	14.0	1.42	12.9	58.56	4.10

Conclusion

In this experiment using air in gasification as supplementation mode there result found better as air suction mode there was less tar and gas quality was good Optimum value of specific gasification rate for gasification of briquette of mix biomass in open core gasifier reactor is 252 kg/h- m^2. Higher gasification efficiency was observed to be 56% in soybean briquette.The lower heating value of producer gas under the optimum operating conditions is about 4.10 - 4.57 (MJ/m^3).The pigeon pea briquette has show the maximum temperature in oxidation zone was 1397 ˚C.which as higher the ash fusion temperature increase. The flame Temperature of soybean briquette, pigeon pea briquette, and mix briquette is 624, 634, and 619 ˚C respectively is attained at the burner. The above studies showed that crop residues briquette were suitable for gasification, and quality gas suitable for power generation.

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