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Design and Performance of a Biomass Briquette based Throatless Downdraft Gasifier

RAJIV VARSHNEY[1]*, J.L. BHAGORIA[2] and C.R. MEHTA[3]

[1]Department of Mechanical Engineering, Department of Mechanical Engineering,
Maulana Azad National Institute of Technology, Bhopal, (India).
[3]Agricultural Mechanization Division, Central Institute of Agricultural Engineering, Bhopal, (India).

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ABSTRACT

The increasing prices of petroleum based fuels compels for the research on alternative fuels. Biomass based fuels give us a new option for power generation. In the present article, a briquette based closed top throatless downdraft gasifier of 20 kW has been designed and its performance is evaluated. Cylindrical briquettes of pigeon pea, lantana and soybean stalks of 6 cm diameter were prepared and used as fuel in the gasifier during the experiment. The distinctive feature of the designed gasifier is that it can operate successfully on biomass briquettes with negligible clinker formation. The optimum length of the briquette was found to be 8-12 cm. The optimum gasifier efficiency was found to be 65.18% with pigeon pea briquettes at a specific gasification rate of 212.96 kg/h-m^2.

Key words*:* Gasifier, gasification, producer gas, biomass, briquettes.

INTRODUCTION

The unstable political and economical relations between the gulf countries and other counties that import oil from them forces the latter to search for new options of energy generation. The renewable sources of energy are environmentally friendly. Bioresources comprise of over 220 billion oven-dry tonnes (about 4500 EJ) of annual production and are potentially the world's largest sustainable source of energy [1]. Biomass is the third largest primary energy resource in the world, after coal and oil [2]. It can be used to produce producer gas which can be used to generate power by running internal combustion engines as well as gas turbines. Biomass is a major source of energy in developing countries, where it provides 35% of all the energy requirements. In developed countries, biomass energy use is also substantial [3, 4]. As an energy resource, biomass ranks fourth in the world, and provides about 14% of the world's energy needs. In developing countries it provides 35% of their energy [5, 6].

Sridhar et al [7] reported that the loose bio-residues generated from agricultural and industrial activity have fine sizes, generally high ash content and low bulk densities. These residues cannot be directly gasified in a packed bed downdraft gasifier due to these reasons – (a) the material movement by gravity is hampered by low bulk density and wall friction, (b) tunneling of air can occur by the creation of a hole in the bed somewhat randomly affecting the gas quality, (c) operation of the gasifier at high throughputs particularly in a classical closed top design leads to high temperature near air nozzles because of the influence of high velocity air flow from the air nozzles on the char and this can lead to ash softening and clinker formation which reduces the effective area for flow through the reactor, further deteriorating the performance of the gasifier; (d) thin walled bio-residues when exposed to high temperature can undergo fast pyrolysis due to high surface area available for reaction. This leads to generation of higher amount of tarry compounds (higher hydrocarbon compounds that can condense and cause deposits in pipe lines and downstream elements) an undesired component for the smooth operation of the system.

The density of residual lignocellulosic biomass is low therefore, its use as energy source is limited. Briquetting of biomass is a densification process which improves its handling characteristics, enhances its volumetric calorific value, reduces transportation cost and produces a uniform, clean, stable fuel or an input for further refining processes. Briquetting of biomass is done either by mixing it with some kind of binder (roll and char briquetting, pelletising) or by direct compacting (piston press technology and screw technology). The technologies used for binderless biomass briquetting include machines based on screw and piston-pressed technology [8].

Many researchers have worked on the gasification of biomass. Skoulou et al studied the gasification of olive kernels in a 5 kW bench scale, bubbling fluidized bed gasifier, aimed at H_2 enrichment of the producer gas. The experimental results revealed that producer gas H_2 content increased at the temperature of T = 750 °C and ER = 0.2, resembling the high-temperature pyrolysis conditions that favour H_2 and CO production. Further increase in ER deteriorated producer gas quality, decreased H_2 content and favoured CO_2, thus lowering producer gas heating value. The data obtained from several experiments indicate that olive kernels produced a medium heating value gas (LHV = 6.54 MJ/Nm^3) at 750 °C and ER = 0.2, while H_2 and CO production were maximized at the same conditions (H_2: 24%vv, CO: 14.3%vv) [9].

Jain and Goss designed and tested, four open core throatless batch fed rice husk gasifier reactors having internal diameters of 15.2, 20.3, 24.4 and 34.3 cm were designed and fabricated. They found that for each reactor the gasifier performance was the best at a specific gasification rate of around 192.5 kg/h-m^2. Under the best operating conditions, the equivalence ratio was 0.40 and the gasification efficiency was around 65%. These parameters may be used for designing rice husk operated throatless gasifiers in the capacity range of 3-15 kW. The gas lower heating value of producer gas under the optimum conditions is about 4 MJNm^{-3} [10]

Ahmed and Gupta examined the evolutionary behavior of syngas characteristics evolved during the gasification of cardboard using a batch reactor with steam as a gasifying agent. Evolutionary behavior of syngas chemical composition, mole fractions of hydrogen, CO and CH_4, as well as H_2/CO ratio, LHV (kJ/m^3), hydrogen flow rate, and percentage of combustible fuel in the syngas evolved were examined at different steam to flow rates with fixed mass of waste cardboard. A new parameter called coefficient of energy gain (CEG) was introduced that provides information on the energy gained from the process. Increase in the sample residence time in the reactor decreases the CEG while it increases the carbon conversion and the apparent thermal efficiency. Hydrogen flow rate peaked close to about second minute into of gasification process which was due to the combined effect of decrease in syngas flow rate with time, increase in hydrogen mole fraction with time, and the evolution of hydrogen as a result of pyrolysis that also occurs at the onset prior to the gasification. However, increase in the steam flow rate had a positive effect on pure fuel yield, hydrogen yield, LHV, apparent thermal efficiency, carbon conversion and coefficient of energy gain [11].

Garcia- Ibanez et al tested Leached orujillo in a 300 kW$_{th}$ atmospheric circulating fluidised-bed (CFB) gasification facility using air as a fluidisation agent. These first test series demonstrated that the CFB test rig operated well and makes it possible to carry out gasification experiments using leached orujillo as a fuel. The effect of experimental conditions on gasification process with the aim of enhancing the gas production and improving its composition and energetic content was analysed. The lower heating value of the producer gas obtained was 3.8 MJ/Nm3 at the lowest temperature (780°C). The carbon conversion in orujillo gasification at the 800°C set points was in the range of 81.0–86.9%. The increase in equivalence ratio did not improve carbon conversion significantly. The gas yield increases when equivalence ratio increases [12].

Dogru et al used a pilot scale (5 kWe) downdraft gasifier to investigate gasification potential of hazelnut shells. The gasifier was efficiently and consistently operated with a range of feed rate between 1.7 and 5.5 kg/h (3:1 turndown). The optimum operation of the gasifier was found to be between 1.44 and 1.47 N m^3/kg of air fuel ratios at the values of 4.06 and 4.48 kg/h of wet feed rate which produced the producer gas with a good GCV of about 5 MJ/m^3 at a volumetric flow of 8– 9 Nm^3/h product gas. At this optimum, low tar and char were produced at a ratio of 0.005 and 0.051 of the feed, respectively. Maximum temperatures in drying, pyrolysis and throat zones were determined as 125, 566 and 1206°C but the throat temperature fell to about 1020°C at the optimum. With hazelnut shells there was no sign of bridging or ash fusion at the optimum throat temperature of about 1000–1050°C. Optimum nut shells feed rate for this size of the gasifier was around 4.02 kg/h. Maximum combustible gas flow was obtained as 10.96 N m^3/h. Optimum char output rate was determined as 0.201 kg/h. Optimum tar output rate was found as 0.023 kg/h. Maximum GCV of the producer gas was analysed as 5.15 MJ/N m^3. It was concluded that hazelnut shells could be easily gasified in a downdraft gasifier to produce good quality gas with minimum polluting by-products [13].

Singh et. al (2006) carried out studies on the fuel properties of cashew nut and its gasification feasibility for open core down draft gasifier. It was found that producer gas calorific value and volumetric percentage of its combustible constituents along with gasification efficiency, in general, increased with the increase in gas flow rate.The maximum gasification efficiency was found to be 70 % at a gas flow rate of 130m^3/h and specific gasification rate of 167kg/h-m^2. Studies revealed that cashew nut shells could successfully be used as feedstock for open core down draft gasifier[14].

Vyas and Singh (2007) presented the results of investigation carried out in studying the fuel properties of Jatropha seed husk and its gasification feasibility for open core down draft gasifier. It was found that producer gas calorific value and concentration of CO along with gasification efficiency, in general, increased with the increase in gas flow rate. The maximum gasification efficiency was found to be 68.31% at a gas flow rate of 5.5 m^3/h and specific gasification rate of 270 kg/h/m^2. Jatropha seed husk could successfully be used as feedstock for open core down draft gasifier[15].

As seen in the literature, there has been substantial work on biomass based gasifier. But there is a little work gasifier which uses biomass briquettes as fuel. In the present study, a throatless downdraft gasifier is designed and its performance is evaluated. The distinctive feature of the designed gasifier is that it can operate successfully on biomass briquettes with negligible clinker formation. The cylindrical briquettes of soybean have been used in the experiment.

Materials and methods

A closed top throatless co-cylindrical downdraft gasifier has been designed for the biomass briquette fuels and tested, which gives excellent results with biomass briquettes. The system is designed, developed and fabricated at the CIAE (Central Institute of Agricultural Engineering), Bhopal. A down draft gasifier has the advantage of low tar formation and as such is very successful for operating engines [16].

The briquettes are also produced at CIAE, Bhopal using piston-press technology based briquetting machine. The gasifier is tested with briquettes of pigeon pea, lantana and soybean. The process of briquetting involves subjecting the biomass to high pressure and temperature which helps in release of lignin from the biomass. This lignin acts as a natural binder and the loose biomass matter gets tightly packed and takes the size and shape of the die [7].

Experimental set up

The experimental set up consists of a gasifier with cooling and cleaning units along with a blower and burner. The ray diagram of the experimental set up is shown in figure 1. A brief description of different units is given in following sections

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Gasifier

The gasifier developed is closed top downdraft gasifier. It is co- cylindrical whose inner diameter is 30 cm. the outside diameter of the gasifier is 36 cm. Between the space of these co-cylindrical gasifier the gas is extracted towards the gasifier with the help of blower. The air tuyers are located at a height of 40 cm from the grate. The water sealing is provided at the bottom of the

Table 1: Technical specification of the gasifier

Type	Downdraft, throatless, closed top
Capacity, biomass	75 kg
Diameter of inner cylinder	30 cm
Diameter of outer cylinder	36 cm
Material used	Mild steel
Ash removal unit	Manual- rotating type

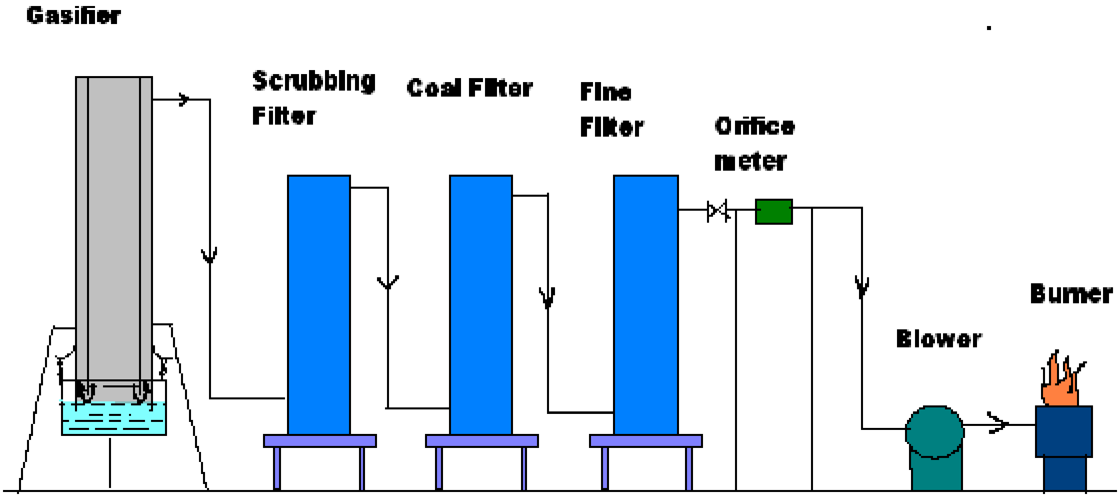

Fig. 1: Experimental set up of gasifier unit

gasifier with the help of a trough. Ash is removed manually for which handle is provided at the bottom of the trough. Other technical specifications are given in table 1.

Gas cleaning unit

Three filters have been used for cleaning and cooling purpose. First one consists of hollow cylindrical iron pieces of 2 cm length and 2 cm length in which water is continuously recirculated from a tank with the help of a pump. This filter serves the purpose of cleaning as well as cooling. The second filter has coal pieces, in which, also, water is continuously recirculated from a tank. This filter further cools and cleans the producer gas. The third filter has coir pith and sheet of foam (3 mm thick) as filter material and it is a fine filter which filters the tar and hence a clean gas is received at the exit.

Blower

The blower used in the suction mode is Tawde Pollutech India Pvt. Ltd, having a capacity of 1000 m^3/h. The suction capacity 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 for the study whose flame shows a successful operation.

Raw materials

Briquettes were prepared using a briquetting machine based on piston-press technology in which pigeon pea, lantana and soybean stalks are pushed into a die of 60 mm diameter by a reciprocating ram by high pressure. These briquettes are broken in the length of 8-12 cm manually and are fed to the gasifier from the top lid which is later closed during the operation. The raw material used in the study is shown in figure 2.

Fig. 2 Pigeon pea briquettes used in the experimentation

Experimental procedure

First the cooling system is started by switching on the pump which recirculates the water in the first two filters from a tank. After that the blower is started and thus suction is created and fire is ignited from the tuyers externally. After about 10 minutes the quality gas is produced. The flame at the burner gives the indication of quality gas

Heating value of biomass briquettes

The heating value of briquettes was measured with the help of bomb calorimeter.

Temperature measurement

S type thermocouple has been used for measuring the temperature of oxidation zone. Data taker system was used for recording the data continuously.

Flow measurement

An orifice meter was developed by designing orificeplate and U- tube manometer, whose coefficient of discharge was found to be 0.65 by calibration.

Heating value of producer gas

The heating value was measured with the help of Junker's calorimeter in which water is heated with the burnt gas.

RESULTS AND DISCUSSION

It was found that 3-4 minutes are required to warm up the gasifier. The maximum temperature attained in the oxidation zone was about 1200°C as shown in figure 3. By extensive experimenting it the optimum length of the briquette was found to be 8-12 mm with minimum choking during the flow of briquettes during the operation. Pigeon pea was found to be optimum material for gasifier. Maximum heating value was found for pigeon pea briquettes which was 18.299 MJ/kg. Maximum Heating value was found for producer gas from pigeon pea briquettes which was 5.03 MJ/m^3. The optimum gasifier efficiency was found to be 65.18% for pigeon pea briquette at a specific gasification rate of 212.96 kg/h/m^2. The maximum efficiency for lantana briquettes was found to be 63.1% at a specific gasification rate of 225.56 kg/h/m^2 The maximum efficiency for soybean briquettes was 62.1% at a specific gasification rate of 231.72 kg/h/m^2 as shown in figure 4.

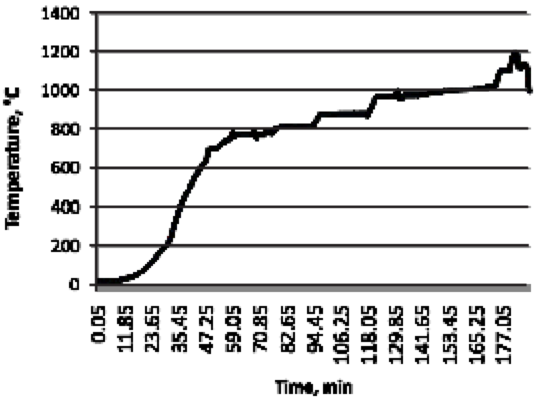

Fig. 3 Maximum temperature attainment of oxidation zone for pigeon pea briquettes wrt time

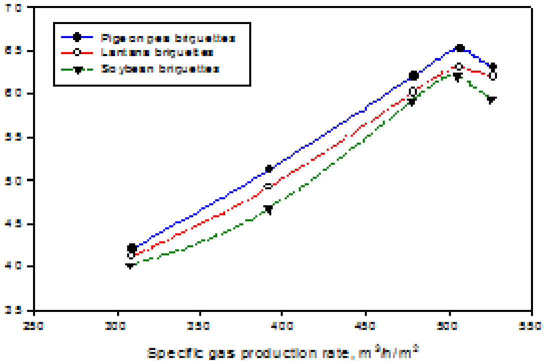

Fig. 4 Effect of specific gas production rate on efficiency with different biomasses of 60 mm diameter

CONCLUSION

It is concluded that the gasifier designed runs successfully with negligible clinker formation. The operation of gasifier shows that

i) The maximum temperature attained in the oxidation zone was about 1200°C which is enough to minimize the tar content.

ii) The optimum length of the briquette was found to be 8-12 mm with minimum choking during the flow of briquettes during the operation.

iii) Pigeon pea was found to be optimum material for gasifier. Maximum Heating value was found for pigeon pea briquettes which was 18.299 MJ/kg. Maximum Heating value was found for producer gas from pigeon pea briquettes which was 5.03 MJ/m^3.

iv) The optimum gasifier efficiency was found to be 65.18% with 60 mm with pigeon pea briquette for specific gasification rate of 212.96 kg/h/m^2. The maximum efficiency for soybean briquettes was 62.1% at a specific gasification rate of 231.72 kg/h/m^2.

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