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Development of a Fuel-flexible Updraft Thermal Biomass Gasifier

Gautam Borthakur — Lecturer (Selection Grade), Department of Mechanical Engineering, H.R.H. The P.O.W. Institute of Engineering & Technology, Jorhat- 785001, Assam, India.

Dr. Dimbendra Kr. Mahanta — Professor, Department of Mechanical Engineering, Assam Engineering College, Guwahati, 781013, Assam, India.

ABSTRACT

The paper addresses issues related to development of a biomass gasifier for thermal applications. The gasifier can accept variety of dry woody biomass which has been proved by testing of the gasifier. Three types of biomass namely wood, bamboo and Ipomoea have been successfully gasified. The maximum power delivered by the gasifier is nearly 14.84 kW at fuel consumption 4 kg hr-1 for wood chips as feed. The power level increases with the increase of calorific value of fuel used. The equivalence ratio is in the range of 0.24 to 0.27 for the three selected biomass. The air-fuel ratio seems independent of biomass types. This type of simple gasifier would be useful in developing countries to meet thermal energy through clean and efficient conversion of biomass.

Introduction:

Energy from biomass accounts for about 15% of the world's primary energy consumption and about 38% of the primary energy consumption in developing countries (Demirbas and Demirbas, 2007). Furthermore, bio-energy often accounts for more than 90% of the total rural energy supplies in some developing countries. Biomass is carbon neutral if sustainably used. In developed countries this renewable source is being utilised for deriving clean energy using more developed technology. But in developing countries biomass is used with very low efficiency of conversion about (10-15 %) in the traditional combustion based devices. The low conversion efficiency leads to wastage of the resource, environmental pollution, adverse effects on health, more CO_2 emission and overall higher economic cost. A better conversion method of energy from biomass will offer many benefits including sustainability, reduction of greenhouse gas emissions, regional development, social structure and agriculture and security of supply. In this regard biomass gasification may be considered as an efficient method of deriving clean energy from biomass which has regained the importance in the last few decades.

Various designs of small gasifier have been proposed by different researchers. Dasappa et al. (1989) reported the development of a five-kilowatt wood gasifier. Bhattacharya et al. (2001) at Asian Institute of Technology, Thailand developed a cross-draft gasifier based cook-stove for community cooking application in Asian countries. Belonio (2005) developed a rice husk gasifier for thermal use. Saravanakumar et al. (2007 a, b) reported the development of an up-draft and a top-lit up-draft long stick wood gasifier. It has been revealed that the gasifiers are generally designed to suit for a particular type of biomass. Therefore a different approach has been proposed in this work in which a gasifier is designed to accept various woody biomass. The expected outcome will be to increase the potential application of the gasifier in different places to use different woody biomass available in the place of use. The approach of the present work is taken with the following objectives: a) to develop of a prototype of a small fuel-flexible up-draft biomass gasifier of simple design, b) to test the gasifier with wood chips and non-timber type locally available woody biomass in order to ensure fuel flexibility, c) to perform experiments to study the performance of the gasifier and to interpret the results.

Development of the gasifier:

Biomass Gasification refers to a thermo-chemical process of converting dry solid biomass directly into a combustible gas by controlled burning of the feed stock with limited supply of air or oxygen in a reactor called gasifier. The heating value of this gas is in the range of 4-6 MJ Nm^{-3} which is a mixture of combustible gases hydrogen (H_2), carbon monoxide (CO) and methane (CH_4) along with non-combustible gases carbon dioxide (CO_2) and nitrogen (N_2) with variable composition (Chopra and Jain 2007). The actual gas composition as well as the heating value of the gas depends considerably on fuel type and gasifier design. The gas also contains heavy hydrocarbons as tar.

The present gasifier is an up-draft gasifier, the simplest type of fixed bed gasifier. The biomass is fed at the top of the reactor and moves downwards as the gas moves in the upward direction. The air intake is at the bottom and the gas leaves at the top. As the biomass moves in counter current to the gas flow, it passes through different zones - drying zone, pyrolysis zone, oxidation zone and finally reduction zone. The major advantages of this type of gasifier are its simplicity, acceptance of high moisture content biomass, high burn-out rate and internal heat exchange leading to low gas exit temperatures and high gasification efficiency. It is interesting to note that the major drawbacks of the gasifier, high amounts of tar and pyrolysis products, is of minor importance if the gas is used for direct heat applications, in which the tars are simply burnt to add to the heat of gas combustion.

A deviation in the design of the present gasifier is that air is supplied to the reactor from the radial direction instead of supplying at the bottom of the grate. This allows the gasifier to accept wide range of biomass, even with high ash content, as the effect of ash accumulation on the grate could be ignored which generally prevent sufficient flow of air through the grate.

The device basically consists of two parts- a cylindrical reactor and a tapered hopper. The reactor core is a mild steel (M.S.) (sheet thickness 2 mm) cylinder of 20 cm diameter and 25 cm height. The reactor was drilled with 42 (forty two) numbers of 16 mm diameter holes in the sides. The hopper is made of same M.S. sheet which is a taper of 100 mm height having bottom diameter equal to the reactor diameter and the diameter at the top is 15 cm. The hopper and the reactor are insulated by castable refractory material. The insulations are covered by two enclosures among which the upper enclosure is a regular M.S. cylinder and the lower one is an octagonal one made of 2 mm M.S. sheet. The hopper is fitted at the top of the reactor with bolt and nut and gasket to prevent any gas leakage. A circular grate of 25 mm spacing was fitted at the bottom of the reactor to support the fuel bed and to allow the ash to fall down in the ash-pit. The ash-pit at the bottom of the gasifier was provided with an air tight door. A comb type agitator was imparted to remove accumulated ash as and when required. The inlet air pipe is a G.I. pipe of 25 mm diameter. The hopper top supports the water seal and the water seal cover supports the gas flow pipe. There are two control valves in the system- one for controlling air flow and the other for regulating gas out of the gasifier.

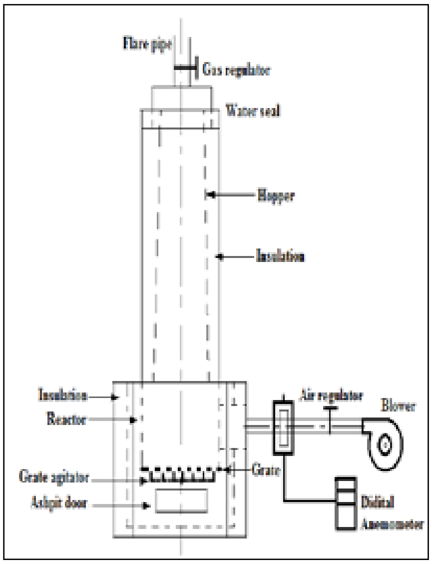

Fig.1. Schematic Diagram of the Up-draft gasifier with blower and air flow measuring instrument.

Materials and methods:
Feed stock:
Three different woody biomass namely waste wood, bamboo and Ipomoea carnea, in the form of chips were used as fuel in the gasifier. The chips were chopped manually into 3-4 cm sizes. The bulk density of the fuel samples were determined by measuring the weight of each fuel sample in a laboratory beaker of known volume. The moisture content of each sample (previously air dried for three weeks) was determined using a hot air oven at 103±2°C up to the arrival of constant weight. The volatile matter, fixed carbon and ash content (% dry basis) were taken from earlier published work (Patil et al. 2000; Garcia et al. 2012). The higher heating value (HHV) of each fuel was determined by using the equation: HHV (MJ kg^{-1}) = 354.3FC + 170.8VM, where, (VM+FC+Ash = 100) as applied by Maiti et al. (2006). The physical and thermo-chemical properties of the feed stocks are presented in Table 1.

Table 1. Physical and thermo-chemical properties of biomass

Properties	Wood	Bamboo	Ipomoea
Bulk density (kg m^{-3})	242	197	158
Moisture content (% wt)	7.91	9.12	8.03
Volatile matter (% db)	68.6[a]	81.47[a]	86.77[b]
Fixed carbon (% db)	29.90[a]	17.33[a]	10.59[b]
Ash content (% db)	1.5[a]	1.2[a]	2.64[b]
Heat value (MJ kg^{-1})	22.26	19.99	18.50

[a] [Garcia et al. 2012]; [b] [Patil et al. 2000]

Trials and test runs:
In order to ensure stable operation several trials were performed on the gasifier [refer to Fig.1]. On the basis of these trials operational procedure on the gasifier were fixed for the performance study.

Fuel was loaded over the top of the hopper leaving a space of 10 cm at the top. Fuel was ignited by introducing a flame (cotton waste soaked in kerosene at the end of a rod) under the grate through the ash pit door. As soon as the fuel caught fire, indicated by evolution of white smoke, the ash-pit door was closed and the blower was turned-on. The air flow was regulated and after a couple of minutes combustible gases formed which caught fire with a brilliant flame when a flame torch was brought into direct contact. The flame was adjusted for complete burning of the gas by regulating the air flow control valve as well as the gas flow valve until a steady state was attained. For measuring fuel consumption additional measured quantity of fuel was fed after certain interval of time. For shutting down the gasifier the blower was turned off and the valves were closed. The residue was collected at the ash pit by operating the ash removal lever and subsequently removed for measurement. The air flow rate was measured from inlet air velocity through a known area of the inlet pipe with a digital anemometer (Agronic model-4822). A flexible junction, specially designed for the purpose, was used. A digital calibrated balance of 10 kg range of 1 gm resolution was used to measure the weight of fresh fuel and residue. Time of operation was recorded with a digital stop watch.

Fig.2 (a-c): Different biomass used in the gasifier a) Wood, b)Bamboo, c) Ipomoea

Results and discussions
General observations:
The gasifier showed steady state operation which was revealed from the visible flame. It was observed that the process had begun with evolution of dense smoke until combustible gas was generated. The maximum flame height was about 1 meter (refer to figure 3). The start-up time was nearly 8 (eight) minutes. As soon as the gas burned with brilliant flame no trace of smoke was observed.

Fig.3 The gasifier in operation; observe (a) clean burning of the gas, (b) flame height

Fuel consumption
It was found that the fuel consumption rate had been highest for bamboo and lowest for dry Ipomoea chips. The variation in fuel consumption rate indicated the influence of other factors such as moisture content, void fraction etc. apart from hating value and bulk density of the biomass.

Power level of the gasifier
Considering reasonably an average gasification efficiency of 60% the power output from the gasifier as derived from input energy (based on FCR) ranged from 12.02 kW to 14.84 kW (re-

fer to table 2). It is revealed that higher the heating value of the feed stock more is the power level from the same gasifier for similar sizes of dry feed stock.

Air to fuel ratio:
The air velocity for different feeds in the most part of the runs is in the range of 2.9 to 3.2 m s^{-1}. Accordingly the average rate of air supply was found to be 5.46 m^3 hr^{-1}. The air to fuel ratio is in the range of 1.52 to 1.64 which indicated a nominal variation. The air flow rate becomes higher towards the end of each run indicating the of end of pyrolytic gasification.

Specific gasification rate:
The specific gasification rate (SGR) is the amount of fuel consumed per unit operating time per unit cross-sectional area of the reactor for a particular feed stock. The highest SGR of the present gasifier was for bamboo and lowest was found for Ipomoea. It may be observed that the SGR depends on moisture content, volatile matter and bulk density and chemical composition of the feed stock.

Equivalence ratio:
The equivalence ratio (ER, the amount of air added relative to the amount of air required for stoichiometric combustion) is an important parameter to characterize gasifier operation. In the present gasifier the ER have been found within the range of 0.24 to 0.27 respectively for stoichiometric value 6.3 for air-fuel in pure combustion of biomass of average composition $CH_{1.4}O_{0.6}$ (Saravanakumar et al. 2007b).

Char conversion:
In the present gasifier the char produced after each batch of operation was measured to find the percentage of char conversion and for all the three feed stocks the value was found near 8-12 %. This low amount of char indicated conversion of biomass to sufficient combustible gases satisfying the intended objective of gasification process.

Table 2. Performance of the gasifier for different feeds

Quantities	Wood	Bamboo	Ipomoea
FCR (kg hr^{-1})	4.00	4.30	3.90
SGR (kg $hr^{-1}m^{-2}$)	214.56	234.94	204.78
ER	0.26	0.24	0.27
Power (kW)	14.84	14.33	12.03
Char (wt %)	12.30	10.70	8.20

Safety in operation:
gas contains carbon monoxide (CO), a poisonous gas. All the joints and the ash pit door were checked with a flame torch to ensure possibility of gas leakage. The result was quite satisfactory. Incomplete combustion of the gas could be avoided with proper burner design. The outer surface temperature of the gasifier was sufficiently high which indicated further scope for reduction of heat loss. A protection shield would be needed to avoid burning injuries.

Conclusions:
A fuel-flexible updraft gasifier has been successfully demonstrated. The easy to fabricate gasifier may be an appropriate device for any developing country for clean energy supply where biomass is widely used, particularly for supplying heat in rural traditional industries. A detailed investigation of the gasifier would reveal more information and would help to find further scope for improvements.

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