Waste to Energy using Biomass Gasification

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Abstract

With one of the highest growth rate India is progressing in many fields and energy demands are increasing by the year. The higher standards of urban living has seen an increase in domestic energy demand. Previously untapped energy sources are being explored including waste to energy conversion from municipal solid waste (MSW). A number of methods are available for the energy conversion and gasification of waste biomass which has caught research interest in recent past. A 5 kW updraft gasifier is designed and fabricated to process rice husk as the feedstock.The designed gasifier can take dried crushed MSW as feedstock. The producer gas obtained from the gasifier is immediately combusted to heat water. The efficiency calculated from water heating output is reported. The low efficiency value is partly due to the heat losses associated with the water heating.

Key Words: Biomass, MSW, Gasification, Updraft Gasifier

1. INTRODUCTION

Effective utilization of waste biomass can be the key to reduce over dependence on fossil fuels. Waste to energy drive is essential to establish a sustainable circular economy. Biomass waste is one of the renewable resources which can be generated in the form of municipal solid waste, sewage sludge, agriculture waste products, dairy waste or byproducts and other related industrial wastes. Many methods are available to treat these wastes including biochemical and thermochemical processes. One of the biochemical process is digestion that produce biogas, but this method is time consuming taking about 2 months. Incineration is one of the thermochemical processes that is routinely used to treat municipal solid waste. Other thermochemical processes like, pyrolysis and gasification are developed in industries to produce charcoal or petroleum byproducts. Gasification is defined as a thermochemical process that converts carbonaceous material into producer gas. Producer gas is also called by other names like syngas and production gas. Producer gas predominantly is made up of carbon monoxide, hydrogen and carbon-di-oxide. The biomass is processed at temperatures excess of 700^{o}C with controlled amount of oxygen and/or steam.

Gasification is well suited for treating of municipal solid waste compared to incineration [1]. Gasification has several advantages compared to incineration.

- Producer gas from gasification can be cleaned and used to produce energy and products such as chemicals, transportation fuels and fertilizers, but incineration only produces high temperature flue gas
- Flue gas from incineration of plastics typically contain dioxins and furans due to availability of excess oxygen. These compounds are difficult to clean near the flue gas exhaust. But gasification process occurring at oxygen deficient reactor avoid producing these compounds.

1.1 Gasifier Types

The process of gasification occurs in nature. Thomas Shirley discovered methane gas from coal mine. First successful gasification unit was built in 1861 by Siemens [2]. This success was followed by a variety of gasification methods including, fixed bed gasifiers, pressurized moving bed gasifiers, and fluidized bed gasifiers, entrained flow gasifiers and plasma gasifiers. The construction, processes, and reactions taking place in biomass and coal gasification have been reported in literature [3-5]. Power generation is streamlined along with gasification in systems such as integrated gasification combined cycle (IGCC).

Gasification technology is proven and is routinely used to produce many products [2]. Several process parameter variations of the basic gasification are used to produce the required products. Some of the solid products that can be produced are charcoal, torrified biomass. Ethanol, biodiesel, and pyrolysis oil can be produced by gasification. Gaseous products predominantly used are producer gas that is a combination of CO, CH_4, CO_2 and H_2. However process parameters like pressure, temperature and moisture can be varied to produce other products including natural gas substitute methane (CH_4), syngas (CO and H_2) and biogas substitute (CH_4 and CO_2) [2].

The typical updraft gasification reactor is shown in the Fig. 1. The temperatures near the hearth zone is typically about 1200 ^{o}C. The temperature progressively reduces along the flow of air upwards to reach about 150 ^{o}C at the gas exit. Approximate temperature ranges and their regions are shown in Fig. 1.

Biomass initially undergoes drying at about 100 ^{o}C, exothermic dehydration between 100 to 300 ^{o}C, preliminary pyrolysis above 200 ^{o}C and gasification process between 300 to 900 ^{o}C [2]. The gasifier design procedure includes the calculation of overall reactor dimensions based on the gasification rate. The specific gasification rate (SGR) depends on major chemical reactions taking place during thermal conversion of biomass. The overall chemical reactions for incomplete combustion of the feedstock taking place in the gasifier can be summarized as follows:

$$C + \frac{1}{2} O_2 \rightarrow CO$$

$$C + CO_2 \rightarrow 2CO$$

$$C + H_2O \rightarrow CO + H_2$$

The typical yield of a gasifier is about 2.5 m^3 / kg of rice husk biomass. At temperature closer to 700 ^oC, we get higher carbon monoxide in the producer gas mix. At higher temperatures carbon dioxide percentage increases due to the reactions reaching complete combustion [6].

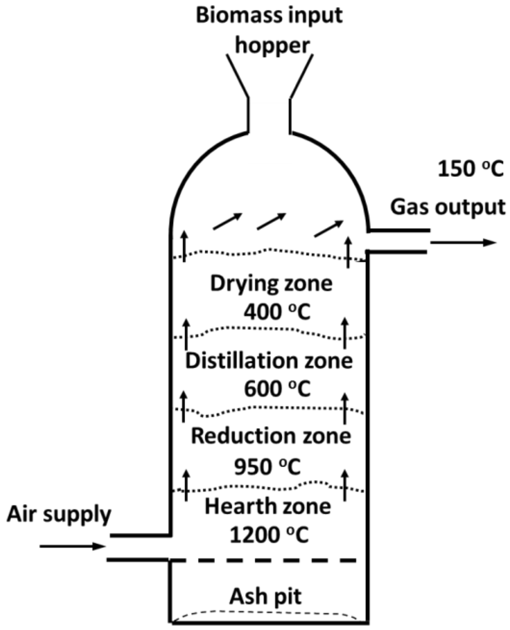

Fig. 1 Schematic of a typical updraft gasifier showing the temperature zones

2. DESIGN PROCEDURE

The design calculations for gasifier follows the following steps:

- Calculation of air fuel ratio
- Calculation of the diameter of reactor based on feed stock consumption rate
- Determination of the height of reactor based on specific gasification rate
- Calculation of the air requirement based on equivalence ratio

Additionally, if the design involves heat transfer minimization, insulation thickness is calculated [7]. Experimental measurements including temperatures along the axis of reactor, and fan flow rate is measured to get the yield of producer gas.

2.1 Nomenclature and Symbols

$\eta_{gasifier}$	Thermal efficiency	(%)
SGR	Specific gasification rate	kg/m^2h
Q	Higher Calorific Value	kJ/kg
AFR	Air Flow Rate	m^3/h
FCR	Fuel Consumption Rate	kg/h
D	Diameter of the reactor	m
H	Gasifier Height	m
T	Operating Time	h
SA	Stoichiometric Air Fuel ratio	
ε	Equivalence ratio	
Q_{in}	Heat input by fuel	kJ
Q_{out}	Heat yield by producer gas	kJ

The input values for calculations are shown below:
Power output = 5 kW
Feedstock feed rate = 3 kg/hr
Equivalence ratio = 0.25
Specific gasification rate = 100 kg/m^2-hr
Gross calorific value of rice husk = 14150 kJ/kg [8]

The stoichiometric air fuel ratio is calculated to get the air flow requirement.

$CO+H_2+O_2 + (79/21)N_2 \rightarrow CO_2+H_2O+ (79/21) N_2$
1 kmol of rice husk has a mass of (12 x 1) + (16) = 28kg
1 kmol of Oxygen has a mass of (1 x 32) = 32kg
Therefore,
O_2 required per kg of fuel = 32/28 = 1.143 kg
Stoichiometric A/F ratio = 1.143/0.233 = 4.905

Assuming 3 kg of fuel / hour

$$\boldsymbol{m}' = \frac{3\ kg\ of\ fuel}{1\text{hour}}$$

The diameter of the gasifier is then given by:

$$D = \sqrt{\frac{4 \times m'}{\text{SGR} \times \pi}}$$

The height of reactor is

$$H = \frac{SGR \times T}{\rho_f}$$

The equivalence ratio is the ratio of actual air fuel ratio to that of stoichiometric air fuel ratio.

$$AFR = \frac{\varepsilon \times m'f \times SA}{\rho_{air}}$$

2.2 Fabrication and Operation of Gasifier

The fabricated gasifier is shown in Fig. 2. The reactor of diameter 205 mm and height of 700 mm was fabricated. The base dimensions were designed to be 400 X 400 X 100 mm height. The cylindrical reactor is placed on the base. The base contains the air supply mechanism and the ash collection. The air supply to the reactor is by 100 X 100 X100 recess in the base as shown in figure 2. The air is supplied using a brushless DC fan rated at 5V. The cylindrical reactor is fitted with burner to accommodate a vessel for water heating.

The startup operation of an updraft gasifier involves the placing of small starter flame at the bottom of the reactor. The air flow is adjusted with the fan and approximately 1 kg of sawdust is added to the reactor. The gasification process typically takes few minutes before the producer gas is generated.

Fig. 2 Fabricated gasifier setup showing the cylindrical reactor, rectangular base with air inlet

Fresh rice husk was selected for the experiments sourced directly from the rice mill. The procured rice husk was sun dried for 12 hours before the experiment to ensure removal of extra moisture. Typical overall diameter of the rice husk was about 1mm.

2.3 Testing of gasifier

The fabricated gasifier was used to heat water to ascertain the feasibility of the device to domestic application. Fig. 3 shows the water heating test performed using the fabricated gasifier. The mass of water used in the test was 700 ml. The temperature rise was found to be 15 ^{o}C for 15 minutes of operation of gasifier. This yields an efficiency of 7%.

$$\eta_{gasifier} = \frac{Q_{out}}{Q_{in}} \times 100$$

$$\eta_{gasifier} = \frac{19.4}{28 \times 10^3} \times 100$$
$$\eta_{gasifier} = 0.07$$

The low efficiency is due to the heat losses due to the open flame heating of water that inherently has heat losses.

Fig. 3 Schematic of a typical updraft gasifier showing the temperature zones

3. RESULTS

The prominent parameter that affect the gasification process is the temperature and equivalence ratio. The reactor temperature is dependent on the equivalence ratio since the extent of combustion reaction is dependent on the availability of oxygen. The temperatures along the axis of the gasifier reactor was measured using an IR thermometer with a range of 0 to 550 ^{o}C range. The temperature profile is shown in Fig. 4. It can be observed that the producer gas obtained from the gasifier is at about 150 ^{o}C, while the hearth zone and the reduction zone were well above 550 ^{o}C.

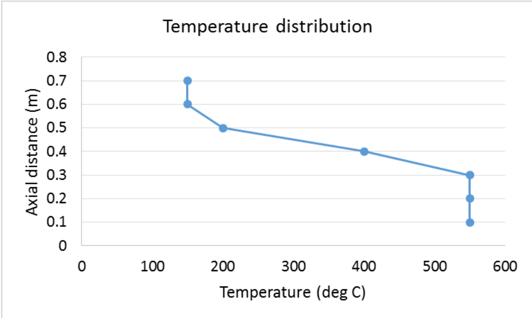

Fig. 4 Temperature distribution updraft gasifier showing the temperature zones

Producer gas yield calculation was done on the basis of the fan capacity. A 3 pin brushless CPU fan was run at 5 V and has a capacity of 7 CFM or 0.2 kg/min. The gasification of 1 kg of rice husk took 15 minutes. Therefore the yield of producer gas is above 3 kg. The flow estimation of producer gas is based on the air flow rate and mass conservation principle.

$$m_{producer\ gas} = m_{air} + m_{feedstock} - m_{ash}$$

In the above equation, mass of air is 3 kg in 15 minutes, mass of feed stock is 1 kg and ash produced was about 0.005 kg. The producer gas also contained tar that needs further cleaning.

The equivalence ratio depends on the type and particle size of feedstock. It is also varied using the fan power. Typical values of equivalence ratio for an updraft gasifier is set to be above 0.25. This ensures reduced tar formation. Fig. 5 shows the open flame that is lit using the producer gas yield from the fabricated gasifier. The equivalence ratio was adjusted based on the type of flame produced. At low fan speeds, the tar formation was reduced but the flame was unstable. Increasing the fan speed produced high CO_2 gas due to complete combustion that blows out the flame. Therefore fan speed was so adjusted to get a clean burning flame.

Fig. 5 Flame over the gasifier reactor

4. CONCLUSION

A 5 kW updraft gasifier was designed and fabricated for the rice husk feedstock. The gasifier was successfully operated for 1 kg of feedstock and about 3.5 kg of producer gas was generated. The producer gas yield was used to heat water and thermal efficiency of the gasifier along with the designed burner was found to be about 7%.

The temperature of the gasifier was measured and was found to be similar to the reported values in the literature. The most important parameters affecting the gasifier performance was found to be temperature and equivalence ratio. The equivalence ratio is found to affect the gasification temperature, and can be modified by fan speed selection.

The overall project design was aimed to use low cost materials and methods that is more suited for rural setting. Efficiency can be further improved by better design of burner.

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REFERENCES

[1] Samolada M.C., Zabaniotou A.A. (2014) Comparative assessment of municipal sewage sludge incineration, gasification and pyrolysis for a sustainable sludge-to-energy management in Greece, *Waste Management,* 34(2), pp. 411 - 420.

[2] Basu P. (2010) Gasification theory and modeling of gasifiers, *Biomass gasification design handbook.* Boston: Academic Press, pp. 117 - 165.

[3] Kumar A., Jones D.D., Hanna M.A. (2009) Thermochemical Biomass Gasification: A Review of the Current Status of the Technology, *Energies,* 2, pp. 556 - 581.

[4] Breault R.W. (2010) Gasification Processes Old and New: A Basic Review of the Major Technologies, *Energies,* 3, pp. 216 - 240.

[5] Umberto A. (2012) Process and technological aspects of municipal solid waste gasification: a review, *Waste Management,* 32(4), pp. 635-639.

[6] Makwana J. P., Pandey J., Mishra G. (2019) Improving the properties of producer gas using high temperature gasification of rice husk in a pilot scale fluidized bed gasifier. *Renewable Energy,* 130, pp. 943-961.

[7] Ojolo S., Abolarin S., Adegbenro O. (2010) *Development of laboratory scale updraft biomass gasifier.* Lagos: LAP Lambert Academic publishing.

[8] Ismail A.F., Yusaf T.F., Mahdi F.M.A., Shamsuddin A.H. (1997) Combustion processes of rice husks for energy, *RERIC International Energy Journal,* 19(2), pp. 63 - 76.