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Research Article

Design and Development of Household Gasifier cum Water Heater

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Abstract

In India, the potential of biomass as an energy resource is very large and accounts about one third of total fuel used in India. The combustion process in traditional cooking store called as chullah is a non ultimate source for cooking and favours incomplete combustion with lower thermal efficiency. The gasifier works on the principle of gasification, has low emission in comparison to traditional cook-stove. This study reveals the design, performance and evaluation of updraft Gasifier with water heater. The performance of gasifier cum heater mainly depends upon the energy needed, diameter of cylindrical reactor, fuel consumption rate. Thermal efficiency of Babul wood was found to be 19.26 %, Thermal efficiency of water heating system was found to be 27.03 per cent. This system was designed based on fuel consumption rate, dimensions of reactor. The economical evaluation was carried out based on Benefit cost ratio and Payback period and it was found to be 1.45 and 4.22, respectively.

***Keywords**: Thermal efficiency, Water heating arrangement, Household gasifier, Biomass, pay Back Period*

Introduction

Biomass Gasification

Gasification, a thermo chemical process, is a century old technology, which flourished quite well before and during the Second World War. The technology disappeared soon after the Second World War, when liquid fuel became easily available. The interest in the gasification technology has undergone many ups and downs in last century. Today, because of depletion of fossil fuels, increased energy demand, fuel prices and environmental concern, there is renewed interest in this century old technology. The advantage of this technology is decentralized energy conversion system which operates economically even for small scale. Woodchips is one of the sources of biomass that can be gasified and it has the greatest potential of any renewable energy option for power production and heating. In gasification, the energy in the biomass is converted into the gaseous form. The produced gas has the potential to be used in a wide range of systems to generate heat and electricity. One attractive option to use the biomass resources in most efficient way is to convert the biomass thermo-chemically into producer gas and use the producer gas as fuel for various thermal applications.

The potential of biomass conversion devices as alternative fuel source to replace conventional fuel is a promising option. Biomass fired gasifier can be a viable and acceptable option to replace the conventional LPG stove. In general, biomass energy use in such cases is characterized by low energy efficiency and emission of air pollutants. Exposure to smoke from indoor biomass burning is known to cause acute respiratory infection and chronic lung disease. One of the most recent prototypes of these improved stoves is the wood-gas stoves or gasifier stove. The wood-gas stoves can be started. Operated and stopped with very low emissions and can use a wide variety of biomass fuels.

Cooking over an open fire means that people are exposed to wood smoke, which irritates their eyes and lungs and makes them susceptible to respiratory diseases. Conventional wood fire cooking is a leading contributor to respiratory and eye diseases among rural women and children and puts extreme pressures on dwindling forest resources. The health damage due to indoor air pollution has been estimated to result in about lakhs of deaths in India. In order to overcome the two major drawbacks of traditional stoves, namely low efficiency and indoor air pollution, a large number of improved biomass fed gasifiers have been developed in different countries.

Materials and Methods

The study area falls at 16° 6' 0" Nlatitude, 78° 18' 0" E longitude and at an altitude of 582.5 m above mean sea level. The design, fabrication technique, experimental procedure and technological analysis have been discussed in this chapter.

Design procedure

Design of gasifier is made by considering BABUL

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WOOD (Prosopis juliflora) as fuel. The size of the stove was estimated by computing these parameters. Alexis T. Belonio (2005) gave different designing parameters for gas stove, as given below. Design of Gasifier is based on average house hold size in India is 6.

Energy Input, FCR

$$FCR = \frac{Qn}{(HVf\xi g)}$$

Where,

FCR - fuel consumption rate, kg/hr

Qn –heat energy needed, Kcal/hr

HVf –heating value of fuel, Kcal/kg

ξg - gasifier stove efficiency, %

$$FCR = \frac{15.8}{15.5 \times 0.70} = 1.45 \text{ Kg/hr}$$

Reactor Diameter, D

$$D = \sqrt{\frac{1.27 FCR}{SGR}}$$

Where,

D –diameter of reactor, m

FCR –fuel consumption rate, kg/hr

SGR –specific gasification rate of biomass, (kg h^{-1}/m^3 kg h^{-1}/m^3 for Babul Wood)

$$D = \sqrt{\frac{1.27 \times 1.45}{90}}$$

D = 14.3 ≅ 15 cm

Height of the Reactor, H

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

Where,

H –length of the reactor, m

SGR - specific gasification rate of biomass, (kg h^{-1}/m^3)

T –time required to consume biomass, hr

ρ - biomass density, kg/m^3

$$H = \frac{90 \times 1.0}{285}$$

H = 31 cm

Amount of Air Needed for Gasification, AFR

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho a}$$

Where,

AFR –Air flow rate, m^3 /hr

FCR - Fuel consumption rate, kg/hr

SA –Stoichiometric air of biomass

ρa - Air density, 1.225 kg/m^3

ε - Equivalence ratio (0.3)

$$AFR = \frac{0.3 \times 1.45 \times 6}{1.225}$$

AFR =2.13 m^3 /hr

Area for primary air requirement, A

$$A = \frac{AFR}{\rho a \times v}$$

Where,

A – Area of opening, m^2

AFR –Air flow rate, m^3 /hr

V – Velocity of air, m/sec

ρa - Air density, 1.225 kg/m^3

Secondary Air Requirement

Stoichiometric air requirement for combustion

Preliminary investigations such as proximate analysis were carried out to compute the theoretical airflow ratio. Based on elemental and proximate analysis, amount of theoretical air required for combustion of 1kg of fuels was calculated by using following formula,

Amount of air required theoretically for combustion of 1 kg of fuel $= \frac{100}{23}\left[\frac{32}{12} \times C + 8\left(H - \frac{O}{8}\right) + S\right]$

Reactor

The reactor will be made up of Mild Steel sheet of 16 SWG (5 mm thick). It's height and diameter will be 0.310m and 0.15m respectively.

Water holding cylinder

It will be around a reactor to hold the water for heating and made up of **Mild Steel**. Its height and diameter will be 0.310 m and 0.231 m respectively.

Insulation

The insulation between the inner and outer body will be used to reduce the heat losses. Material use will be Glass Wool And thickness of insulation will be 0.03m.

Grate

Grate is placed above primary air inlet. Grate is made from M.S. Bars (6 mm). The gap between the grate should be such that no wood pieces should fall out which are fed in to the gasifier . The grate was provided at 0.050m above the bottom of the gasifier for material support and ash removal.

Primary Air Inlet

M. S. sheet was used for design of primary air inlet at the bottom of the reactor. For entry of air 3 holes of 0.040 m opening will be provided.

Secondary Air Inlet

As per requirement of secondary air for gasification, 9 holes of 0.015m diameter will be provided.

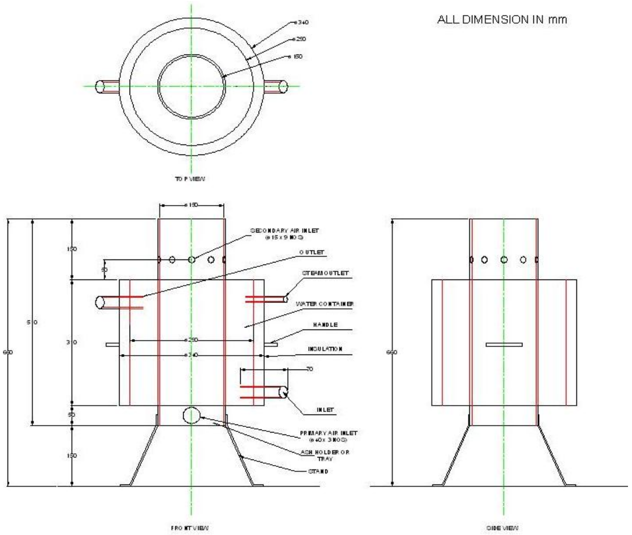

Fig1: Design of household size gasifier cum water heater

Ash chamber

It will be provided to collect ash from the grate and made up of **Mild Steel**. It's height and diameter will be 0.05m and 0.15m.

Water inlet

The inlet will be provided to supply water into water containing cylinder. It's diameter will 0.03m.

Water outlet

It will be provided for removal of hot water. It's diameter will 0.03m.

Steam outlet

When hot water will not be required, then steam produced will be used for electricity generation. Fig 1 shows the Design of household size gasifier cum water heater.

Performance Evaluation of Gasifier cum water heater

Water Boiling Test

Thermal efficiency of cooking stove will be determined by carrying the standard water boiling test (WBT). In the standard WBT, a known quantity of water is heated on the stove. The quantity of water evaporated after complete burning of fuel is determined to calculate the efficiency by using the following formula. Thermal efficiency of a cooking stove may be defined as the ratio of heat actually utilized to the heat theoretically produced by complete combustion of a given quantity of fuel (which is based on the net calorific value of the fuel).

$$\eta(\%) = \frac{M_{wi}C_{pw}(T_e - T_i) + m_{evap}H_1}{F \times CV} \times 100$$

Where,

M_{wi} - Mass of water present initially in cooking vessel i.e. two third volume of vessel, kg;

C_{pw} - Specific heat of water, kJ kg−1 K−1;

m_{evap} - Mass of water evaporated, kg;

F - Mass of fuel burned i.e. charcoal, kg;

T_e - Temperature of boiling water, K;

T_i - Initial temperature of water in pot, K;

H1 - Latent heat of vaporization of water at 373 K, KJ kg−1

CV – Net calorific value of fuel, kJ kg−1

Results and Discussion

Energy extraction from biomass is one of the best options to manage increasing energy demand at global level. The efficient biomass utilization will also unload the pressure on limited reserve of commercial fuels. Thermal gasification is one of the established and proven processes for harnessing the biomass energy.

Performance evaluation of open top gasifier based on House hold cooking system

The open top gasifier was evaluated to determine the various operational parameters for thermal application.. The analysis of the feedstock for the gasification was studied for the proximate analysis and calorific value estimation.

Properties of feed stock

The air dried biomass of babul (Acacia nilotica) cut into convenient size, i.e. 4-5 cm diameter and 5-7 cm long was used as feed stock for testing of gasifier system. Physical and thermal properties of feed stock influence the operation of the thermal system to a great extent. The physical properties include moisture content, proximate analysis and bulk density. The results obtained are mentioned in Table 1.

Table 1: Proximate analysis and calorific value of wood, babul (Acacia nilotica)

Sr.No.	Property	Value
1	Moisture content, %	11.33
2	Volatile matter, %	67.56
3	Ash content, %	2.1
4	Fixed carbon, %	19.01
5	Higher heating value, kcal kg-1	3224.2
6	Bulk density kg m^{-3}	259

The proximate analysis of the biomass babul (Accacia nilotica) revealed that it is suitable of the fuel for gasification. It was observed that, the average moisture content of biomass was found to be 11.33 per cent. The moisture content of the fuel under study was in the acceptable limit (below 15 per cent) to ensure free flow and good quality gas production. The most desirable components, which governed the suitability of the fuel for gasification, that the average fixed carbon was found to be 19.01 per cent in babul (Acacia nilotica).

The heating value of fuel was the major factor determining the suitability of fuel for gasification. The results obtained showed that the average higher heating value was found to be 3224.2 kcal kg-1 for biomass babul (*Acacia nilotica*) under study.

Thermal efficiency by water boiling test

The water boiling test of open top gasifier was carried out to evaluate the thermal performance of open top gasifier. The average thermal efficiency of open top gasifier was found to be 19.26 per cent. Shown in Fig 2. The higher thermal efficiency of open top gasifier than the traditional biomass cooking system revealed to scope for fuel saving.

Fig 2: Water boiling test

Standard water boiling test

Wood fuel used	= Babul (*Acacia nilotica*)
Calorific value of the fuel, kcal kg-1	3321.2
Fuel consumption rate, kg h-1	= 1.45 kg/hr
Mass of fuel, kg	1.3
specific heat of water, kcal kg-1	1
Volume of water before test, kg	= 1.7 kg
Volume of water after test, kg	= 1.1 kg
Time required for boiling water, min	20
Maximum temperature, ^{0}C	= 99°c
Mass of utensil, kg	= 0.4 kg
Specific heat of utensil with lid, kcal kg-1	0.21

Table 2: Observations obtained from water boiling test

Time (min)	Temperature (°c)
0	26
10	76
20	99

$$\eta = \frac{\text{SHw + SHu + LHu}}{Mfu+Hvf} \times 100$$

$$= \frac{1.7\times1\times(99-26)+0.35\times0.215\times(99-26)+540\times1.3}{1.3\times3321.2}\times 100$$

η = 19.26 %

Power output rating by cooking test

The cooking test of gasifier was carried out to evaluate the performance of cooking of gasifier. The power output rating of gasifier was found to be 0.97 kW. The details are shown in Table 3.

Table 3: Observations obtained from cooking test

Sr. no.	Particulars	Observations
1	Quantity of food, gm.	500
2	Time required for cooking, min.	15
3	Fuel consumed, gm.	750

Power output rating = $\frac{F \times CV \times \eta}{860 \times 100}$ kW

Where,

F = Quantity of fuelwood burnt, kg/h;

CV = Calorific value of fuelwood, kcal/kg; and

η = Thermal efficiency of the cooking stove (%), as calculated above.

Power output rating = $\frac{1.3\times3321.2\times19.26}{860\times100}$ = 0.97 kW

Theoretical efficiency of water heating system

The water heating test of gasifier was carried out during water boiling test to evaluate the performance of water heating system of gasifier. The average theoretical efficiencyof water heating system of gasifier was found to be 27.03 per cent.

Table 4: Temperature of water in water holding cylinder with respect to time

Time (min)	Temperature (°c)
0	26
10	54
20	73
30	99

Energy liberated from fuel

Q_f = Calorific value of fuel (kcal/kg) × Mass of Fuel (kg)

= 3321.2 × 1.3

Q_f = 4317.56 kcal

Energy gained by water

$Q_W = m \times C_p \times dT$

= 16 ×1× (99-26)

Q_W =1168 kcal

Efficiency of water heating (η) = $\frac{1168}{4317.56}\times 100$,

η = 27.03 %

Economic evaluation of open top gasifier system

Benefit-cost ratio

The benefit cost ratio was calculated by dividing present worth of benefit stream with the present worth of cost stream and found to be 1.45 for cooking using open top gasifier.

Pay-back period

The pay-back period of open top gasifier cooking system was found to be 4.22 months for the initial investment of open top gasifier.

Conclusions

1) Developed gasifier stove produced less smoke as compared to traditional chullah for different biomass.
2) Thermal efficiency obtained developed gasifier was 19.26 per cent when Babul wood used as fuel.
3) The economical evaluation was carried out based on Benefit cost ratio and Payback period and it was found to be 1.45 and 4.22, respectively. It can be inferred that the developed gasifier is technically as well as economically feasible.

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