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Biomass Stove: Effect of Air to Fuel Ratio on Thermal Efficiency

Balaji Dhopte, Sandeep Mundhe
Department of Chemical Engineering
MGM'S Jawaharlal Nehru College of Engineering
Cidko 431003, Maharashtra, India.

Prasad Kokil
Sanjay Techno Plast Pvt. Ltd.
Waluj 431136, Maharashtra, India

Abstract— **Energy is the prime mover of economic growth and plays a vital role in to sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources, which are readily available with low cost and environment friendly. Use of biomass fuel, as an alternative to conventional fossil fuels, would provide solution to global warming problem. For optimization of air to fuel ratio and with an object of achieving high thermal efficiency, experiments were carried out on Eco Chulla 'Elegant' model having forced draught configuration. Changing fan speed rpm was varied, fuel used was garden waste in all experiments. The set up, preparation and thermal efficiency calculation were based on guidelines provided in Bureau of Indian Standards (BIS) IS 13152(Part 1): 2013**

Keywords—Eco chulla elegant stove; Biomass pellets as a fuel; Battery box; thermal efficiency:

I. INTRODUCTION

Energy is a vital input for economic and social development. Almost 90% of the India's rural population uses biomass as fuel for cooking and heating purposes. Biomass contributes over a third of primary energy in India. Biomass fuels are predominantly used in rural households for cooking and water heating, as well as for traditional and artisan industries. Biomass delivers most energy for the domestic use (rural - 90% and urban - 40%) in India, [7]. Wood fuels contribute 56% of total biomass energy [10]. In rural areas scarce with cash income, combined with freely available biomass resources, leads people to continue to rely on biomass for cooking. In the last few decades, these developing countries have experienced a rapid depletion of natural forest resources that has resulted in hardship for the people living in rural areas, especially women and children who spend a considerable part of their time and energy in search of fuel wood and bio fuels and often have to cover long distances. Besides, deforestation has also led to many negative ecological consequences so main problem with the traditional biomass use is the social costs associated with excessive pollution [7]. The incomplete combustion of biomass in traditional stoves releases pollutants like carbon monoxide, methane, nitrogen oxides, undesirable particulate matter etc. These pollutants cause considerable damage to health, especially of women and children who are exposed to indoor pollution for long duration [11][8]. Another assosiated problem is energy inefficiency. Modern programmes initiated by various Governments aims to overcome these problems. Cook stoves may be classified in various ways based on configuration, material, mode of biomass, combustion etc.[4]The Indian Government also has started programmes to make improved chullas or cook stoves. The Indian Government in 1950 launched National Programme on Improved stove. Over 25.9 lakh improved stoves have been set up during 1997-98 [2]. The efficiency of an improved stove ranges from 15 to 25% as against an efficiency of only 5-10% found in the conventional stoves [5].

Looking at above scenario we decided to work on improving efficiency of biomass cookstove, In this paper various experiments were conducted at two different fan rpms to check the effect of air fuel ratio on thermal efficiency of biomass cookstove. For all the experiments, a fixed setup used was viz. elegant eco chulla, battery box, vessel, and use of biomass pellets i.e garden waste.

A. Principle of combustion:

Combustion, heat transfer and fluid flow are the three main processes which occur in a cookstove. By controlling these processes, thermally efficient stoves can be designed. The combustion process is dependent on the physico-chemical properties of the fuel (size, shape, density, moisture content, fixed carbon content, volatile matter, etc.), quantity and mode of air supply (primary and secondary air) and the conditions of the surroundings (temperature, wind, humidity, etc) [1],[3]. Combustion of wood takes place in following sequence [9]:

1. Drying
2. Pyrolysis
3. Combustion of volatiles
4. Char oxidation

II. BIOMASS PROPERTY

Biomass refers to organic materials that come from plants. It stores energy from sunlight by photosynthesis in bonds of carbon, hydrogen and oxygen molecules. It is characterized into four main types: woody plants, herbaceous plants/grasses, aquatic plants and manures[1]. Biomass is presently estimated to contribute of the order 10–14% of the world's energy supply. The sources of biomass are specially grown energy crops, agricultural wastes, forestry residues, the organic fraction of municipal wastes and garden waste. Its energy is converted to heat, power or chemical feedstock mainly by thermo-chemical conversion [1],[9]

Biomass selected for experimental work was garden waste had moisture content less than 10% and having the gross calorific value as 3500 gm/hr tested though an out source agency. The main differences lies in the ash content, particle size and density.

A. Biomass stove construction

For experimentation eco chulla elegant model with forced draught of air was used. Fan was operates at different as rpm by varying its speed. Battery box of 6 Volt and has maximum speed of 1700 rpm. So efficiency effect is checked at maximum speed. Burning capacity at 1600 rpm is 0.547 kg/h and at 1700 rpm it is 0.576 Kg/h. From the burning capacity heat input is calculated which is obtained as 1619 Kcal/h and 1705 Kcal/h respectively.

III. EXPERIMENTAL PROCEDURE

All the experiments were conducted using garden waste pellets, which were taken from the same batch of manufactures by using eco pelletiser machine. Experiments were conducted as per guidelines in IS 13152. The results of useful heat efficiency of stove were analysed by calculating burn rate/ burning capacity, delivered heat flux and heat input.

A. Determination of burning capacity rate

If the biomass pellet fuel burning rate per hour is not known then it can be calculated by the method described below and was used to estimate the burning capacity of the chulla.

- Asbestos sheets were placed on the platform of the electronic weighing machine to protect it from heating, and then stove was placed above it as shown in Fig. 1.
- As per BIS up to ¾th height of combustion chamber fuel is fed to stove or stacked in the combustion chamber.
- Sprinkle 10 -15 ml of diesel on the fuel from the top of stove/ combustion chamber mouth.
- Note down the weight of biomass stove with fuel, let the mass be M_1 Kg.
- After half an hour of lighting, weight the chulla with fuel residues again and let the mass be M_2 Kg.

  Burning Capacity $= 2x(M_1 - M_2)$ (cal / h) (1)

  Heat Input per hour $= 2x(M_1 - M_2)xCV$ (Kcal/h) (2)

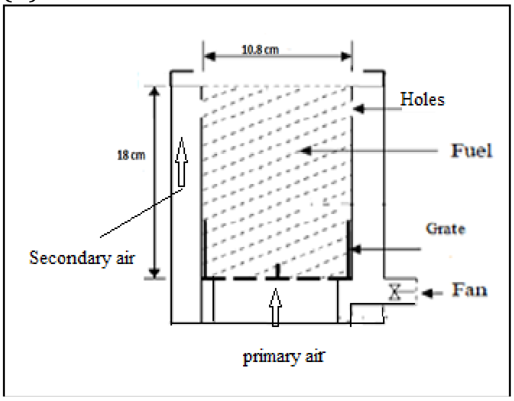

Fig.1. Schematic of eco chulla elegant model.

B. Experimental setup

- Measured quantity of biomass fuel feed in combustion chamber.
- 10-15gm of diesel used for initial ignition of fuel bed.
- Fuel was ignited from the top.
- After establishing good flame, a pot (32 cm diameter) with water quantity of 2 Lwas placed over the stove.
- Burn rate was monitored continuously by noting down the change in the weight of fuel.
- After temperature of water in the pot reaches below 5^0C boiling point of water experiment was stopped.

Conditions for Carrying Out Thermal Efficiency Test

1. Test Room Conditions, the air of the test room shall be free from draughts likely to affect the performance of the chulla. The room temperature shall be 25+5 ºC at the beginning.
2. At the start of the test, the chulha and the wood being used shall be at room temperature.The following terms are used in the analysis of results.

$$\text{Burn rate} = \frac{\text{Weight loss of fuel}}{\text{Time}}, \text{ (gm/min)} \quad (3)$$

3. Thermal efficiency of a chulla 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).

C. Instruments and Other Accessories:

Calorific value of the garden waste pellets was determined by the bomb calorimeter through an outsource agency, Mercury in glass thermometers 0-100ºC, Single pan balance 1 kg capacity (dial with least count of 10 g.), Measuring jars; 1-1, 2-1 and 5-1 capacity, Stop-watch or time measuring device, Pairs of tongs, metallic tray and sticks, Piece of clean cloth.

D. Vessels

The size of the vessel was used as recommended by manufacturer as in BIS IS: 13152 ANNEX A. 32cm diameter size aluminums vessels were used from which flame is not outflow from bottom of vessel. The quantity of water to be taken for the thermal efficiency test depends upon the burning capacity rating of the chulla and from which heat input rate is calculated. Used elegant eco chulla model haves the below 2000 kcal/h heat input rate so quantity of water is 2 L as per IS 13152 clause A-3.4. Water quantity is kept constant for the all comparable experimental results.

E. Procedure

- Stack the measured weight of test fuel in the combustion chamber in honey comb fashion.
- Measure the weight of the vessel with lid and stirrer. A minimum of two such vessels in a set will be required. Put the recommended quantity of water at 23 + 5 ºC (t1).
- Sprinkle 10 - 15 ml of diesel for easy lighting on the test fuel and light the biomass. Simultaneously start the stop watch.

- The water in the vessel shall be allowed to warm steadily till it reaches a temperature of about 80 ºC then stirring is commenced and continued until the temperature of water reaches 95 ºC. Note down time taken to heat the water up to final temperature i.e less than 5 ºC below the boiling point.
- Remove the vessel having temperature of about 95 ºC from the chulla and put the second vessel immediately on the chulla. Prepare first vessel for subsequent heating.
- Repeat the experiment by alternatively putting the two vessels taken until there is no visible flame in the combustion chamber of the chulla. Note down the temperature of the water in the last vessel.

$$H_{out} = (n-1)[\{WxC_v + wxC_w\}(t_2 - t_1) + \{WxC_v + wxC_w\}(t_3 - t_1)](kJ) \quad (4)$$

$$H_{in} = (H_{fuel} xX_{fuel}) + (H_k xX_k)(kJ) \quad (5)$$

$$\eta = \frac{H_{out}}{H_{in}} x100(\%) \quad (6)$$

Where as

w mass of water in vessel, (kg)
W mass of vessel complete with lid and stirrer, (kg)
X_{fuel} mass of solid fuel consumed, (kg)
H_{fuel} 'net' calorific value of wood (or solid fuel), (kJ/kg)
X_h volume of kerosene consumed, (ml)
H_k calorific value of kerosene, (kJ/kg)
t_1 initial temperature of water, (ºC)
t_2 final temperature of water, (ºC)
t_3 final temperature of water in last vessel at the completion of test, (ºC)
n total number of vessels used.
C_w specific heat of water (= 4.186 kJ/kg ºC)
C_v specific heat of the material of the vessel (aluminium) (= 0.896 kJ/kg ºC)
H_{out} heat output of the stove (heat utilized), (kJ)
H_{in} heat input into the stove (heat produced), (kJ)
η thermal efficiency, (%)

IV. RESULTS AND DISCUSSION

The experiments were carried out for two different rpms 1600 and 1700. To check the reproducibility, the same experiments were repeated as given in trial 2 experiments.

A. Experiments on thermal efficiency at 1600 rpm

- *Parameters followed:*
- At 1600 rpm and garden waste used as biomass fuel.
- Vessel size recommended by manufacturer and rest is as per BIS.
- Water quantity 2 L as per BIS.

Table 1. Thermal efficiency results for the constant rpm 1600 with change in fuel weight

Sr. no.	Fuel weight (gm)	Trial 1 Efficiency%	Trial 2 Efficiency%	Ash %
1	635	36.87	36.97	16.53
2	585	35.05	35.2	15.38
3	535	34.7	35.17	16.82
4	485	35.77	35.47	16.59
5	435	31.73	32.06	17.24
6	385	31.01	31.54	16.88
7	335	28.28	29.16	17.91

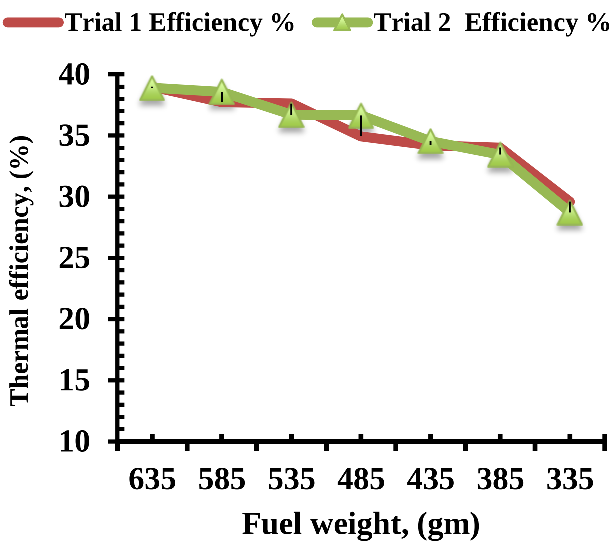

Fig 2. Variation of thermal efficiency with fuel weight at 1600 rpm

B. Experiments on thermal efficiency at 1700 rpm

- *Parameters followed:*
- At 1700 rpm and garden waste used as biomass fuel.
- Vessel size recommended by manufacturer & rest is as per BIS.
- Water quantity 2 lit as per BIS.

Table 2. Thermal efficiency results for the constant RPM 1700 with change in fuel weight

Sr. no.	Fuel weight (gm)	Trial 1 Efficiency %	Trial 2 Efficiency %	Ash %
1	635	39	38.9	19.69
2	585	37.74	38.58	20
3	535	37.62	36.71	19.63
4	485	34.94	36.65	20.61
5	435	34.2	34.55	20.68
6	385	34.02	33.45	19.48
7	335	29.6	28.72	22.38

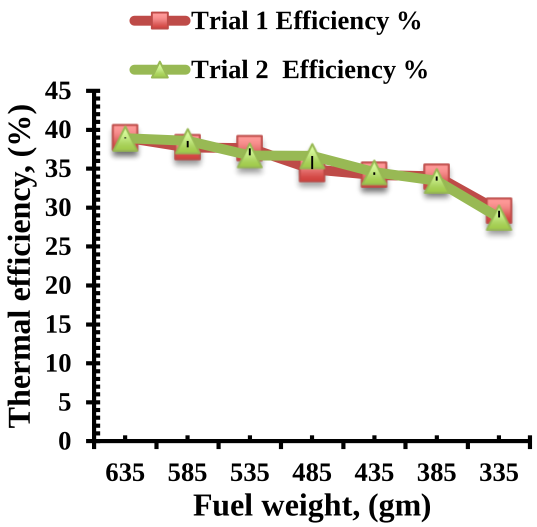

Fig 3.Variation of Thermal Efficiency with fuel weight at 1700 rpm

V. CONCLUSION

1. The decreasing values of thermal efficiency with decreasing fuel weight pattern were observed similar for rpm values of 1600 and 1700. Average thermal efficiency for respective rpm was calculated as 34 % and 35 %.

2. The decreasing in thermal efficiency values is more pronounced for fuel weight of values around 50% recommended by IS 13152, for both 1600 and 1700 rpm.

3. Burn time variation of the order of 5 to 15 min was observed.

4. Burning capacity rate with change in rpm were 25 to 70 gm of variation in biomass fuel was observed.

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