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Design and Economic Feasibility of Community Biomass Cook Stove

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ABSTRACT

The physical and proximate analysis of the fuel used during cooking was determined. The properties viz., moisture content fixed carbon, volatile matter, ash content was determined and the physical properties like bulk densities, resistance to water penetration and the shatter resistance of agro residue briquettes were determined to know the suitability of fuel for cook stove. The cook stove was fabricated as per designed specifications computed by considering the heat energy requirement of 8076 kcal per batch for the community food cooking with the feed rate of briquettes and the solid wood of 2.5 kg/h and 3.03 kg/h, respectively. The stoichiometric air required for the combustion process was worked out so as to ease in combustion of fuel in the cook stove. The thermal profile of the cookstove for the various temperature zones viz., outer temperature, flame temperature, exhaust air temperature was recorded during the experimentation. The burning rate of the developed cookstove was worked out for the briquettes and solid wood fuels. The proximate analysis of the selected fuels like fixed carbon and the heating value showed that fuel selected for the cookstove was found suitable for combustion. The bulk density of briquette was found 38.84 % more than solid wood therefore it occupied less space to store in the cookstove as compared to solid wood (subabul). The design of the community sized agro residue based briquetted cook stove of 4.48 kW rated capacity was found suitable for cooking the food for above 25 members in batch. Based on the design parameters, area of primary air inlet for the selected fuels and area of secondary air inlet was determined and found to be 40.13 cm^2 and 10.9 cm^2, respectively. The inner and outer diameter of reactor was found to be 19 cm and 27 cm, respectively. The height and cross sectional area of the reactor was worked out to be 33 cm and 1395 cm^2 respectively. The thermal efficiency of cookstove on burning briquettes was 37.54 % found 6.33 % more than solid wood fuel at the corresponding average flame temperature and burning rate of solid wood of 730.2 ^{0}C and 3.03 kg/h, respectively. The estimated cost of the system was Rs. 12000/- with 2 year and 1 month payback period and benefit cost ratio of 1.28. It could be inferred that the developed agro residue based briquetted cook stove is technically as well as economically feasible in the present energy context.

Keywords

Design, Community cook stove, Air requirement, Sizing, Power rating, Economic.

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Introduction

The worldwide demand of energy is expected to rise dramatically in the near future. India requires more and more energy due to urbanization. Environmental factors also have an increasingly important role in shaping our future energy demands. The world requires cleaner and more sustainable energy sources to avoid pollution and climate change. Many alternative sources of energy are being proposed and evaluated such as solar power, wind energy, tidal energy and energy from biomass sources (Alam, 2000).

The energy is broadly utilized in five major sectors namely households, industry, transport, electric power generation and agriculture. Renewable energy obtained from solar, wind, biomass, hydro or any other resource is capable of contributing to meet the energy demand for these five sectors to some extent (Anon, 2010). The development based on commercial fuels is not sustainable due to the current level of pollution and deterioration in natural resource base. There are drastic changes in the composition and behavior of our atmosphere due to rapid release of polluting combustion products from fossil fuels (Banarjee *et al*., 1990).

The use of the community stove will be for much longer time at a stretch as compared to the domestic stoves which have much shorter cooking cycles. Fuel uses for community cook stove are big logs, small twigs, processed fuel (briquettes or chopped wood). Stove may be forced draught or natural draught based; they may be fixed or portable etc (Belonio *et al*., 2000). Agro residues are being used for briquetting which is also called as white coke. The surplus agro residues are being used for densification in binder less briquetting processes. In Akola District, more than 15 biomass briquetting plants are in operation which utilizes variety of agro residue for briquetting viz. soybean straw, ground nut shells, pigeon pea etc. For community cooking large size biomass gasifier based cookstove operating on biomass briquette could replace conventional use of wood. To meet out the demand of the local dhabas and road sides' hotels requirement and to suit the domestic use cook stove based on agro residue briquettes has been designed and developed.

Materials and Methods

The present study on agro residue based cook stove was carried out to design the community size cook stove. The designed system was fabricated at workshop and tested at the Department of Unconventional Energy Sources and Electrical Engineering, Post Graduate Institute, Dr. PDKV, Akola. The properties of feedstock, design of cookstove, fabrication technique, equipment, instruments used, experimental procedure and technological analysis have been discussed in this chapter.

Properties of agro-residue biomass fuel

Woody biomass of Leucaena leucocephala (subabul) and agro residue briquette (soybean) were tested for its physical and thermal properties. Prior to gasification following tests were conducted to determine the quality of fuel (Bhattacharya *et al.*, 2004).

Physical properties of agro residue biomass fuel

The physical properties such as moisture content, overall length and diameter, bulk density, shatter resistance and resistance to water penetration of biomass fuel were determined.

Moisture content

Moisture content was determined immediately prior to conduct other analysis. Moisture content was determined by oven drying method. Samples were dried at temperature 110^0 C for one hour

The moisture content (wb) was determined by using formula, (Dixit *et al*., 2006)

Moisture content (wb) = $(W_1 - W_2 / W_1) \times 100$ … (1)

Where,
W_1 - Initial weight of sample, g
W_2 - Final weight of sample, g

Overall length and diameter of briquette and woody biomass

To measure the overall length and diameter of agro residue briquettes and woody biomass, scale and vernier caliper was used.

Bulk density

Water displacement method was used to measure the volume of individual briquette. The briquettes were coated with wax, in order to prevent any water absorption during merging process Each briquettes was weighed and then dipped into hot wax (70°C) for a couple of times until fully covered. The waxed briquette were weighed and then submerged into water in suspension position and weight of displaced water was measured and recorded as the volume of the wax briquettes The volume of each briquette was calculated by subtracting the volume of coating wax from the volume of wax briquettes The volume of coating wax was obtained by dividing its weight of the wax obtained by subtracting original weight of briquette from the weight of wax briquette by its volume (Dubey *et al.*, 2000; Jain, 2006; Khardiwar *et al.*, 2014).

Volume of sample = Volume of waxed sample – Volume of wax

$$= V - \{(W_3 - W_2) / \text{density of wax}\} \quad \dots (2)$$

Where,
W_1 = Initial weight of sample, g
W_2 = Weight of sample + string, g
W_3 = Weight of waxed sample + string, g

Shatter resistance

It was measured as the percentage loss of weight from shattering. Each briquette was subjected to ten repeated drop from 1 m height on a concrete surface. The percent loss was then calculated. The shatter resistance of briquette was calculated by using formula,

Percent weight loss (%) = $[(W_1\text{-}W_2 / W_1)\ 100\%]$
Shatter resistance (%) = 100 – percent weight loss ... (3)

Where,

W_1 = Weight of briquette before shattering, g
W_2 = Weight of briquette after shattering, g

Resistance to water penetration

It is measure of percentage wider absorbed by a pellet immersed in water. Each briquette was immersed in10 cm of water column at 27 for 30 sec. The percent water gain was calculated and recorded by using following formula (Khardiwar, 2013).

Water gain by briquette (%) = $(W_2 – W_1 / W_1)\ 100$ ... (4)

Where,

W_1 = Initial weight of briquette, g
W_2 = Weight of wet briquette, g

Thermal properties

The important thermal properties of agro residue briquette and woody biomass fuel include calorific value, volatile matter, ash content and fixed carbon.

Ash content

On combustion, the organic matter in biomass burns off leaving behind 'ash' which is product of oxidation of the mineral matter. This is measure of the unwanted impurities present in a biomass. It was determined in a muffle furnace at a temperature of 550 ^{0}C for 1 hour. The procedure was repeated until no variation in the weight was observed.

Volatile matter

Weighed exactly 1-g sample previously at 950 + 20 ^{0}C and weighed platinum crucible (diameter 2.5 — 3.5 cm, capacity 10-20 ml) with close fitting lid, which has bent for escape of volatile matter. Spread the materials evenly, close with lid and placed in muffle furnace maintained at 925 ± 20 ^{0}C and shut the door.

After heating exactly for 7 minutes crucible was taken out the and first brought down its temperature to room temperature rapidly (to avoid oxidation of its contents) by placing in a cold iron plate and then transferred warm crucible to dessicator to bring it to room temperature. Take the final weight of crucible and contents.

Volatile (%) = [(B-C)/ (B-A) 100-% moisture content] … (5)

Where,

A = Weight of empty crucible, g
B = Weight of crucible + sample before heating, g
C = Weight of crucible + sample after heating, g

Fixed carbon

The residue remaining after volatile matter release has been expelled, contains the mineral matter originally present and non volatile or fixed carbon. The fixed carbon was thus calculated as follows (Panwar and Rathore, 2008; Panwar and Salvi, 2011).

Fixed carbon (%) = 100 – (% moisture + % ash + % V.M.) … (6)

Design of community sized biomass briquette based cook stove

The up draft type agro residue briquette cook stove for cooking of the community food was designed and developed. The step wise procedure for design, development, and evaluation of up draft agro residue briquetted cook stove has been discussed as follows (Yohannes, 2011; Sengar *et al.*, 2015).

Design of up draft type cook stove

The initial design conditions and assumptions made for the fabrication of up draft agro residue based briquetted cook stove system are listed in table 1.

The following design parameters were considered for the design of the up draft gasifier based agro residue briquetted cook stove with single pot for community cooking.

Heat required for community cooking, Q_n

The total amount of heat required for cooking of food for 50 people estimated as below.

Energy needed

This refers to the amount of heat that needs to be supplied by the stove. This can be determined based on the amount of food to be cooked and/or water to be boiled and their corresponding specific heat energy as shown in table 2.

The amount of energy needed to cook food can be calculated using the formula,
Amount of energy needed to cook rice

$$Q_{n1} = (m_r C_{p(rice)} + m_w C_{P(W)})\Delta t + m_r \lambda_f \quad \dots (7)$$

Amount of energy needed to cook vegetable

$$Q_{n2} = (m_v C_{p(veg)} + m_w C_{P(W)})\Delta t + m_v \lambda_f \quad \dots (8)$$

$$Q_n = Q_{n1} + Q_{n2} \quad \dots (9)$$

Where,

λ_f – Latent heat of vaporization, 589 kcal/kg

m_r – Mass of rice, kg

$C_{p(rice)}$ – Specific heat of rice, kcal/kg°C

m_{w1} and m_{w2} - Mass of water, kg

$C_{P(w)}$ – Specific heat of water, kcal/kg°C

m_v – Mass of vegetable, kg

$C_{p(veg)}$ – Specific heat of vegetable, kcal/kg°C

Q_{n1} – Heat required for pot-1, kcal

Q_{n2} – Heat required for pot-2, kcal

Q_n – Total heat required, kcal

Energy input

The amount of fuel i.e. biomass for generation of heat for cooking of food in cooking was calculated as

$$EI = \frac{Q_n}{(H_{vf} \times \eta_g)} \quad \ldots\ldots (10)$$

Where,

EI – Energy input rate, kg/h

Q_n – Heat energy needed, kcal/h

CV_f – Calorific value of fuel, kcal/kg

η_g – cook stove efficiency, %

Reactor diameter

The diameter of cylindrical shape reactor of up draft cook stove was calculated by using following relation,

$$D = \sqrt{\frac{1.27 \; EI}{SGR}} \quad \ldots\ldots (11)$$

Where,

D – Diameter of reactor, m

EI – Fuel consumption rate, kg/h

SGR – Specific gasification rate of biomass, kg/m^{2}h

Height of the reactor

The height of cylindrical shape reactor of up draft cook stove was calculated as,

Duty hour of cook stove is 2 hour,

Fuel holding capacity

$$= \frac{\text{Fuel requirement}}{\text{Bulk density of fuel}} \quad \ldots\ldots (12)$$

$$\text{Area of grate} = \frac{EI}{SGR} \quad \ldots\ldots (13)$$

$$\text{Height} = \frac{\text{Fuel holding capacity}}{\text{Area of grate}} \quad (14)$$

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 1 kg of fuels was calculated by using following formula,

Amount of air required theoretically for combustion of 1 kg of fuel

$$= \frac{100}{23}\left[\frac{32}{12} \times C + 8\left(H - \frac{O}{8}\right) + S\right] \quad (15)$$

Amount of air needed for combustion

The amount of air required for combustion of the fuel in the reactor was determined by using following formula,

$$AFR = \frac{\varepsilon \times EI \times SA}{\rho_a} \quad \ldots\ldots (16)$$

Where,

AFR – Air flow rate, m^3/h

EI – Energy input rate, kg/h

SA – Stoichiometric air of biomass

ρ_a – Air density, 1.225 kg/m^3

ε – Equivalence ratio, 0.3

Area for primary air requirement

Area for primary air requirement was determined as

$$A_p = \frac{AFR}{v} \quad \text{...... (17)}$$

Where,

A_p – Area of opening, m^2
AFR –Air flow rate, m^3 /h
v – Velocity of air, 0.2 m/sec

Secondary air requirement

The secondary air requirement for burning of cook stove is calculated by assuming the general composition of gas, and oxygen requirement of different combustion reaction has taken into consideration as follow:

H_2- 15 %, CO- 18 %, and CH_4- 1 %
Combustion Reactions: for Producer gas
$2H_2 + O_2 \rightarrow 2H_2O$
$2CO + O_2 \rightarrow 2CO_2$
$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

Insulation thickness

The insulation thickness, designed by R is dependent on thermal quantities k and h_c

$$R = \frac{k}{h_c} \quad \text{...... (18)}$$

Where,

k = Thermal conductivity of insulation (glass wool), $Wm^{-1}K^{1}$
h_c = Heat transfer coefficient, $Wm^{-2}K^{-1}$
Total thickness of insulation, $t_i = 2 \times R$

System description

The details of developed briquetted cook stove are elaborated below (Fig. 1) and Inner cylinder (Fig. 2).

Reactor

The reactor is the heart of the stove where producer gas was produced. The outside wall of the reactor is made of 10 gauge mild steel sheet. Outside diameter of the reactor frame was 27 cm. The inside wall was made of 10 gauge mild steel sheet with 19 cm diameter. An inner cylinder (Fig. 3) and outer cylinder welded from top and bottom making a hollow space for providing secondary air supply through holes of inner cylinder (Fig. 3).

Grate

The grate was made of cast iron circular plate of 18 cm diameter, this grate was welded with a 7.5 cm height cylinder and ash falls though the grate into the cylindrical chamber and from there to ash pit. An ash scraper was fixed below the small cylinder, to break the lumps of ash accumulated inside the chamber. Ash could otherwise block the flow of fresh fuel from the fuel chamber into the reaction chamber.

Ash pit box

A mild steel ash pit box have 10x22.5x22.5 cm dimension provided below the reaction chamber. The ash could be removed when filled with ash in pit. The ash pit box made of mild steel sheet was fixed to the reaction chamber body. A handle was welded to the ash pit box for easy opening and closing. The ash accumulated in the ash pit was periodically removed.

Primary air inlet

The primary air inlet was made in a mild steel sheet, and attached on one side of the reactor. A sliding door provided at the bottom of the primary air inlet could be used to control the gasification rate inside the reactor by controlling the flow of primary air. There were four holes each of 3.57 cm diameters provided at bottom of reactor.

Grate up down pedal

This arrangement was provided to supply uniform heat at constant rate to the vessel even after fuel was used during combustion.

The grate up down pedal was made with angle having 30x0.3x2.5 cm dimension of mild steel, and the angle connecting to center of grate. The up down pedal had a three adjustment steps each of gave 2.5 cm grate height.

Ash removing handle

The ash removing handle having 25x3.2x0.5 cm dimension made of mild steel rod was provided for removal of ash. It was provided at the bottom of stove chamber. When ash accumulated at the chamber below the grate it could be remove with the help of ash removing handle.

DC fan

A fan of 5 watts 12 volts DC with battery backup was used to provide the amount of air required for gasification. The battery could be charged with 230 volt AC supply and run for 6-7 hr. with fully charged battery. The amount of air supply could be controlled using regulator of fan. The fan was fixed in a blower chamber having 12x12 sq.cm dimensions.

Wheels and handle

Four numbers of heavy castor wheels were provided at the bottom of cook stove and two handle at top was provided for easy transport of the cook stove.

Top rest

Top rest was made up of cast iron with a conical shape to provide the uniform flame to the pot and to reduce heat losses. A briquette feeding door is provided for continuous feeding of fuel having dimension 8x10 cm. opening. The pot could easily mount on the top rest. As per the design specification, cook stove was fabricated in the workshop of Department of UCES and EE as shown in figure 4.

The agro residue based briquetted cook stove, included a reactor chamber, blower and top rest. The agro residue biomass-fired briquetted cook stove consisted of three main parts i.e. reactor chamber, blower air inlet, grate up down pedal and combustion chamber, insulated glazing of glass wool in the outer jacket of cylinder, castor wheels and ash pit box. Different parts of the stove could be attached together by screw and welding mechanism.

Controlled cooking test (CCT)

This is a field test used to evaluate the stove performance of a new cook stove under the common or traditional cooking methods. CCT is designed to compare the different cook stove's performance in a controlled manner by controlling fuels, pots, and operation of the stove. Local users prepare a traditional food on the stoves, so that stoves can be compared, by cooking the same food in the same pot and give their opinions for modification in the cook stove model. It reveals what is possible in households under ideal conditions. The CCT stimulates the actual cooking, when the stove subjected to more realistic through controlled conditions. The test was performed for evaluating the following aspects regarding the cook stove; (i) to compare the amount of fuel used by different cook stoves to cook a food or meal, (ii) to compare the time needed to cook that food (Sharma and Panwar, 2009).

Evaluation of thermal efficiency

The size of the vessel and the quantity of water was taken for the thermal efficiency test was selected according to IS 13152 (Part 1) (Plate 3.5). The mathematic formula to evaluate the efficiency of cook stove is used as below; (Patil and Singh, 2004)

$$\eta = \frac{m_{wi}\ c_{pw}\ (T_e - T_i) + m_{i,evap}\ \lambda_f}{m_f CV_f} \quad \ldots(19)$$

Where,

m_{wi} – Mass of water initially, kg

c_{pw} – Specific heat of water, kcal/kg °C

T_e – Temperature of boiling water, °C

T_i – Initial temperature of water, °C

$m_{i,evap}$ – Mass of water evaporated, kg

λ_f – Latent heat of vaporization of water, 589 kcal/kg

m_f – Mass of fuel burned, kg

CV_f – Calorific value of fuel, kcal/kg

Economic evaluation of cook stove

For the success and commercialization of any new technology, it is essential to know whether the technology is economically viable or not. Therefore, an attempt was made to analyse the economics of the developed system. In view of finding out economic feasibility of developed system, four different economic indicators namely net present worth, benefit cost ratio, internal rate of return and payback period were determined (Rathore *et al*., 2009)

The yearly cost of operation calculated based on the following assumption

a. The operating life of the system was assumed to be 10 years.
b. A discount rate (i) of 10 per cent was used.
c. The agro residue based briquetted cook stove can be operated 300 days in a year.
d. Present system was compared with the conventional method of cooking.
e. The cost of one kg of agro residue briquette was assumed to be Rs.4/-.

Net present worth

The difference between the present value of all future returns and the present money required to make an investment is the net present worth or net present principals for the investment. The present value of the future returns can be calculated though the use of discounting. Discounting essentially a technique by which future benefits and cost streams can be converted to their present worth. The interest rate was assumed as the discount rate for discounting purpose. A project returns the same benefit in each of several years and we need to know the present worth of that future income stream to know how much it is justified in investing today to receive that income stream. The most straight forward discounted cash flow measure of project worth is the net present worth (NPW). The net present worth may be computed by subtracting the total discounted present worth of the cost streams from that of the benefit stream. To obtain the incremental net benefit gross cost is subtracted from gross benefit or the investment cost from the net benefit. The mathematical statement for net present worth can be written as:

$$NPW = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} \quad \ldots\ (20)$$

Where,

C_t = Cost in each year
B_t = Benefit in each year
t = 1, 2, 3................n
i = Discount rate

Benefit cost ratio

This is the ratio obtained when the present worth of the benefit stream is divided by the present worth of the cost stream. The formal selection criterion for the benefit cost ratio for measure of project worth is to accept projects for a benefit cost ratio of one or greater.

In practice, it is probably more common not to compute the benefit cost ratio using gross cost and gross benefit, but rather to compare the present worth of the net benefit with the present worth of the investment cost plus the operation and maintenance cost. The ratio is computed by taking the present worth of the gross benefit less associated cost and then comparing it with the present worth of the project cost. The associated cost is the value of the goods and service over and above those included in project costs needed to make the immediate products or services of the project available for use or sale. Project economic cost is the sum of installation costs, operation and maintenance and replacement costs.

The mathematical benefit-cost ratio can be expressed as:

$$\text{Benefit-cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}} \text{ …... } (21)$$

Where,

C_t = Cost in each year

B_t = Benefit in each year

t = 1, 2, 3................n

i = discount rate

Payback period

The payback period is the length of time from the beginning of the project until the net value of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflow.

Results and Discussion

The community sized agro residue based briquetted cook stove was fabricated in the workshop of Dept. Of UCES and EE, Dr. PDKV, Akola. The designed system was tested for its technical as well as economic feasibility for community cooking. The data was collected during the water boiling test and emission testing. The data were observed along with parameters such as initial temperature of water, hot water temperature and ash remaining. Moisture content, proximate analysis in which fixed carbon, volatile matter and ash content were determined. Physical properties of biomass briquettes were determined such as overall length and diameter of briquettes, bulk density, shatter resistance and resistance to water penetration. Flame temperature, flue gas outlet temperature, stove surface temperature, burning rate, power output rating, emission characteristics and thermal efficiency were determined. Economical feasibility of developed system was evaluated in terms of net present worth, benefit-cost ratio and payback period. This chapter deals with the results of the technical and economical feasibility of community size agro residue based briquetted cook stove.

Properties of biomass

The main feed characteristics are the nature of the thermal degradation which basically depends upon the chemical and physical composition of the fuel and partly upon the prevailing conditions of heat and mass transfer. A physical and thermal property of feed stock influences the operation of the thermal system to a great extent. Physical properties control the flow behavior while the chemical properties are important to understand how the reactions proceed.

Moisture content and proximate analysis

The details of the biomass characteristics are given in table 3. The feed used during the test was briquette (soybean) and solid wood (subabul). The average moisture content of the feed stock used in experiment was recorded 9.33 % w.b. for briquette and 8.57 % w.b. for solid wood. The composition of proximate analysis was worked out for the selected biomass feedstock. The detail of proximate analysis of biomass feedstock is given in table 3. The fixed carbon recorded in both feed stock and it was 13.86 %, 24.63 % for briquette and solid wood respectively. The volatile matter and ash content of biomass feed stock were determined as same depicted in table 3. The calorific value of feed stock was taken from (Anon, 2014) for briquette and (Varunkumar *et al*., 2011) for subabul. The detail calculations for the thermal properties of biomass was given in Appendix-A. Similar investigation was also made by (Zanjani *et al*., 2014).

Physical properties of biomass

The average length of briquette and solid wood recorded as 66.66, 54.00 mm respectively. Diameter of briquette was 90 mm and for solid wood 3.15 mm were recorded also bulk density of feed stock were recorded as 0.605, 0.364 g/cm^3 for briquette and solid wood respectively. Resistance to shattering and resistance to water penetration were recorded for briquette and solid fuel as depicted in table 4. The physical properties of biomass found to be appropriate for the experiment. Similar investigation were also made by (Birwatkar *et al*., 2014; Jittabuta, 2015).

Design of agro residue based briquetted cook stove

The community sized agro residue based briquette cook stove was designed for specific requirement of heat in cooking. The design of community cookstove has been worked out for fifty (50) persons. The heat requirement has been determined for cooking rice and vegetables. The total heat requirement for cooking rice was found to be 5363.02 kcal. The heat requirement for the preparation of rice (7.5 kg) and for vegetable (4 kg) was calculated to be 8076.42 kcal. The details of the heat energy involved in the design of community cookstove are depicted in table 5. The EI (energy input) of cookstove was found to be 2.76 kg/h (Ghoshray, 1986).

The specification of community cookstove is depicted in table 6. The inner diameter of the reactor of stove was found to be 19 cm and outer diameter of stove was worked out to be 27 cm and height of inner reactor was calculated 33 cm. the primary and secondary air inlet was found to be 40.13 cm^2 and 10.9^2 respectively (Jorapur and Rajvanshi, 1995). The overall power capacity was calculated and found to be 4.48 kW. The stoichiometric air required for complete combustion of 1 kg of feed stock found to be 5.24 kg. Amount of air needed and secondary air requirement for combustion was worked out to be 3.54, 4.72 m^3/h respectively depicted in table 7.

Thermal efficiency of community cook stove

Thermal efficiency of the community cookstove for briquette is depicted in figure 5. It is clear evidence that, the developed community cookstove, have more energy efficient than the market community cookstove (Fig. 5). The thermal efficiency of the market community stove and developed community stove was observed to be 31.08 % and 35.42 % respectively. The developed community stove was found 12.25 % more thermal efficient than the market community stove during testing for agro residue briquette (Tripathi *et al*., 1995).

Controlled cooking test (CCT)

The controlled cooking test of developed community cook stove was carried out at Boys Hostel, Dr. PDKV, Akola. A 15 kg of rice was cooked during the controlled cooking test in 36 min. The details of cooking test is shown in table 8 and the fuel was saved in developed cook stove up to 44.22 % than traditional stove, similarly time was saved up to 18.18 % (Bhattacharya *et al*., 2002).

Table.1 Initial design assumptions for design of up draft type cook stove

SN	Design parameters	:	Particulars
1	Combustion type	:	Up draft
2	Type of fuel	:	Biomass briquette
3	Calorific value of fuel, kcal/kg	:	4170
4	Bulk Density of fuel, kg m^{-3}	:	613
5	Gasification efficiency, %	:	70
6	Specific gasification rate, kg $m^{-2}h^{-1}$	:	99
7	Equivalent ration, ε	:	0.3
8	Stoichiometric air fuel ratio, kg of air kg^{-1} of biomass	:	5.24
9	Cooking of food (50 person)	:	Rice and vegetable

Table.2 Energy requirement for cooking food and for boiling water

SN	Food	Specific heat, kcal/kg°C	Total energy needed, kcal/kg
1	Rice	0.42 – 0.44	79.3
2	Vegetables	0.93	74.5
3	Water	1	72

(Source: Belonio and Anderson, 2005)

Table.3 Moisture content and thermal properties of biomass feedstock

Biomass feedstock	Average moisture content, % (w.b.)	Proximate composition, %			Calorific value, kcal/kg*
		Fixed carbon, %	Volatile matter, %	Ash content, %	
Briquette (Soybean)	9.33	13.86	64.4	9.4	4170
Leucaena leucocephala (Subabul)	8.57	24.63	65.13	2.67	3700

*[18]

Table.4 Physical properties of biomass feedstock

Biomass type	Length, mm	Diameter, mm	Bulk density, kg/m^3	Shatter resistance, %	Resistance to water penetration, %
Briquette	66.66	90	605	94.26	63.86
Solid wood	54.00	3.15	364	99.50	98.03

Table.5 Designed heat requirement of community cookstove

SN	Particulars	Specification
1	Heat required for cooking 7.5 kg rice, kcal	5363.02
2	Heat required for cooking 4 kg vegetable, kcal	2713.40
3	Total heat required, kcal	8076.42
4	Energy Input, kg/h	2.76

Table.6 Designed specification of community cookstove

SN	Particulars	Specification
1	Inner diameter of reactor, cm	19
2	Outer diameter of reactor, cm	27
3	Height of inner reactor, cm	33
4	Cross sectional area, cm^2	1395.41
5	Area for primary air inlet, cm^2	40.13
6	Area of secondary air inlet, cm^2	10.9
7	Air flow rate, m^3/h	4.72
8	Capacity, kW	4.48

Table.7 Designed air requirements for cook stove

SN	Particulars	Specification
1	Stoichiometric air required, kg	5.24
2	Amount of air needed for combustion, m^3/h	3.54
3	Secondary air requirement, m^3/h	4.72

Table.8 Evaluation of stove in controlled cooking test

SN	Parameter	Cook stove		Remarks
		Traditional	Developed	
1	Cooking material rice, kg	15	15	
2	Fuel used, kg	4.5	2.51	Saving fuel of 44.22 %
3	Time to cook, min	44	36	Saving in time of 18.18 %
4	User opinion	More time requirement and smoke is more	Less smoke and user friendly	Overall developed stove is feasible

Table.9 Cost estimation of community size agro residue based briquetted cook stove

SN	Material	Dimension / Requirement	Cost Rs.	Total cost Rs.
1	Mild steel sheet (10 gauge)	40 ft^2	100 / ft^2	4000
2	Stainless steel sheet (16 gauge)	6.0 ft^2	95/ ft^2	570
3	Glass wool	1.5 kg	150/kg	225
4	Inverter and DC fan	1	2000	2000
5	Ash pit box	1	500	500
6	Iron casting	13 kg	200/kg	2600
7	Miscellaneous			1000
8	Manufacturing cost			1105
	Total			**12000**

Table.10 Economic feasibility evaluation parameters of cookstove

SN	Parameter	Value
1	Fuel used in traditional cookstove, kg/day	29.10
2	Fuel used in developed cookstove, kg/day	11.06
3	Net fuel saving, kg/day	18.04
4	Annual fuel saving, kg	5412
5	Rate of fuel, Rs/kg	4
5	Annual fuel saving, Rs	21648
6	Discount rate, %	10

Table.11 Cash flow for developed cookstove

year	Cash Outflow, Rs	Pw of cash Cost, Rs	Cash Inflow, Rs	PW of benefit, Rs	Net present value, Rs
1	**2**	**3**	**4**	**5**	**(5-3)**
0	12000	12000.00	0	0	-12000.00
1	14972	13610.91	21648	19680.00	6069.09
2	14972	12373.55	21648	17890.91	5517.36
3	14972	11248.69	21648	16264.46	5015.78
4	14972	10226.08	21648	14785.88	4559.80
5	14972	9296.43	21648	13441.70	4145.27
6	14972	8451.30	21648	12219.73	3768.43
7	14972	7683.00	21648	11108.85	3425.84
8	14972	6984.55	21648	10098.95	3114.40
9	14972	6349.59	21648	9180.87	2831.28
10	14972	5772.35	21648	8346.24	2573.89
		103996.46		133022.58	29021.13
				NPW	**29021.13**
				B:C ratio	**1.28**

Table.12 Payback period for community cookstove

Year	Initial Investiment	Income	Net cash flow benefit	Cumulative net cash flow
0	12000			
1		21648	6069.09	6069.09
2		21648	5517.36	11586.45
3		21648	5015.78	16602.22
4		21648	4559.80	21162.02
5		21648	4145.27	25307.29

Payback period = 2 yr 1 month

Fig.1 Solid isometric view of briquetted cook stove

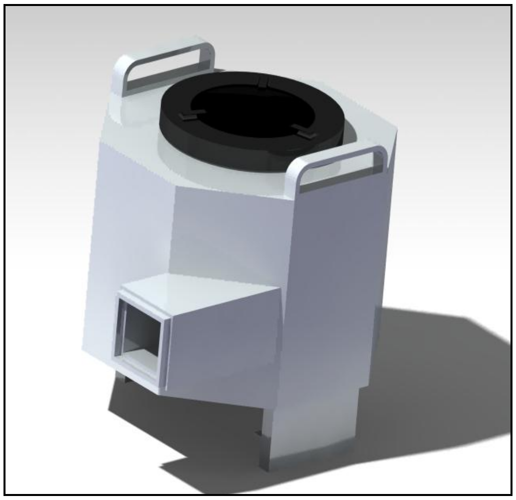


Fig.2 Side view and top view of briquetted cook stove

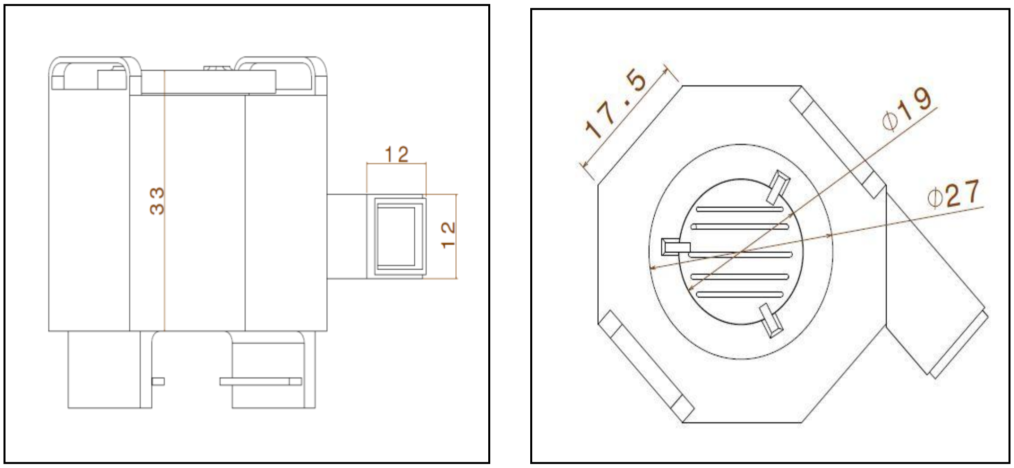


Fig.3 Solid view of inner cylinder reactor

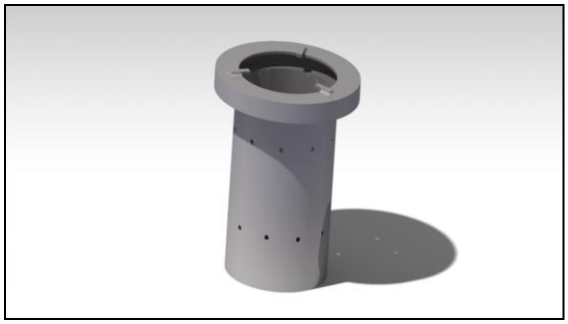
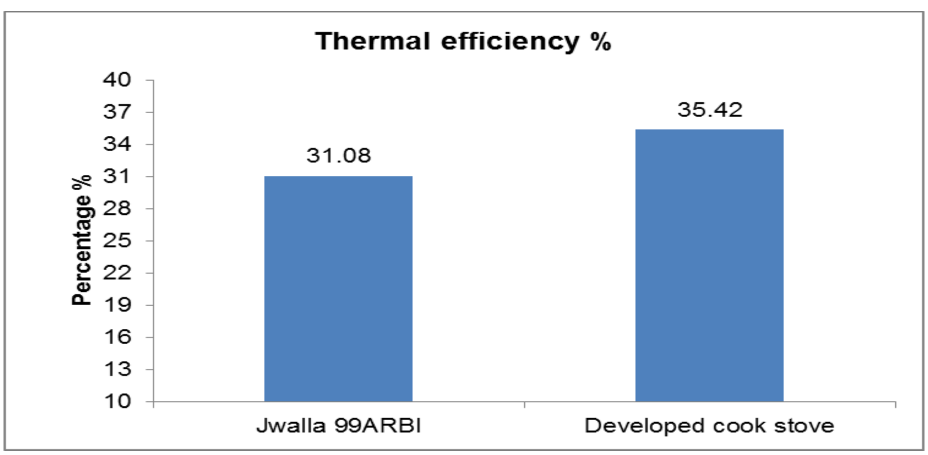


Figure.4 Developed community cook stove in operation

Fig.5 Comparative evaluation of thermal efficiency



Economic feasibility of community cook stove

The economic feasibility of the developed community cookstove was evaluated using discount cash flow (DCF) method. The economic parameters are present worth of cost, present worth of benefit, net present value, internal rate of return, payback period was determined over the net saving of fuel by the developed community cookstove (Pathgi and Sharma, 2012) The total cost of developed cookstove was calculated by the material required for construction as depicted in table 9.

Table 10 depicted the information used to analyze the economic feasibility of the community cookstove. The net saving in cost per annum was worked out and found to be Rs. 21648. The cost of fabrication of the stove is found to be Rs. 12000. The annual operation cost was determined and found to be Rs. 14972.

Discounted cash flow method

The economical performance has been worked out by considering the cost and benefit. Table 11 showed the discount cash flow analysis over the period. The discounted factor consider for the analysis was 10 %. The present worth cost after the 10 year was found to be Rs. 103996. The present worth of benefit after 10 year was worked out to be Rs. 133022.

The net present value of the project is positive and hence the developed cookstove has offered the financial benefits to the end user. The net present value for the 10 year of cash flow analysis was found to be Rs. 29021.

The benefit cost ratio of the financial system has been worked out for the cost and benefit involved over the period. The benefit cost ratio of the cookstove was observed to be 1.28 as depicted in table 11.

The payback period of the investment involved has been workout. The total fabrication and installation cost of developed community cookstove was Rs. 12000. Table 12 showed the information of payback period. The payback period of the investment was found 2 years and 1 month only.

In conclusion, the cook stove was fabricated as per designed specifications computed by considering the heat energy requirement of 8076 kcal per batch for the community food cooking with the feed rate of briquettes and the solid wood of 2.5 kg/h and 3.03 kg/h, respectively. The stoichiometric air required for the combustion process was worked out so as to ease in combustion of fuel in the cook stove. The performance of developed cookstove was carried out as per the procedure specified in the BIS test code IS 13152 (Part 1).

The thermal profile of the cookstove for the various temperature zones viz., outer temperature, flame temperature, exhaust air temperature was recorded during the experimentation. The burning rate of the developed cookstove was worked out for the briquettes and solid wood fuels. Based on the water boiling temperature during the experimentation and federate of fuel the thermal efficiency of cookstove was determined. The average power output of the community cookstove was found to be 4.48 kW.

Based on the results obtained during the experimentation following conclusions could be drawn:

1. The proximate analysis of the selected fuels like fixed carbon and the heating

value showed that fuel selected for the cookstove was found suitable for combustion.

2. The bulk density of briquette was found 38.84 % more than solid wood therefore it occupied less space to store in the cookstove as compared to solid wood (subabul).
3. The design of the community sized agro residue based briquetted cook stove of 4.48 kW rated capacity was found suitable for cooking the food for above 25 members in batch.
4. Based on the design parameters, area of primary air inlet for the selected fuels and area of secondary air inlet was determined and found to be 40.13 cm^2 and 10.9 cm^2, respectively. The inner and outer diameter of reactor was found to be 19 cm and 27 cm, respectively. The height and cross sectional area of the reactor was worked out to be 33 cm and 1395 cm^2 respectively.
5. The thermal efficiency of cookstove on burning briquettes was 37.54 % found 6.33 % more than solid wood fuel at the corresponding average flame temperature and burning rate of solid wood of 730.2 ^{0}C and 3.03 kg/h, respectively.
6. Thermal efficiency of developed cookstove was found to be 12.25 % higher than the locally available community cookstove of same size.
7. The controlled cooking test of the developed cookstove revealed that the time required for cooking 15 kg of rice was 8 minutes and 1.99 kg less fuel than traditional bhatti thus 18.18 % time and 44. 22 % fuel saved respectively in the developed cook stove cookstove.
8. The estimated cost of the system was Rs. 12000/- with 2 year and 1 month payback period and benefit cost ratio of 1.28. It could be inferred that the developed agro residue based briquetted cook stove is technically as well as economically feasible in the present energy context.

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