

Original Research Article

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## Feasibility Evaluation of Briquette Biomass Cook Stove for Rural Area

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### ABSTRACT

#### Keywords

Biomass, Briquette, Wood, Community stove and Thermal efficiency.

#### Article Info

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The performance of the agro residue based briquetted cook stove was carried out with agro residue briquette and solid wood. Thermal efficiency of cook stove was determined by conducting water boiling test. The thermal efficiency of cook stove on burning briquettes was 37 % found 6.33 % more than solid wood fuel at the corresponding highest flame temperature and burning rate of solid wood of 730.2°C and 3.03 kg/h, respectively. Thermal efficiency on burning of briquette with grate height adjustment and without grate height adjustment was found to be 35.42 % and 33.23 % which was 6.18 % higher than without grate height adjustment. The estimated cost of the system was Rs. 12000/- with 2 year and 1 month payback period and benefit cost ratio was found as 1.28.

### Introduction

Community cooking normally refers to cooking of food for a group of about 25 or more persons in hostels, schools, community centers, hotels, rural/semi urban restaurants and road side dhabas, places of worship, residential monasteries, ashrams, caterers, suppliers of mid-day meals for schools etc. Community cooking is done using a coal-based traditional oven/furnace (bhatti) and direct burning of wood in ovens. Recently the use of LPG-based burners has also become a common practice in India. It is obvious that the use of a biomass gasifier based system for community cooking may provide an overall efficiency of about 40 per cent as compared to 8 to 20 percent from traditional oven/furnace,

etc. Biomass gasifier based community cooking systems are available in the thermal rating of 17.5 to 291 kW [1]. 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. Agro residues are being used for briquetting which is also called as white coke [2]. The surplus agro residues are being used for densification in binderless 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 cook stove operating on biomass briquette could replace conventional use of wood and LPG. Hence in order to replace conventional fuel it is essential to design and develop a gasifier based cook stove based on agro residue briquettes [3].

## **Materials and Methods**

### **Performance evaluation of biomass cook stove**

The performance of the agro residue based briquetted cook stove has been tested according to IS 13152 (Part 1). The performance of agro residue briquette cook stove tested with agro residue (soybean) briquette (Fig. 1) and solid wood (Fig. 2).

Efficiency of cook stove was determined by carried out standard water boiling test [4]. During test various parameters such as flame temperature, outside stove temperature, remaining ash, gas outlet temperature and water temperature were measured (Fig. 2). The following parameters were measured during the performance evaluation of the biomass cook stove (Fig. 3).

### **Flame temperature**

The flame temperature of burning gas was measured by using thermocouple attached with temperature indicator

### **Outside stove temperature**

The outside temperature of stoves was measured with the help of non-contacting thermometer.

### **Air outlet temperature**

The air outlet temperature was measured by using thermocouple attached with temperature indicator.

### **Ash**

After total burning of biomass the remaining ash were weighed by using weigh balance.

### **Thermal Efficiency**

The thermal efficiency of a biomass cook stove indicated how well that stove could transfer the energy content in the fuel to the cooking pot [5, 6 &7].

### **Determination of burning capacity rate**

The fuel burning rate of the designed cook stove was estimated according to BIS test code IS 13152 (Part 1) as follows [4, 5, 8, 9];

The fuel was stacked in a honey comb fashion in combustion chamber up to 3/4 of the height of the combustion chamber.

Weight the cook stove with fuel was taken, and noted as M1 kg.

10 ml of kerosene was sprinkled on the fuel from the top of cook stove.

The time of complete combustion that is up to the last flame was noted down as T minutes.

Then the cook stove with residue was weighed and noted as M2 kg.

Then the burning capacity of the cook stove as heat input per hour was calculated as follows:

$$\text{Heat input per hour} = \text{B.R.} \times \text{CVf} (1)$$

Burning rate (B.R.) =  $\{(M1 - M2) / T\} \times 100$   
(2)

Where,

M1 = The initial mass of the cook stove with test fuel in kg,

M2 = The mass of the cook stove with fuel residues, after burning the test fuel for particular time (T) minutes in kg.

CVf = Calorific value of the test fuel in kcal/kg.

**Procedure carried out for thermal efficiency test**

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), [5, 7, 8, 10];

The thermal efficiency and the emission test were carried out without adding any additional fuel. The test was repeated and the average was taken.

For the designed cook stove the test fuel was taken as per burning capacity rate of the cook stove for an hour.

Then the test fuel was divided into 6 equal lots. Its mass was noted as EI.

The first lot of the test fuel was stacked in honey comb fashion in the combustion chamber.

Then the vessel was put with lid and stirrer.

10 ml kerosene was sprinkled for easy ignition of the test fuel.

Feeding of fresh test fuel lot was done after every 6 minutes.

The water in the vessel was allowed to warm steadily till it reached a temperature of about 90 °C, then stirring was commenced and continued until the temperature of water reached 95 °C. Then, time taken to heat the water from initial temperature T1 to the final temperature T2 °C was noted.

Then the vessel was removed from the cook stove and the second vessel was put immediately on the cook stove. The first vessel was prepared immediately for subsequent heating.

The experiment was repeated alternatively by putting N vessels till there was no visible flame in the combustion chamber of the cook stove. The temperature of the water in the last vessel was noted as T3 °C (Fig. 1)

$$\eta = \frac{m_{wi} c_{pw} (T_e - T_i) + m_{i, \text{evap}} \lambda_f}{m_f CV_f} \quad (3)$$

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

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

$\lambda_f$  – Latent heat of vaporization of water, 589 kcal/kg

$m_f$  – Mass of fuel burned, kg

CVf – Calorific value of fuel, kcal/kg

**Power output rating**

The power output is the amount of energy produced by the system in kW. Power output can be calculated by using formula [6, 7, 8, 10, 11]

$$P = \frac{F \times CV \times \eta}{860 \times 100} \quad (4)$$

Where,

F = Burning rate, in kg/hr

CV = Calorific value of fuel, in kcal/kg

$\eta$  = Thermal efficiency of stove, %

### **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 [12, 13]. 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 (Fig. 2).

### **Emission Test**

The emission from the smoke of cook stove consisted of determination of carbon monoxide (CO), nitrogen oxide (NO<sub>x</sub>), sulphur oxide (SO<sub>x</sub>), carbon dioxide (CO<sub>2</sub>), and hydrocarbon (HC) etc. The emission characteristics were carried out with the help of gas analyzer (Fig. 3). Emission analysis carried out at Anacon laboratory pvt. Ltd., Nagpur [14, 15].

### **Results and Discussion**

The community sized agro residue based briquetted cook stove was fabricated in the workshop of the department. 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.

### **Performance evaluation of agro residue based briquette cook stove**

The performance of biomass briquette cook stove was carried out for soybean briquette in the department laboratory. The performance test has been carried out according to BIS test code IS 13152 (Part 1). The evaluation of cook stove has been worked out for the various parameters; the standard water boiling test was carried out to know the performance level and heat utilized during the operation, temperature profile of cook stove, emission analysis of smoke, burning rate of stove, thermal efficiency, remaining ash and power output rating were recorded during the test.

### **Temperature profile of community cook stove**

The temperature performance of community cook stove has been determined for different feed stock.

### **Water temperature**

In the table 1, temperature of water in pot was measured with and without grate height

adjustment with briquette and subabul used as feedstock. It was found that burning with subabul water temperature rises faster as compared to briquettes. But in both feedstock with grate height adjustment water temperature rising was faster.

In figures 1 and 2 various temperatures of cook stove were recorded with grate height adjustment and without grate height adjustment with burning of briquettes and subabul wood. Temperature gain with burning of subabul was faster rate and slower rate with burning of briquettes. It was observed that with using grate height adjustment temperature gain was faster in burning of subabul wood as well as in briquettes.

**Flame temperature**

The flame temperatures of cook stove were recorded with grate height adjustment and without grate height adjustment with burning of briquettes and subabul wood (Fig. 3).

Highest temperature was recorded using subabul as fuel with grate height adjustment i.e. 730.2<sup>0</sup>C. but flame off in 45 min whereas

burning of briquette provided 55 min of flame and highest temperature attained was 662.3<sup>0</sup>C as depicted in table 2 (Fig. 4).

**Surface temperature of cook stove**

Surface temperature of cook stove was recorded at top, middle and bottom to know the amount of heat dissipates through conduction and the user safety. It was well below the safety limit of 60<sup>0</sup>C due to the insulation provided at top, middle and bottom of community cook stove.

Various surface temperatures of cook stove were recorded from top, middle and bottom of cook stove with time (Fig. 5). The highest temperature at top of was 58.1<sup>0</sup>C at middle was 51.3<sup>0</sup>C and at bottom was 46.2<sup>0</sup>C. As depicted in table 3.

**Flue gas outlet temperature**

It was the temperature recorded at the outlet of chimney. The highest temperature recorded through burning of subabul wood was 370.9<sup>0</sup>C and through burning of briquettes was 350.2<sup>0</sup>C as depicted in table 4.

**Table.1** Effect of grate height adjustment on water temperature

SN	Time, min.	Temp. without grate height adjustment, °C		Temp. with grate Height adjustment, °C	
		Briquette	Subabul	Briquette	Subabul
1	0	29	29	29	29
2	5	33.4	30	31.2	33.1
3	10	49.8	41.5	44.5	46.3
4	15	46.5	53.3	51.1	61.5
5	20	55.6	68.2	64.8	78.2
6	25	68.2	82.4	77.5	95.7
7	30	79.1	98.6	83.2	100
8	35	91.3	100	95.2	100
9	40	100	100	100	100
10	45	100	99.9	100	100
11	50	99.3	99.2	100	99.2
12	55	98.9	98	99.3	98.8
13	60	97.8	97.7	98	98.2

**Table.2** Effect of grate height on flame temperature

SN	Time, min.	Temp. without grate height adjustment, °C		Temp. with grate Height adjustment, °C	
		Briquette	Subabul	Briquette	Subabul
1	0	-	-	-	-
2	5	284.7	282.3	294.2	290.3
3	10	358.3	379.2	385.6	387.9
4	15	456.3	497.1	472.3	492.8
5	20	517.3	587.8	526.4	582.7
6	25	572.1	657.2	570.3	660.3
7	30	616.5	680.4	610.9	730.2
8	35	590.3	520.5	662.3	690.4
9	40	434.4	445.8	647.4	520.3
10	45	312.13	317.6	610.3	390.7
11	50	-	-	530.2	357.2
12	55	-	-	445.4	-
13	60	-	-	-	-

**Table.3** Surface temperature of community cook stove

SN	Time, min.	Temp. using agro residue briquette, °C		
		Top	Middle	Bottom
1	0	36	36	36
2	5	36.3	36.2	36.6
3	10	44.2	37.2	37.1
4	15	45.1	37.9	37.8
5	20	47.2	39.4	39.2
6	25	50.3	42.8	42.4
7	30	55.6	44.5	44.8
8	35	55.2	45.7	45.9
9	40	58.1	51.3	46.2
10	45	53.4	51.1	44.8
11	50	55.6	48.2	44.1
12	55	54.8	46.9	42.7
13	60	51.4	46.2	40.9

**Table.4** Flue gas outlet temperature using briquette and subabul with grate height adjustment

SN	Time, min.	Temp. with grate Height adjustment, °C	
		Briquette	Subabul
1	0		
2	5	61.4	98.2
3	10	217.5	230.5
4	15	270.5	280.5
5	20	332.6	350.8
6	25	340.5	350.9
7	30	345.6	370.9
8	35	350.2	361.3
9	40	348.2	350.4
10	45	336.2	345.5
11	50	320.6	333.5
12	55	309.5	320.5
13	60	285.2	295.6

**Table.5** Power rating of community cook stove

SN	Biomass feedstock	Burning rate, kg/h	Ash remaining, %	Power output, kW
1	Briquette	2.5	6.5	4.27
2	Solid wood (subabul)	3.03	4.82	4.69
Average		2.76	5.66	4.48

**Table.6** Comparison of different cook stoves with agro residue briquette as fuel (with top rest)

SN	Particulars	Values	
		Jwalla 99 ARBI	Developed briquetted cook stove
1	Type of cook stove		
2	Weight of fuel, kg	3	3
3	Calorific value of fuel, kcal/kg	4170	4170
4	Initial water temperature, °C	29	31
5	Boiling water temperature, °C	96	96
6	Weight of pot 1, kg	2.960	2.960
7	Weight of pot 2, kg	2.675	2.675
8	Weight of water + pot 1, kg	27.960	27.960
9	Weight of water + pot 2, kg	27.675	27.675
10	Final weight of water + pot 1, kg	27.870	27.850
11	Final weight of water + pot 2, kg	27.560	27.495
12	Weight of water evaporated in pot 1, kg	0.090	0.110
13	Weight of water evaporated in pot 2, kg	0.115	0.180
14	Temp. attained in last pot, °C	45	70
15	Wt. of water evaporated last pot, kg	0.030	0.060
16	Thermal efficiency, %	31.08	35.42



**Table.7** Comparison of different fuel with developed briquetted cook stove without top rest

SN	Particulars	Values	
		Agro residue briquette	Biomass wood (subabul)
1	Type of feedstock		
2	Weight of fuel, kg	3	3
3	Calorific value of fuel, kcal/kg	4170	3700
4	Initial water temperature, °C	29	31
5	Boiling water temperature, °C	96	96
6	Weight of pot 1, kg	2.960	2.960
7	Weight of pot 2, kg	2.675	2.675
8	Weight of water + pot 1, kg	27.960	33.960
9	Weight of water + pot 2, kg	27.675	33.675
10	Final weight of water + pot 1, kg	27.855	33.880
11	Final weight of water + pot 2, kg	27.525	33.585
12	Weight of water evaporated in pot 1, kg	0.105	0.080
13	Weight of water evaporated in pot 2, kg	0.150	0.090
14	Temp. attained in last pot, °C	75	65
15	Wt. of water evaporated last pot, kg	0.080	0.035
16	Thermal efficiency, %	37.54	35.16

**Table.8** Comparison of cook stove with and without grate height adjustment

SN	Particulars	Values	
		Briquette HA	Briquette
1	Type of feedstock		
2	Weight of fuel, kg	3	3
3	Calorific value of fuel, kcal/kg	4170	4170
4	Initial water temperature, °C	31	28.5
5	Boiling water temperature, °C	96	96
6	Weight of pot 1, kg	2.960	2.960
7	Weight of pot 2, kg	2.675	2.675
8	Weight of water + pot 1, kg	27.960	27.960
9	Weight of water + pot 2, kg	27.675	27.675
10	Final weight of water + pot 1, kg	27.850	27.890
11	Final weight of water + pot 2, kg	27.495	27.565
12	Weight of water evaporated in pot 1, kg	0.110	0.070
13	Weight of water evaporated in pot 2, kg	0.180	0.110
14	Temp. attained in last pot, °C	70	55
15	Wt. of water evaporated last pot, kg	0.060	0.025
16	Thermal efficiency, %	35.42	33.23



**Fig.1** Determination of thermal efficiency in laboratory



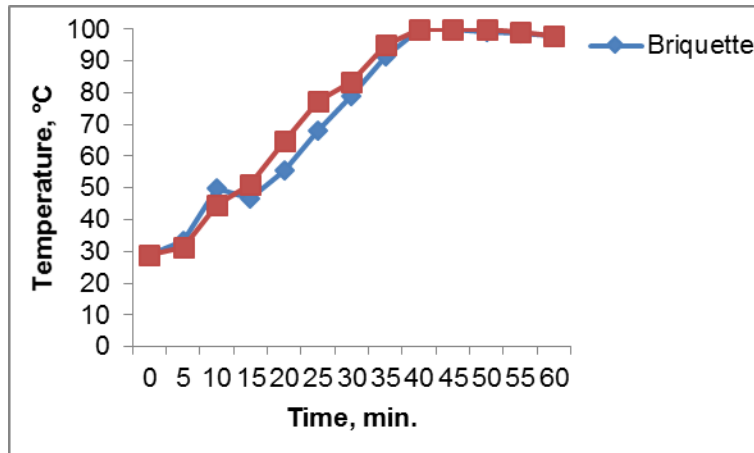
**Fig.2** Controlled cooking test at boys hostel kitchen



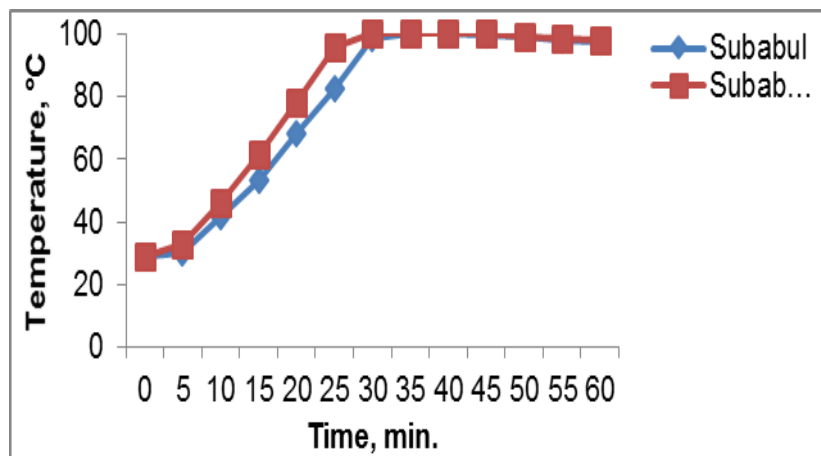
**Fig.3** Smoke analysis of the developed cook stove



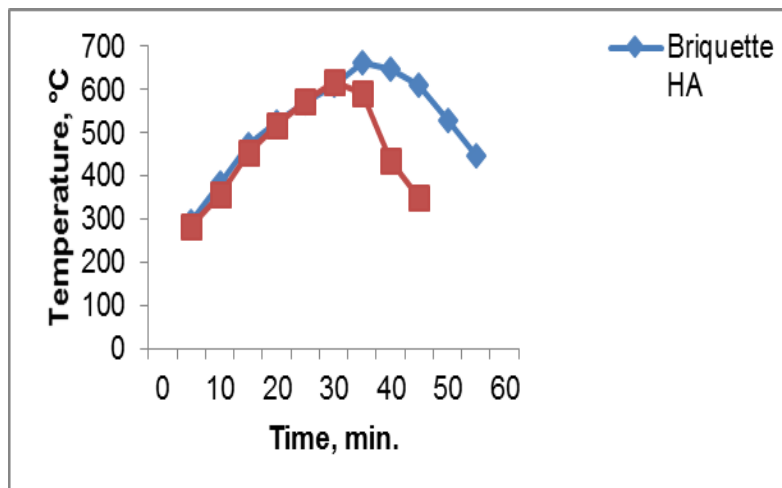
**Fig.4** Variation of water temperature using briquette fuel with and without grate height adjustment



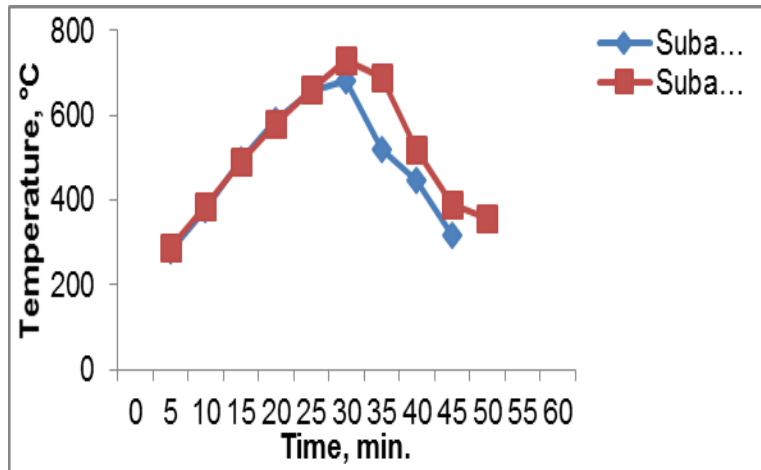
**Fig.5** Variation of water temperature using subabul fuel with and without grate height adjustment



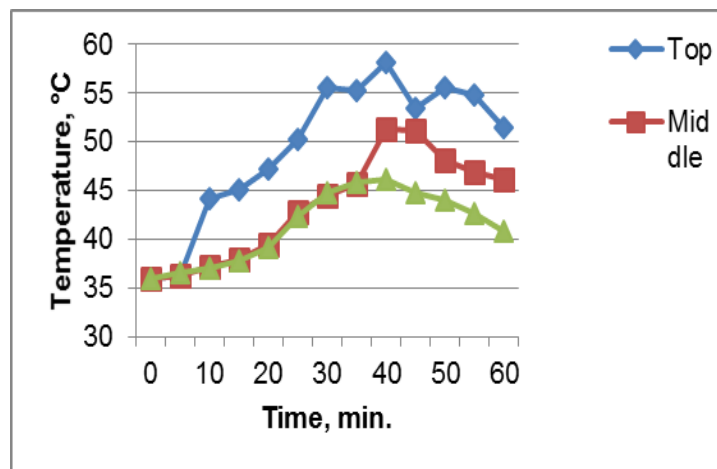
**Fig.6** Variation of flame temperature using different grate height adjustment



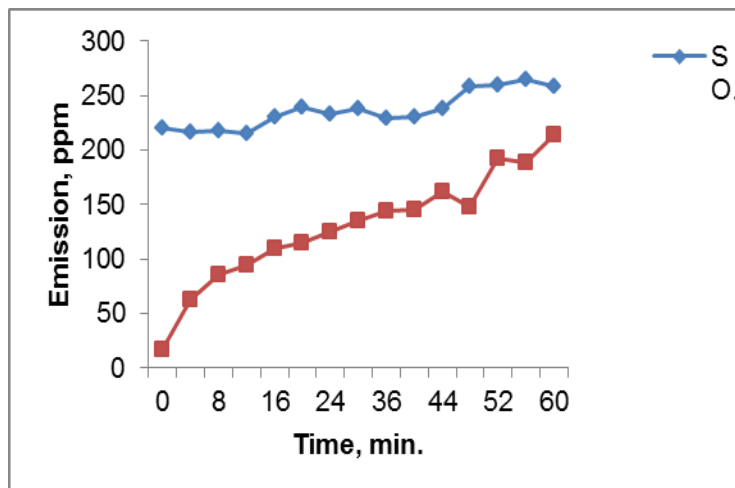
**Fig.7** Variation of flame temperature using different grate height adjustment



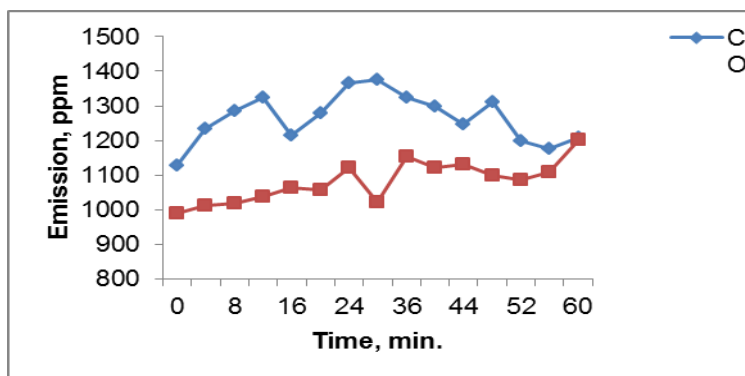
**Fig.8** Surface temperature of cook stove at top, middle and bottom



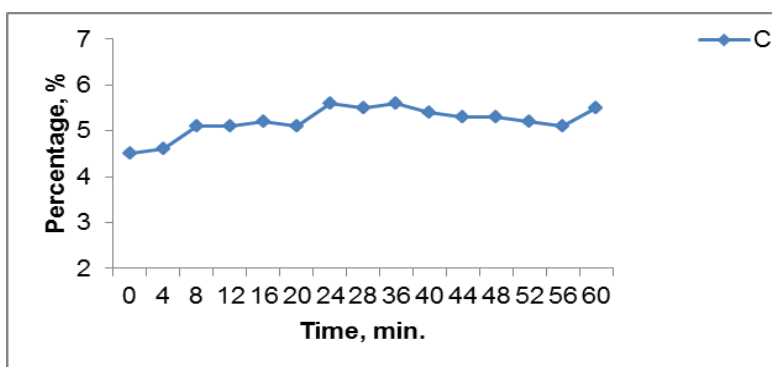
**Fig.9** SO<sub>x</sub> and NO<sub>x</sub> emissions from briquetted cook stove



**Fig.10** CO and HC emissions from briquetted cook stove



**Fig.11** Emission of CO<sub>2</sub> from briquetted cook stove



**Burning rate and capacity (power output) of cook stove**

The burning rate of the developed community cook stove has been worked out for the biomass feedstock selected in the experimentation. The burning rate of the cook stove mainly applicable with the heat required for the preparation of cook. The total heat requirement for the experiment was worked out to be 8076 kcal. The energy input / burning rate (kg/h) for the briquette was observed to be 2.5 kg/h and for solid wood it was 3.03 kg/h respectively. Table 5 showed that burning rate of solid wood is higher than the briquette fuel. The ash remaining during the experiment is depicted in table 5. The ash remaining in solid wood was recorded to be 4.82 % and in briquette 6.5 %. The capacity of developed community cook stove has been determined on the feed rate of cook stove heating value of fuel used and the thermal efficiency. Table 5 showed the power

rating output for briquette feed was observed to be 4.27 kW for energy input rate of 2.5 kg/h. Similarly the power output for solid wood was worked out for the energy input rate of 3.03 kg/h and observed to be 4.69 kW. The average power output of the community cook stove was found to be 4.48 kW.

**Thermal efficiency of community cook stove**

The stove was basically developed for the higher thermal energy utilization. The fuels used for the evaluation was taken as briquette and the solid wood. The thermal efficiency of stove was evaluated as per the testing norms mentioned in BIS test code IS 13152 (Part 1). Thermal efficiency is the function to capture the heat generated by the stove after the burning of fuel. The thermal efficiency of the developed community cook stove has been compared with the stove available in the market. The thermal efficiency was found more than similar test

carried out by Panwar *et al.*, 2008 for 5 kW stove.

Thermal efficiency of the community cook stove for briquette is depicted in table 6. It is clear evidence that, the developed community cook stove, have more energy efficient than the market community cook stove. 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.

The developed community cook stove has been tested for the various arrangements like with arrangement of top rest and without top rest. The top rest influences on the flame orientation to the vessel and thereby on the heat utilization. Table 7 showed the details of thermal efficiency of community cook stove for briquette and solid wood. It is found that, thermal efficiency of stove was 37.85 % for briquettes and 35.16 % for solid wood without top rest.

Table 8 depicted the results of efficiency for briquette with an adjustment of grate height. The grate height adjustment in the combustion chamber was at zero level at full loading of fuel and after the ignition as burning of fuel the grate height in the combustion chamber increased upto 7.5 cm and hence decreasing the combustion zone area. Table 8 showed the result obtain for the thermal efficiency of community cook stove for briquette fuel with top rest. The thermal efficiency for the grate height adjustment was found to be 35.42 % and similarly for without height adjustment it was 33.23 % (Figs 6 and 7).

#### **Emission evaluation smoke from community cook stove**

The smoke emission from the biomass cook stove is the major concern to human health and environment. The smoke content mainly CO<sub>2</sub>, CO, NO<sub>x</sub>, SO<sub>x</sub>, HC which have adversely

affects the environment of kitchen. The developed cook stove has been tested for the biomass feed stock viz. briquettes and solid wood. The smoke emission analysis was worked out for the one hour of combustion of briquette fuel in the community cook stove. The NO<sub>x</sub> and SO<sub>x</sub> emission from cook stove has been analyzed by using the gas analyser. The SO<sub>x</sub> emission during the test period was found 215 to 265 ppm. The trends of NO<sub>x</sub> and SO<sub>x</sub> emission from cook stove is depicted in figure 9.

The emission of CO and HC from the cook stove was analysed for the same biomass sample. Figure 10 revealed that the content of CO in the smoke is in the average of 1129 ppm to 1375 ppm during the test period. The hydrocarbon (HC) content in the smoke shown in table 10 and it was in the range of 990 ppm to 1203 ppm. The carbon dioxide emission from the burnt fuel during the test was reported to be 4.5 % to 5.6 % and approximately it was constant during the test period (Fig. 11).

The performance of developed cook stove was carried out as per the procedure specified in the BIS test code IS 13152 (Part 1). The thermal profile of the cook stove for the various temperature zones viz., outer temperature, flame temperature, exhaust air temperature was recorded during the experimentation. The burning rate of the developed cook stove 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 cook stove was determined. The average power output of the community cook stove was found to be 4.48 kW. 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. The thermal efficiency of cook stove 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 0C and 3.03 kg/h, respectively. Thermal efficiency of developed cook stove

was found to be 12.25 % higher than the locally available community cook stove of same size.

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