DESIGN AND DEVELOPMENT OF ECO-FRIENDLY BIOMASS COOKSTOVE

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Abstract*—India launched the National Biomass Cookstoves Initiative (NBCI) through the Ministry of New and Renewable Energy in 2009. NBCI indicated that biomass cooking stoves have potential to directly address health and welfare concerns. Modifications are needed for traditional cookstoves for dealing with health problem and incomplete combustion of biomass and etc. in order to achieve high efficiency as like LPG with affordable price for the end users. It results in fuelwood saving, avoiding air pollution and green house effects. The paper deals with various functional requirements of eco-friendly biomass cookstove. Study of various designs of biomass cookstove has been carried out for enlisting functional requirements of eco-friendly biomass cookstove. Based on these findings of functional requirements, various designs of biomass cookstove have been proposed. From these proposed designs, a final design of biomass cookstove was manufactured and water boiling test (WBT) was carried out for performance evaluation of stove. The outcomes from this study are increased thermal efficiency due to complete burning rate of fuel with use of fan. It has also helped in reducing fuel consumption and specific fuel consumption with using fan. Further, due to complete combustion of fuel results in less pollution. The stove design is simple and sturdy, durable, easy for manufacturing and use and has a long life.

***Index Terms*—Biomass Cookstove, Specific Fuel Consumption, NBCI, LPG**

I. INTRODUCTION

India has large agricultural land estimated around 180 million hectares. Around 67% of households in India directly depend on the agriculture and this account around 22% of GDP (Gross Domestic Product). Rural areas are one of the most significant parts of India as 70% of the population still lives in the rural areas [1]. As estimated around 2.4 billion people globally rely on the solid fuels like coal and biomass (crop residue, cow-dung and firewood) for their cooking and heating energy requirements, thus burning 2 million ton of biomass each day [2].

The urban areas have accelerated toward modern fuels, but this is not observed in the rural area. Peoples are spending several hours in front of the cook stove for preparing their meals and other requirement. The burning of solid fuels causes indoor air pollution due to emission of harmful substances such as carbon monoxide, particulates, benzene and formaldehyde at levels up to 100 times higher than the recommended limits set by WHO. Indoor air pollution (IAP) from traditional biomass burning contributes to serious health problems, particularly cancer and respiratory infections that cause an estimated 1.6 million premature deaths annually. More- over, literature suggests that incomplete combustion products and black carbon from traditional biomass burning have a significant contribution to climate change [3].

Because of these reasons subject of biomass based domestic cooking in India has received increasing attention in the last five decades. The current advanced biomass stove has achieved substantial emissions reductions over traditional stoves, but there is still additional improvement needed to reach LPG-like emission levels [4].The improved cook stove is expected to use any solid biomass fuel without regard to shape, size or moisture. The stove technology could be improved significantly using advanced combustion techniques.

II. LITERATURE SURVEY

Cooking tests and qualitative surveys [2] compared traditional three-stone fire with the improved, manufactured stove models based on ‘rocket’ design. The performance parameters in cooking tests were specific fuel wood consumption and cooking time. This survey has gathered information about cooking practices, stove preference and their usability, and willingness to pay for stove types. Test results showed that the manufactured stoves yield a substantial reduction in specific fuel wood consumption relative to the three-stone fire, with results varying by stove type and type of food cooked. Survey of data suggests that fuelwood saving is one of the important benefit, overall preference of stove depends upon combination of this and other factors, like cooking time, stove size and ease of use. It highlights the testing multiple cookstoves for preparation of a variety of food items, combined use of quantitative stove tests in combination with qualitative surveys to determine suitability of cookstoves for household use.

Health problems, climate change impact are the result of burning of biomass. The major focus is on commercial cookstoves companies in India because of its large population centers, supportive and stable policy environment, and rapid economic growth. Six elements of business models are: design, customers targeted, financing, marketing, channel strategy, and organizational characteristics [3].

In [4] authors have focus on health, energy security, environment and climate impacts of the current pattern of biomass use in the country for cooking in relation to cleaner cooking options such as LPG. Fuel consumption measurements are compared using traditional three-stone fire with “rocket” design. Specific Fuel Consumption (SFC) key metric is used, defined as the weight of firewood consumed in cooking a single batch of food divided by the total weight of the food, measured after cooking. There are two tests: paired tests and unpaired test. In paired test conditions were controlled where as in unpaired tests, conditions are not strictly controlled, between two large sets of independent three-stone fire and rocket stove tests. The results showed that rocket stoves have significantly lower SFC values without prolong cooking time as compared with three-stone fires [5].

In [6] authors examine the design of improved biomass cookstoves and the contents that facilitate their effective use and dissemination. The primary aim of improved cookstove is to improve the overall efficiency of cooking process. For achieving this fundamental technical and practical method are discussed and consolidated. Conflicts arising from balancing technical perfection and user needs are also explored.

Current metal or mud stoves [7] are having air intake above the firewood, thus lowering gas temperature and incomplete combustion. Around 20 improvements are provided, which leads to high burning temperature, reduced firewood consumption and less soot development.

Manufacturing cost is lower and acceptable to the users as a result of modifications. Authors explain the principles of improvements and detailed sketches of the solutions.

Authors [8] have investigated the question "how to burn wood and biomass using cooking stove?" in the paper. The heat transferred to the pot will mostly determines the fuel efficiency of cookstove, since high combustion efficiency transforms a large part of the wood into heat which is easy to achieve. The factors that are affecting the combustion of fuel are also explained. External supply of air into the combustion chamber eliminates increased air exchange into the house.

Authors [9] characterized indoor and personal particle exposure. Stationary monitors are used for measuring hourly indoor particulate matter (PM) with aerodynamic diameter ≤ 10 µm for rural and urban kitchens. This indicates that biomass burning for cooking contributes substantially to indoor particulate levels and this exposure is elevated for cooks. The personal exposure monitoring data exhibit variation that would be obscured by the use of more aggregate measures, especially during cooking periods.

III. FUNCTIONAL REQUIREMENTS OF BIOMASS COOKSTOVES

Based on the literature survey, a summary of functional requirements of biomass cookstove is made as follows:

1. The cookstove should not pollute the environment [4].
2. The cookstove should burn fuel with less smoke [4].
3. The cookstove should not blacken the utensils [4].
4. The cookstove can use any type of fuel i.e. wood, coal, dung, Grass etc.
5. The cookstove can emit less or no carbon dioxide [4].
6. The cookstove should have long life [4].
7. The cookstove should have high combustion efficiency i.e. cooking time should be less [4].
8. The ash collected in the cookstove should be easily cleanable and disposable.
9. The cookstove should be environment as well as user friendly.
10. The cookstove should not cause any health problems to the user.
11. The cookstove has the ability to cook a variety of food with variable quantity : vegetarian and non- vegetarian [2] [6].
12. The cookstove should take less fuel to burn [2].
13. The cookstove should require little or no-training for its working [3].
14. The cookstove should be durable [3].
15. The cookstove has comfortable to use [6].
16. The cookstove should take less design and manufacturing cost [6].
17. If possible cookstove should have fuel storage tank [6].
18. The cookstove should have easy method of loading the fuel [6].
19. The cookstove must have low initial cost and be available in local market [7].
20. The cookstove should adapt any type of vessel/utensils size [7].
21. The cookstove should have little or no maintenance cost [7].
22. The cookstove has the ability to control heat output [8].
23. The cookstove should be fire resistant [8] .
24. The cookstove should be user friendly [8].
25. The cookstove should have high thermal efficiency [8].
26. The cookstove should have high rate of heat transfer [8].
27. The cookstove should have good speed of ignition and should have the capability of fast change in the heat level [8].
28. The setup of the cookstove should be simple, occupy less space and weight [8].
29. The cookstove should looks good and attarctive in design.
30. The cookstove should be stable at its working time and must be easy to start and stop.

IV. PROPOSED DESIGNS OF BIOMASS COOKSTOVES

Some of the proposed designs for biomass cookstove based on literature survey are given below:

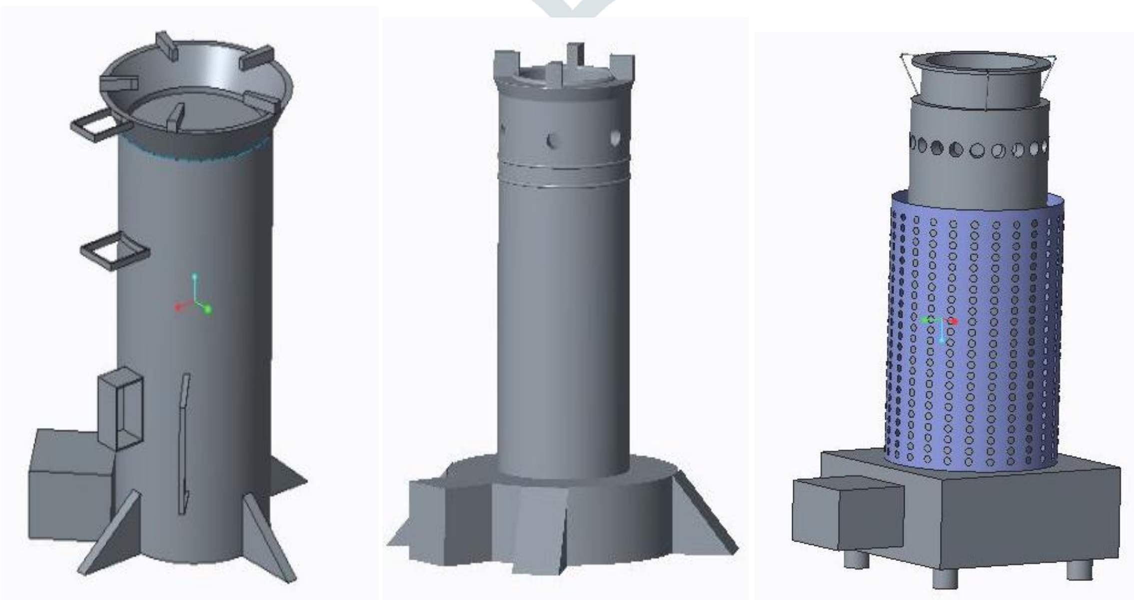

Figure 1 Proposed design first, second, third

V. Final Designs Of Biomass Cookstoves

Considering all proposed designs, the final design of biomass cookstove with considering all technical parameters is given below:

Figure 2 Final design of biomass cookstove

The stove is made up of 2mm MS plate, having a height of 350 mm. The stove has given design features such as fan, chimney, ash tray (ash removal mechanism).

VI. Performance Analysis Of Stove Using Water Boiling Test

The water boiling test (WBT) is a laboratory test that evaluates stove performance while completing a standard task in a controlled environment to investigate the efficiency of the stove.

Readings of WBT (without fan) :

Table 1 Readings of WBT (Without Fan)

Fuel		**Time for boiling**				
	Setup time (Ts) min	***T_1^0C (Temp. at start)***	***T_2^0C (5 min)***	***T_3^0C (10 min)***	***T_4^0C (15 min)***	***T_5^0C (Last)***
Biomass	3	$30^0\,C$	$50^0\,C$	$72^0\,C$	$94^0\,C$	$100^0\,C$ (17 min)
	3	$30^0\,C$	$52^0\,C$	$71^0\,C$	$93^0\,C$	$100^0\,C$ (16 min)
	3	$30^0\,C$	$51^0\,C$	$73^0\,C$	$95^0\,C$	$100^0\,C$ (15 min)

Data for calculation without using fan:

Initial temp.: 30 °C, Final temp.:100 °C, Wt. of empty pot: 0.5 kg, Initial wt. of fuel: 1.6 kg, Avg. wt. of ash: 0.09 kg, Initial wt. of water: 1.7 kg, Final wt. of water: 1.5 kg, Sp. Heat capacity of water: 4.168 KJ/Kg°C, Sp. Heat capacity of pot: 0.71 KJ/Kg°C, Sp. Heat capacity of fuel: 1.25 KJ/Kg°C, Mass of fuel: 0.55 kg, Latent heat of evaporation of water: 2260 KJ/Kg, Calorific value of fuel: 4127.25 Kcal/Kg.

1. Thermal efficiency: It is defined as the proportion of fuel energy that is delivered to the cooking utensil.

$$Thermal\ efficiency = \frac{4.186 * W_i(T_f - T_i) + 2260(W_i - W_f)}{M_f C_f}$$

Where, W_i=Initial mass of water (Kg)
T_f= Final temp. of water (°C)
T_i= Initial temp. of water (°C)
W_f=Final mass of water (Kg)
M_f= Mass of fuel (Kg)
C_f = Calorific val. of fuel (KJ/Kg)

$$Thermal\ efficiency = \frac{4.186 * 1.7(100 - 30) + 2260(1.7 - 1.5)}{0.55 * 4127.25} = 41.85\%$$

2. Fuel consumed (f_{cd}) : It is the difference between pre-weighted bundle of wood and the wood remaining at the end of the test phase.
   (f_{cd}) =$f_{ci} - f_{cf}$= 1.6-0.09= 1.51 kg
3. Boiling time (Δt): Boiling time is the difference between start and finish times of the experiment.
   Δt=t_f-t_i= 17-3=14 Min.
4. Burning rate: It is the measure of the rate of fuel consumption while bringing water to a boil.

Burning rate= $\frac{f_{cd}}{\Delta t}$=1.52÷14= 0.1085 (Kg/min).

5. Specific fuel consumption: It is defined as the fuel required to produce a unit output. $Sf_c = \frac{f_{cd}}{W_i}$ = 1.52÷1.7=894 (Grams wood/ltr. water)

Readings of WBT (with fan):

Table 2 Readings of WBT (With Fan)

Fuel		**Time for boiling**			
	Setup time (Ts) min	T_1^0C ***(Temp. at start)***	T_2^0C ***(5 min)***	T_3^0C ***(10 min)***	T_4^0C ***(15 min)***
Biomass	3	$30^0\,C$	$56^0\,C$	$77^0\,C$	$100^0\,C$ (13 min)
	3	$30^0\,C$	$57^0\,C$	$78^0\,C$	$100^0\,C$ (12 min)
	3	$30^0\,C$	$57^0\,C$	$78^0\,C$	$100^0\,C$ (12 min)

Data for calculation with using fan:

Initial temp.: 30°C, Final temp.:100°C, Wt. of empty pot: 0.5 kg, Initial wt. of fuel: 1.6 kg, Avg. wt. of ash: 0.15 kg, Initial wt. of water: 1.7 kg, Final wt. of water: 1.4 kg, Sp. Heat capacity of water: 4.168 KJ/Kg°C, Sp. Heat capacity of pot: 0.71 KJ/Kg°C, Sp. Heat capacity of fuel: 1.25 KJ/Kg°C, Mass of fuel: 0.55 kg, Latent heat of evaporation of water: 2260 KJ/Kg, Calorific value of fuel: 4127.25 Kcal/Kg.

1. Thermal efficiency $= \frac{4.186*W_i(T_f-T_i)+2260(W_i-W_f)}{M_f C_f}$

$$= \frac{4.186*1.7(100-30)+2260(1.7-1.4)}{0.55*4127.25} = 51.81\%$$

2. Fuel consumed $(f_{cd}) = f_{ci} - f_{cf}$= 1.6-0.15= 1.45 kg
3. Boiling time (Δt) : $\Delta t = t_f - t_i$= 13-3=10 Min
4. Burning rate: $\frac{f_{cd}}{\Delta t}$=1.45÷10= 0.145 (Kg/min)
5. Specific fuel consumption: $Sf_c = \frac{f_{cd}}{W_i}$ = 1.45÷1.7=852 (Grams wood/ltr. water)

I. CONCLUSION

The outcomes of the study are:

a) Thermal efficiency of stove with fan increases.
b) Fuel consumed, specific fuel consumed and boiling time reduced with the use of fan.
c) Due to complete burning of fuel the pollution is less.
d) The stove design is simple and sturdy, durable, easy for manufacturing and use and has a long life.

The design has been analysed using WBT, however, detailed effect of air by providing fan is to be evaluated using CFD.

REFERENCES

[1] Kaveri Gill "A Primary Evaluation of Service Delivery under the National Rural Health Mission (NRHM): Findings from a Study in Andhra Pradesh, Uttar Pradesh, Bihar and Rajasthan", *Planning Commission of India* May 2009.

[2] Edwin Adkins, Erika Tyler, Jin Wang, David Siriri, Vijay Modi, "Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa", *Energy for Sustainable Development* 14, 2010, pp 172–185.

[3] Gireesh Shrimali, Xander Slaski, Mark C. Thurber, Hisham Zerriffi, "Improved stoves in India: A study of sustainable business models*", Energy Policy* 2011, pp 1-14.

[4] C. Venkataraman, A.D. Sagar, G. Habib, N. Lam, K.R. Smith, "The Indian National Initiative for Advanced Biomass Cookstoves: The benefits of clean combustion", *Energy for Sustainable Development* 14, 2010, pp 63–72.

[5] Edwin Adkins, Jiehua Chen, Jacob Winiecki, Peter Koinei, Vijay Modi, "Testing institutional biomass cookstoves in rural Kenyan schools for the Millennium Villages Project", *Energy for Sustainable Development* 14, 2010, pp 186–193.

[6] Richard Black, "Improved Biomass cookstove programmes: Fundamental criteria for success", Rural Development Dissertation, the Centre for the Comparative Study of Culture, *Development & the Environment, the University of Sussex*.

[7] Sjoerd Nienhuys, "Cooking Stove Improvement, Design for Remote High Altitude Areas Dolpa Region", *Adaptative Research and Implementation Centre*, Nepal, 8 April 2005.

[8] Mark Bryden, Dean Still, Damon Ogle, Nordica MacCarty "Designing Improved Wood Burning Heating Stoves", *Aprovecho Research Center and Shell Foundation.*

[9] Ruoting Jiang and Michelle L. Bell, "A Comparison of Particulate Matter from Biomass-Burning Rural and Non-Biomass-Burning Urban Households in Northeastern China", *Environmental Health Perspectives*, July 2008, pp. 907-914.

[10] C.S Rani, T.C, Kandpal and S.C. Mullick, "Preliminary study of water boiling test procedures used for performance evaluation of fuelwood cookstoves", Energy Convers Mgmt Vol. 33, No. 10, Year-1992, pp. 919-929.