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Design, Fabrication and Testing of a Forced Draft Biomass Cook Stove

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Abstract: *An approach towards an Improvement in performance of cook stoves has been a great challenge to scientists and researchers as biomass cook stoves are one of the basic needs of people living in rural areas. But due to household pollution by Traditional Cook stoves causes illness to people preparing for their regular meals near it. So, taking an initiative for Designing, Fabricating and Improvisation in the performance of Forced Draft cook stoves by placing proper Primary and Secondary holes in combustion chamber which gives better air distribution for proper combustion to get Lower Emission rates. Various experimentations are being performed on the basis of standard protocols i.e. BIS (Bureau of Indian Standards), VITA (Volunteer in Technical Assistance), EPTP (Emission Performance Test Protocol), WBT (Water Boiling Test) amongst which BIS had an upper hand and had very less uncertainty of errors due to which it is mostly being used in checking and improving emission performance of cook stoves for more efficient use with less chances of health issues. This paper consists of Design, Calculations and Constructional working of Forced Draft Biomass Cook stove and also the Burning rate Calculations were carried out to check fuel burnt rate.*

Keywords: Cook stoves; Biomass; Forced Draft; Lower Emission rates

I. INTRODUCTION

In 2018, total population across world was near about 7.63 billion [1] out of which approximately 3 billion [2], [3] people rely on polluting Cook stoves i.e., nearly 39.31% of people around the world uses open fires to cook family meals. Amongst this, 3.8 million of people die prematurely due to household or indoor gas pollution causing diseases such as Pneumonia, stroke, Lung Cancer, Ischaemic Heart disease, etc. Household pollution emits gases such as Carbon monoxide (CO), Sulphur Oxides (SO_x), Carbon di-oxide (CO_2), & Nitrogen Oxides (NO_x) [4]. Recent facilities such as LPG provided by government gives a limited cost saving option to rural areas so they prefer Cook stoves instead, which gives no investment of refilling of any Gases such as Biomass are easily available for combustion purposes. Due to increase in death rate due to indoor air pollution, evaluation towards improvement in cook stove performance i.e. Thermal Efficiency and Emission Control becomes a necessary approach. Some Uses Coal and some uses wood as a fuel.

Main aim for the Improvisation and Research on cook stoves is to reduce the impact of poisonous gases on Human beings and to adapt customer motivation such that they would buy these cook stoves for their good. As evolution of biomass Cook stoves is increasing rapidly, customer acceptance has become a biggest challenge to researcher due to their harmony and user friendly needs [5].

There are two types of Cook stove available in market i.e. Direct Combustion and Gasifiers where in Combustion Cook stoves biomass is burnt without any influence of external air supply, which results into unclear combustion with more amount of unburnt fuel or biomass at the end of process so Gasifier Cook stoves are preferred which gives much cleaner combustion as compared to Direct combustion cook stoves. So evaluation towards Gasifier cook stoves plays an important role for futures evolution. Gasifiers separate Gas generation from gas combustion where optimization of heat depends drying and pyrolysis of solid fuel which is first converted into gases [6]. Forced draft cook stoves works on the principle of gasification with cleaner combustion as compared to fuel used like solid fuels. It gives higher efficiency results due to uniform combustion and proper mixture of air input with fuels. These cook stoves enables Thermochemical conversion with some sub-stoichiometric reactions. Here reduction reactions take place between fuel and an oxidant. It is important to maintain the reaction stoichiometrically stable for increase in power output to get better efficiency [7]. Temperatures of Gasifier and conventional stoves range from 1000 o C-1100 o C and 700 o C-800°C respectively. This Higher flames results into better rate of Heat transfer and cook stoves will work at higher efficiency.

These types of cook stoves have high efficiency ranging from 35% to 50% [9], consisting Forced draft type arrangement with lower emissions rate. This paper includes Material, Design, Fabrication, Analysis and Lab Testing of Cook stove.

II. Design and Fabrication

Performing experimentation on Forced Draft Cook stove starts up with Designing of Stove considering ambient conditions, Weight and Cost analysis with proper Geometric Dimensioning and Tolerances. Cook stove consist of Outer Body, Combustion Chamber, Fan, Speed Regulator and Insulation. Design of Cook stove was carried on Solid works and analysis in Ansys with calculations considering various Losses, Ambient and Maximum Temperature conditions with Design Parameters. Some basic Design parameters considered while designing Cook stoves are:

1. Gap between pot and combustion chamber.
2. Air flow rate.
3. Diameter of combustion chamber.
4. Height of cook stove.
5. Number of primary and secondary holes.
6. Diameter combustion chamber and outer skirt of cook stove.
7. For providing complete combustion of fuel in combustion chamber, supply of air to the chamber is such that the fire gets necessary air. In forced draft cook stove, the terms, primary air and secondary air, has to supplied in a 1/3rd ratio so that the fire gets excess air for gasification of wood (term called pyrolysis).

Calculation on the basis of requirement of air at Primary and Secondary holes, we have to consider some following parameters which fulfill the requirement of air flow from holes with proper distribution:

3.1 Primary Air Path

Initiation of Combustion takes place from primary holes, so more air is required for heating up. It is a Forced Draft Biomass Cook stove so requirement of primary air is fulfilled by external air supplied by draft Bernoulli's Equation:

$$P + 1/2\ \rho V^2 + \rho g H = Constant \quad (1)$$

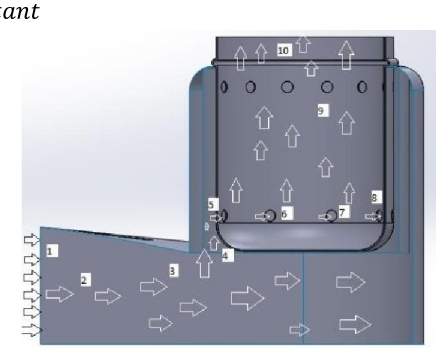

Figure 2(a): Air Path from Entry to Exit of Primary holes

Sr No.	Losses	Values
1	Fan	$0.0002m^2T$
2	Sudden Contraction	$742.613m^2T$
3	Friction	$0.049mT$
4	Sudden Expansion	$41205.99m^2T$
5	90^o Bend	$281.84m^2T$
6	Sudden Contraction	$28112.67m^2T$
7	90^o Bend	$148510.162mT^2$
8	Entry	$497113.0346\ mp^2$
9	Sudden Contraction	$44554.45m^2T$
10	Sudden Expansion	$490099m^2T$
11	Zone	$13638.792mp^2$
12	Exit	$4891.248mp^2$

Table 1: Calculation for Primary Holes

Putting all the Values in Bernoulli's equation we get:

$$1.471+18530.04\,[m_p]^2=C \tag{2}$$

3.2 Secondary Air Path

Secondary air path shows flow from entry of cook stove to the exit of secondary hole considering all losses. Points 1 to 7 represents occurrence of all losses. Calculation regarding all losses considering Bernoulli's equation and including factors such as temperature and Velocity change is taken into an account.

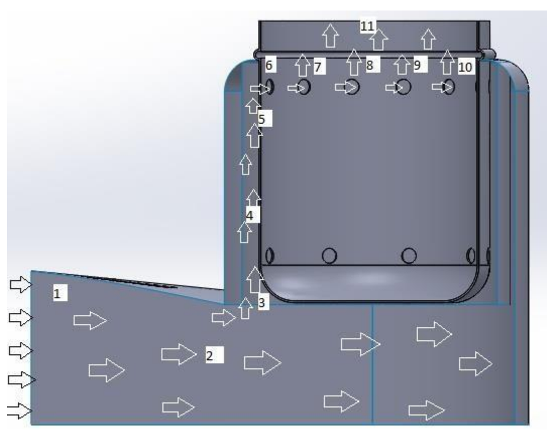

Figure 3(a): Air Path from Entry to Exit of Secondary holes

Sr No.	Losses	Values
1	Fan	$0.0002m^2T$
2	Friction	$0.049mT$
3	Sudden Expansion	$41205.99m^2T$
4	90^oBend	$281.84m^2T$
5	Sudden Contraction	$28112.67m^2T$
6	Friction	$5.41(mT\text{-}mp)$
7	90^oBend	$2005*10^6(mT\text{-}mp)^2$
8	Entry	$3131191.337*(mT\text{-}mp)^2$
9	Sudden Contraction	$60.2021*10^3*(mT\text{-}mp)^2$

10	Sudden Expansion	$6.622*10^5(mT\text{-}mp)^2$
11	Exit	$14.9*10^3(mT\text{-}mp)^2$

Table 2: Calculation for Secondary Holes

Putting all the Values in Bernoulli's equation we get:

$$929099.54 〖m_p〗^2 − 2476.13 m_p + 2.17 = C \quad (3)$$

929099 .54 〖�� p 〗^2 − 2476 .13 �� p +2.17=C (3)

Design Consist of a Draft tangentially connected with a body to give better Swirl and Turbulence to air such that it will give better combustion. Number of Primary holes and Secondary holes are 9 and 8 respectively in Combustion chamber considering best Air distribution ratio of 70:30. Constructional details of Cook stove is as follows:

Sr. No.	Parameters	Dimensions
1	Length	263mm
2	Height	194mm
3	Width	165mm
4	Position of Draft	Tangentially

Table 3: Constructional Details

Figure 4: (a) Front View of Cook stove (b) Left hand side view of Cook stove

III. Experimental Setup and Testing

Dealing with different types of tests after manufacturing of cook stove, various tests performed are Burning Rate Tests, Emission Tests, and Water Boiling Tests which are required to be performed 3 times each. Before performing these tests, planning and checking of setup with respect to performance of cook stove must be checked thoroughly.

3.1 Burning Rate Tests

Burning Rate(kg/hr)	M_1(kg)	M_2(kg)
0.72	3.15	2.79
0.742	3.155	2.78
0.71	3.145	2.79

Table 3.1: Burning Rate Tests

Average Burning Rate Capacity:

= (0.72+0.742+0.71)/3

= 0.725 kg/hr

3.2 Water Boiling Tests

Water Boiling tests are relatively simple and short simulation technique for following testing procedure. Using this test it helps to achieve upto certain efficiency by measuring Heat rate of cook stove unit it boils the water. T he main purpose to design a new cook stove was to reduce emission rates so this test also helps to check and reduce emission rates. [7]

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Gases	Test I	Test II	Test III
O2	20.8%	21%	20.6%
CO	0.010ppm	0.017ppm	0.026ppm
SO2	73 ppm	64 ppm	60 ppm
NO	2ppm	3ppm	2.5ppm
N2O	6ppm	7ppm	9ppm
CO2	0.09%	0.10%	0.15%

Table 3.2: Recorded Emissions in WBT

3.3 Calculations

Various experimentations were performed five times using same fuel for further calculations of Thermal efficiency. As per the results Data collection gave various values to find the following:

$$H_{out}= [(n-1)\times (W\times C_v+ w\times Cw)\times(T_2-T_1)] +[(W\times C_v+ w\times C_w)\times(T_3-T_1)] \quad (4)$$

$$H_{in}= (X_{fuel}\times H_{fuel})+ (X_k\times H_k) \quad (5)$$

$$\eta=(H_{out}/H_{in})\times 100 \quad (6)$$

Where,

- w = Mass of water in vessel, in kg. = 4.8
- W = Mass of vessel with lid in kg. = 0.887
- X_{fuel} = Mass of solid fuel consumed, in kg = 0.72
- H_{fuel} = 'Net' calorific value of wood (or solid fuel), in kJ/kg = 15000
- X_k = Mass of kerosene used for ignition (kg) = 15
- H_k = Calorific value of diesel (KJ/Kg) = 45000
- T_1 = Initial temperature of water in °C = 21
- T_2 = Final temperature of water in °C = 95
- T_3 = Final temperature of water in last vessel at the completion of test in °C = 80
- n = total no vessel used = 3
- C_w = specific heat of water = 4.186kJ/kg/°C
- C_v = specific heat of the material of the vessel (aluminium) = 0.896 kJ/kg/°C

IV. Results

While designing cook stoves various parameters and models were formed i.e. Mathematical and CAD. Considering all losses in Cook stove during air flow, Bernoulli's equation were formed which helps in calculating velocities and mass flow rate of air at primary and secondary holes respectively. Equations formed are stated below:

$$1.471+18530.04 \ 〖m_p〗 \ \text{^}2=C \quad (2)$$

$$929099.54 \ 〖m_p〗 \ \text{^}2-2476.13m_p+2.17=C \quad (3)$$

Comparing both equations we get:

Table 4: Result

Holes	Number	Diameter(m)	Mass Flow Rate	Velocities(m/s)
Primary	9	0.014	0.000923033	0.6662
Secondary	8	0.0065	0.000390781	1.4728

With proper % Distribution of Air in Primary and Secondary holes i.e. 70.25% and 29.74% respectively, we get our mathematical results as expected. Comparing Thermal Efficiencies of Old and Newly designed cook stove we get:

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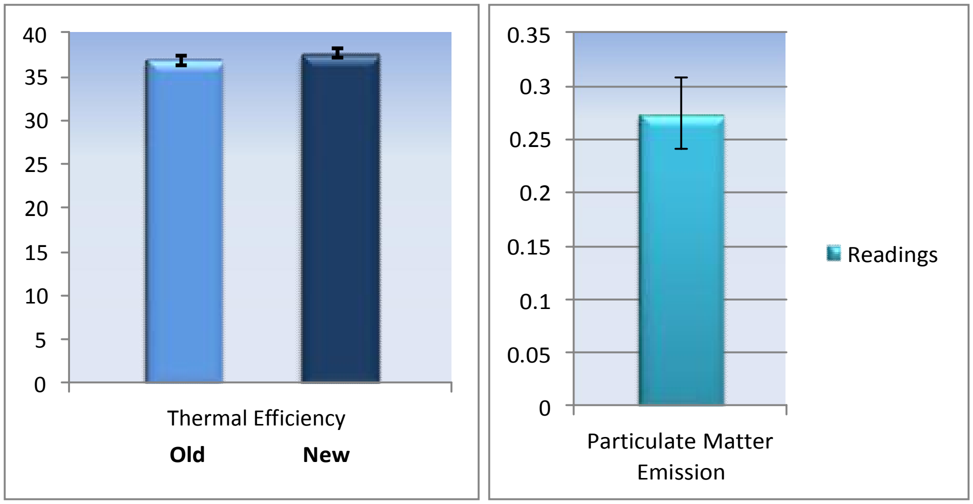

(a) (b)

Figure 5: (a) Efficiencies Comparison between Old and New Cookstove (b) Plot of PM Emission

V. Conclusion

The BIS test on forced draft cook stoke reviled the efficiency and output of stove. The net cost of cook stove rounded over to 1500 bucks. The initial stage of cook stove gave 36.8% efficiency with clean combustion of wood, giving out only 10 – 12 gm of ash.

The upgraded version Cook stove with proper insulation coating and costing of 250 bucks which gave improved efficiency of 37.64%.The efficiency improvement of 0.84%, which comes out as 78 bucks per unit efficiency. The test ran for 1hr and the stove ran for 50min at full capacity for available wood. The heat output is more than sufficient to meet the demands at domestic level. The design with flexible stand makes stove very versatile for different loads of applications, like daily use to small gathering of 30 people feast.

The main focus in designing was to keep the efficiency as high as possible while keeping the weight and cost of project to minimum. The ideal efficiency is 40%, and the prototype manages to peak at 37.64%.

References

[1]. The World Population 2018 [Internet]. Available from: http://www.geoba.se/population.php?pc=world& page=1&type=28&st=rank&asde=&year=2018;[cited08.03.2018].

[2]. Household Air Pollution and Health by World Health Organisation [Internet]. Available from:https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-healthhealthsurvey;[cited08 .03.2018]

[3]. International Organisation for Standardization to Improve health with new standards for cleaner cook stoves [Internet]. Available from: < https://www.iso.org/news/ref2302.html>[cited 08.03.2018].

[4]. What are the emissions of burning wood? by © 2019 eXtension. All rights reserved [Internet]. Available from:https://articles.extension.org/pages/43735/what-are-the-air-emissions-of-burning-woodemissions[cited 09.03.2018].

[5]. Survey Based Behavior and Impact Assessment A Case Study of Improved Cookstove Adoption in Rural Honduras, October 2018 DOI: 10.1109/GHTC.2018.8601900, Conference: IEEE Global Humanitarian Technology Conference, At: San Jose, CA;https://www.researchgate.net/publication/325321845_Survey_Based_Behavior_and_Impact_Assessment_A_Case_Study_of_Improved_Cookstove_Adoption_in_Rural_ Honduras;[cited 10.03.2018].

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[6]. Sutar, Kailasnath B., Sangeeta Kohli, M. R. Ravi, and Anjan Ray. "Biomass cook stoves: A review of technical aspects." Renewable and Sustainable Energy Reviews 41 (2015): 11281166 [cited 10.03.2018].

[7]. Sonarkar, P. R. & Chaurasia, A. S. (2016). “Design and Performance Evaluation of Forced Draft Cooking Stove”. Presented at International symposium & 69th annual session of IIChE (CHEMCON-2016), Chennai, December 27-30, India [cited 13.03.2018].

[8]. Cook stoves in India more Polluting than Thought by Times of India [Internet]. Available from: https://timesofindia.indiatimes.com/home/environment/pollution/cookstoves -in-india-more-polluting-than-thought-study/articleshow/62348593.cms[cited 08.03.2018].

[9]. Ramtara Cook stoves from Ram Tara Engineering Company, Clean Cooking Catalog [Internet]. Available from http://catalog.cleancookstoves.org/stoves/238; [cited 15.03.2018].