Design and Experimental Analysis of Efficient Biomass Stove

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ABSTRACT

This research article is examined about the highly efficient firewood fuelled cooking stove. The thermal efficiency of this stove can achieve a maximum efficiency. This sort of stove isn't only highly efficient but also hygienic. The main role of this task is to fabricate a biomass stove and to test the stove for the domestic use. However, for this, an efficient design is required. The design of this biomass stove includes huge number of optimization in various parameters. Biomass energizes are utilized by about a large portion of the total population once a day for cooking. While these stoves regularly look straightforward in appearance they are famously hard to test. By their extremely nature biomass stoves are normally genuinely uncontrolled devices which regularly display a lot of variability in their performance. With a specific end goal to characterize a stove and comprehend the process which are happening inside, and through this begin to configuration better stoves, this variability and vulnerability should be diminished however much as could reasonably be expected.

Keywords: *Biomass stove, design, fabrication, efficiency, analysis,*

1. INTRODUCTION

The old style stoves comprise of an edge work of blocks, mud blocks or stones above which the pot is set. The stove is open along the edge for bolstering in the firewood's. Stoves of this sort have just lower efficient and are exceptionally UN - hygienic. In the present time of high energy costs, it is judicious to utilize energy transformation device of high efficiency, the traditional Chula's are wasteful has just around (5%-10%). Due to the increasing expense of the fuel and to accomplish better working condition. It is basic to create wood consuming stoves of high efficiency.

Many examiners have added to a cutting edge comprehension of the thermodynamics of cooking stoves. The logical investigation of wood consuming stoves has achieved the point where a lot of accord now exists about how stoves work. Dr.Larry Winiarski has contemplated ignition and wood consuming cooking stoves for over thirty years. He has helped associations manufacture a great many stoves in nations around the globe. Dr. Winiarski is the Technical Director of the Aprovecho Research Center, where stoves have been a noteworthy subject of concentrate since 1976. The group at Eindhoven University, drove by Dr. Krishna Prasad and including Dr. Dwindle Verhaart and Dr. Piet Visser, explored different avenues regarding wood stoves for over 10 years and composed essential books regarding the matter. Dr. Sam Baldwin compressed a very long time of involvement in West Africa and in the lab in his far reaching book Biomass Cook Stoves: Engineering Design, Development and Dissemination (1987).

Yuanbo *et al*. in his paper discussed the development and benefits of modern highly efficient fire wood fueled cooking stove in china. He had introduced the highly efficient fire wood stove, incorporates the water boiling test device and NG-II type composite highly efficient fire wood stove. He had proved the thermal efficiency of the stove that attained (25-30%). This type of stove is not only highly hygienic but also highly efficient. [1]

Shankar B.Kausley, Aniruddha, B.Pandit et at. in their paper they had point by point the hypothetical investigation of strong fuel burning in a domestic stove. In their work they planned diverse relentless state and also shaky state burning models. The steady state models included the calculation of effective most extreme flame temperature, these models had been utilized to discover the effects of stove geometry and fuel properties on the stove execution parameters, for example, compelling greatest fire temperature, suction made inside the stove propagation of ignition inside the stove, and the fuel copy rate, which assume an essential part in the design of such stoves for maximum thermal efficiencies. [2]

Joshua Agen broad, Morgan Deffort, Cory Kreutzer *et al.* in their paper the authors had developed a simple model for understanding the simplified, but fundamental operating behavior of natural convection biomass cooking stoves. An upper limit to both fire power and efficient combustion is observed. [3]

C.L.Orange, M.Defoot, B.Willson *et al.* in their paper the authors had explained about the combustion. Which is a complex process with chemical reactions occurring in the liquid, solids and gas phases simultaneously. In their research over 200 components had been identified to exist in the gas phase alone during biomass combustion. Moisture limits the local temperature in the wood until the water had been vaporized. The energy required for the vaporization of water in the fuel will lower the temperature in the combustion chamber slowing the rate of combustion. Moisture in the fuel will also have the effect of reducing the adiabatic flame temperature and increasing the amount of air required for complete combustion. [4]

Christian L'Orange, John Volckens, Morgan De Fort *et al.* in their paper the authors had explained about the pot temperatures and the stove wall temperatures. The cooking pot temperature had a significant impact on the emissions. The hot pot and the cold pot tests resulted in different emission rates and size distribution relative to the base line of the stove conditions. The temperature of the stove wall affected the particle emissions by changing the combustion region inducing thermophoresis. The overall temperature of the stove had an increase in oxidation. [5]

The improved stove depends on the old style stove however it furnished with a grate and chimney which enhances the combustion and raises the thermal efficiency. It is likewise more sterile being used. The highly efficient stove was created amid the 1980's and enhances the combustion and energy usage of the novelty stove. The thermal efficiency of this sort of stoves can achieve up to (25-30%).

2. THEORETICAL ANALYSIS

To fabricate a new stove some of the specifications are to be analysed. So to do that the theoretical analysis is done according to the stove design and the feeding properties. And these analyses are listed below. Indeed, even an open fire is regularly 90% efficiency at crafted by transforming wood into energy. Be that as it may, just a little extent, from 10% to 40%, of the discharged energy takes it into the pot. Improving combustion efficiency does not obviously help the stove to utilize less fuel. Then again, improving heat transfer efficiency to the pot has an extensive effect. Enhancing the ignition proficiency is important to diminish smoke and destructive emanations that harm wellbeing. Enhancing heat exchange productivity can altogether decrease fuel utilize. Fire is normally great at its activity; however pots are not as great at catching warmth since they are wasteful heat exchangers. Inorder to reduce emission and fuel utilize, the stove creator's activity is to first tidy up the fire and after that power however much vitality into the pot or frying pan as could be expected. Both of these functions can be refined in an all around built cooking stove. It is constantly best practice to add a fireplace to any wood consuming cooking or heating stove. Moreover, it is desirable over utilize a cleaner consuming stove to ensure air quality in and outside of the house. chimney that remove smoke and different emmisions from the living space ensure the family by decreasing exposure to pollutant and wellbeing dangers. Significantly cleaner burning stoves without a chimney can make unfortunate levels of indoor air contamination. Unvented stoves ought to be utilized outside or in open territories. At the point when stacks are not moderate or down to earth utilizing a hood over the fire, or opening windows, or making vents in the rooftop under the overhang are all approaches to diminish the levels of harmful pollution. The utilization of a cleaner burning stove can likewise be useful in such manner at the same time, if conceivable, all wood consuming stoves ought to dependably be fitted with a useful chimney.[6]

2.1 PROPERTIES OF WOOD

2.1.1 Proximate analysis in (%)

Volatile content	87
Char	1.32
Ash content	1
Moisture content	10

Table. 1. Proximate analysis of wood in % basis

2.1.2 Ultimate analysis in (%)

C	49.05
H	6.5
O	43
N	0.4
Ash	0.6

Table 2. Ultimate analysis of wood in % basis

2.1.3 Composition of wood

In terms of molecular Volume

$$C = \frac{49.5}{12} = 4.125 \text{ mol}$$

$$H = \frac{6.5}{2} = 3.25 \text{mol}$$

$$O = \frac{43}{32} = 1.3437 \text{ mol}$$

$$N = \frac{0.4}{28} = 0.0142 \text{ mol}$$

Hence O_2 react with H_2 in the ration of 1:2

= 2 x 1.3437

= 2.6874 mol.

H_2 Combine ratio O_2 content of the fuel = 3.25- 2.6874

= 0.5626 mol.

2.1.3.1 O_2 required for combustion of 100 Kg of wood

Molecules Volumes	O2 Required for combustion
C=4.125 mol	4.125 mol/vol $C + O_2 \rightarrow CO_2$
for H = 3.25-2.6874 = 0.5626 mole	$\frac{0.5626}{2} = 0.2813 \frac{mol}{vol}$
O = 0.000 N = 0.01428 mol	$2H_2 + O_2 \rightarrow 2H_2O$
	=4.4063 mol / vol / 100kg of wood

Table. 3. oxygen required for combustion of 100 kg of wood

Air Contain $N_2$and O_2 in Volume Ratio of 79:21 = 3.762

O_2 required for combustion = 4.4063 mol / vol.

Outside air required for combustion = 4.4063 + 4.4063 (3.762)

= 20.982 mol / 100 Kg of wood.

Stoichiometric air required for combustion of 1 Kg of wood

$$= \left(\frac{20.9828}{100}\right) x\, (22.4) m^3$$

= 4.7 m^3/ Kg of wood.

3.1.4 Products of Combustion

Co_2 = $4.125 \frac{mol}{Vol}$

H_2 = $3.25 \frac{mol}{Vol}$

N2 = 4.4063 (3.762) + 0.01428

Vol N_2 = $16.5907 \frac{mol}{Vol}$

$\sum_{vol}$ = $23.9657 \frac{mol}{Vol}$

= 23.9657 (22.4) Nm^3

For 100 Kg of wood = 536.8316 Nm^3

Therefore, the volume of combustion of 1 Kg of wood

Burnt = 536.8316/100

= 5.368 Nm^3

Heat of combustion Kcal/kg	Heat absorbed/produced Kcal/kg
C=8137.5	8137.05 (49.5)/100 = 4028.66.
H=2890.5	(2890.5*1.25)/100 =325.24
Total	4028.66+325.44=4353.30

Table. 4. Products of combustion total heat absorbed / produced

Therefore, the Calorific Value of wood is = 4353.30-2.6874

= 4350 kcal/kg

3. DESIGN OF BIOMASS STOVE

3.1 The height and the Diameter of the Chimney

3.1.1 Height of the Chimney

Ca = Mass density of air outside chimney
Cg = Average mass density of hot gas.

Ca = 353×(1/tq)

= 353×(1/273+30)

= 1.1650 Kg/m^3

Cg = 353×(1/tq)
Cg = 353×(1/273+400)
= 0.5245 Kg/m^3

Density of air = $1.165\,\frac{Kg}{m3}$

Density = $\frac{mass}{Volume}$

1.165 = $M_a/4.7$

Ma = 6.84 Kg

$10\frac{N}{m2}$ = (1.165-0.5243) x 9.81 x H

H = 0.6283

$30\frac{N}{m2}$ = (1.165-0.5243) x 9.81 x H

H = 2.09m.

Therefore, total height of the stove including the chimney =2m.

3.1.2 Diameter of the Chimney

$$H1 = H\left\{\left[\left(\frac{ma}{ma+1}+1\right)\right]x\left(\frac{tg}{ta-1}\right)\right\}$$

$$= 0.6238\left\{\left[\left(\frac{6.84}{7.84}+1\right)\right] x \left(\frac{673}{303-1}\right)\right\}$$

H1 = 0.6636 m

$$C = \sqrt{2gH1}$$

$$= \sqrt{2x9.81 \times 0.6636}$$

C = 3.608 m/s

$$D = 1.128 \frac{\sqrt{mg} x\ c}{Cg}$$

Mass of hot gases = ma + 1

Mass of air = ma

$$mg = \frac{total\ mass\ of\ hot\ gases}{Time}$$

$$mg = \frac{6.84+1}{3600}$$

mg = 2.17×10^{-3} kg

D = 0.0381264m.

Therefore, the diameter of the chimney = 0.0381264m.

3.2. The Height and Diameter of the stove

The total Height of the stove from bottom of the stove to top of the chimney =2m

Therefore the height of the stove from grate to combustion chamber = 0.34m

In a stove with no chimney, heat release rate is 20 Wt/cm^2 of grate area.

The heat release rate of the stove = 4000 Wt.

$$\frac{4000}{20} = 200\ cm^2$$

$$200\ cm^2 = \frac{\pi}{4} d^2$$

$$= 16\ cm$$

Therefore, the diameter of the stove = 16 cm

= 0.16 m.

3.3 DRAFT MODELING OF THE BIOMASS STOVE

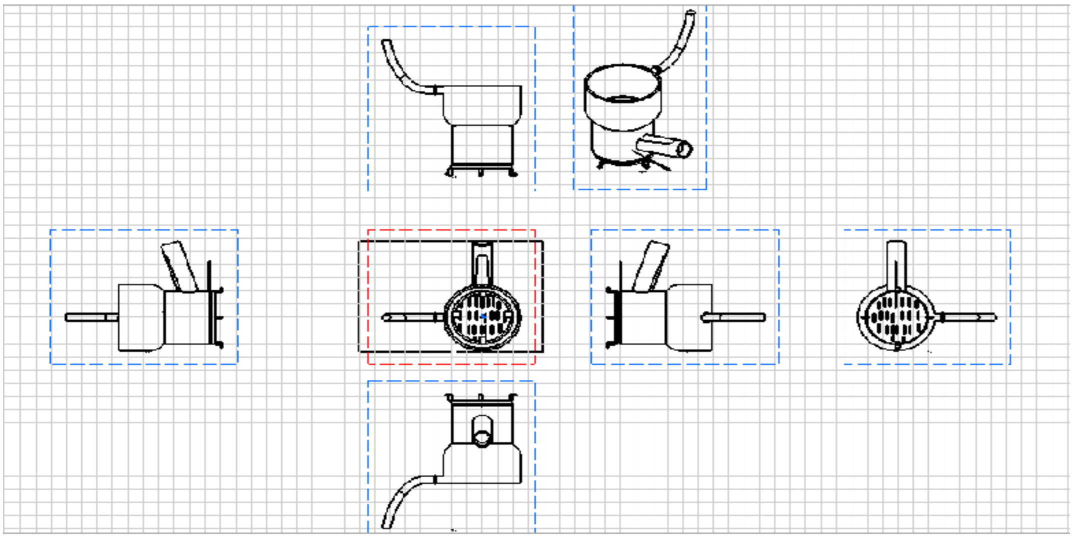

Fig. 1. Drafting of the Biomass Stove

3.4 OVERALL SPECIFICATION OF THE STOVE

CONTENTS	DIMENSIONS(mm)
Height of the Chimney	1000
Diameter of the Chimney	40
Height of the Stove	340
Diameter of the Stove	160

Table 5. Overall specification of the Stove in mm

4. DESCRIPTION OF THE STOVE

As due to the increase of the fossil fuels now a day's it is very difficult to the people to cook for their daily needs, and also due to the enormous amount of usage of the fossil fuels there is a severe demand on fossil fuels. So by keeping all these things in the mind it is decided to fabricate a newly designed Biomass fuelled cooking stoves for domestic purpose, so that all peoples can use this kind of stoves and thus the demand for the fossil fuels gets reduced. And the efficiency of the stove is also kept in mind during the designing process.[7]

4.1 FEATURES INCORPORATED IN THE STOVE

The listed below are the some of the features which are to be in-corporated in a newly designed stove. 1. Grate 2. Wood pieces 3. Pre-heated air supply 4. Chimney 5. Wood pre heating 7. Insulation of stove

Fig 2 Fabricated Biomass Stove

The main theme of this work is to fabricate a newly designed biomass fuelled stove. Because as due to the increase in cost of the conventional fuels like petroleum fuels it is very difficult in the future to adopt these fuels for the daily needs like cooking etc. So by keeping these all things in the mind it is decided to fabricate a newly designed biomass fuelled stove. In this newly designed stove some of the new features are included. By knowing the needs of the people this design has been formulated. By the improvement of this design it will be very useful for the people to cook their foods in less cost and also purely hygienic. Thus to improve the design the following steps are made. First the literatures are collected and then the calculations are made regarding the new stove design. First the chimney and the stove size are calculated. Thus by calculating the dimensions the height of the stove is calculated. Then the diameter of the stove is calculated as same way the height and the diameter of the chimney is also calculated. After calculating the dimensions of the stove then the design procedures are made. To make an efficient design several papers are collected and existing design of the stoves are reviewed and thus a new design is formulated by in-cooperating the new ideas in to the stove. Thus these new ideas will be more effective for the performance of the stove. Then the new design of the stove is done in the Auto-Cad software. Then the material selections are made. The optimum material is selected for the proposed design. Then the fabrication work is to be done. Then the efficiency of the newly designed stove is tested. If any optimizations are needed is made and thus these optimizations are to be made to increase the performance of the stove. Optimization parameters are done on Fuel feed rating, Air supply rate and Shape of the vessel. Then the final results are calculated.

5. CALCULATION OF EFFICIENCY

5.1. WATER BOILING TEST

This modified variant of the notable Water Boiling Test (WBT) is an unpleasant re-enactment of the cooking process that is planned to enable stove designer to see how well energy is transferred from the fuel to the cooking pot. It can be performed on most stoves all through the world. The test isn't expected to supplant different types of stove evaluation; be that as it may, it is outlined as a straightforward technique with which stoves are made in better places and for various cooking applications can be looked at through an standardized and replicable test. [8]

Fig 3. Boiling of water in biomass stove

5.2 PROCEDURE FOR DOING WATER BOILING TEST

- Water boiling test is made for finding the efficiency of the stove.
- Pot used for the test is of aluminium material
- Water is the basic need for the water boiling test.
- The pot should be open top no lid should be used for closing the vessel.
- Dry wood is used as a feeding for the stove.
- The stove test is performed by noting the temperatures at particular time intervals. Test is conducted for 1 hour
- Mass of the pot of water is measured before and after the test. Mass of the fuel before and after the test is also measured
- The readings are then tabulated and the efficiency is calculated

S.no	Time in minutes	Temp of water in Celsius
1	0	25
2	11	30
3	15	40
4	19	47
5	26	48
6	32	51
7	40	59
8	45	69
9	50	74

10	55	86
11	65	93
12	70	99

Table. 6. Water temperature at regular time period

5.3. CALCULATION OF EFFICIENCY

Thermal efficiency h_h = [4.186($T1_{hf}$ – $T1_{hi}$) ($P1_{hi}$ – $P1_{hf}$) +2260 w_{hv}]/f_{hd}. LHV

$T1_{hf}$ = Temperature of water after test = 99 ^{o}c

$T1_{hi}$ = Initial temperature of water = 25 ^{o}c

$P1_{hi}$ = Mass of pot of water = 2000 g

$P1_{hf}$ = Mass of pot of water = 700 g

w_{hv} = $P1_{hi}$ – $P1_{hf}$ = 2000-700 = 1300g

LHV= Lower heating value of wood = 20,000 kJ/kg

f_{hd} = Equivalent dry wood consumed

= [f_{hm} (LHV(1-MC) - MC(4.186(T_b-T_a)+2257)) – C_h .LHV_{char}]/LHV

MC = moisture content of a wood = 15% = 0.15

f_{hm} = f_{hi} – f_{hf} = 1000 – 300 = 700g,

where, f_{hi} = mass of fuel before test = 1000g

f_{hf} = mass of fuel after test = 300 g

T_b = Local boiling point temperature = 100 ^{o}C

T_a = Ambient temperature = 30 ^{o}C

C_h = amount of char remaining after test = 200 g

LHV_{char} = lower heating value of charcoal = 30,000 kJ/kg

So,

f_{hd} = [700(20000(1-0.15) – 0.15(4.186(100-30)+2257)) – 200*30000]/20000

= 431.72 g

Therefore,

Efficiency h_h = [4.186(99-25)(2000-700)+2260(1300)]/431.72*20,000

= 0.386 = 38.6%

CONCLUSION

A biomass stove of 4kW capacity has been designed the detailed drafting diagram has been drawn by using the CATIA software. The fabrication of biomass stove. the efficiency of the stove will be calculated if any optimization is needed to increase the efficiency of the stove, that will be made and through that the efficiency of the stove will be increased.

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