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Energy Efficient Wood Stove

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***Abstract* – This paper has attempted to propose an improvement in the design of non-conventional woodstove. The paper highlights the current problems faced by the rural population in India that uses the traditional stoves/chulha to cook food.This paper is the modest attempt towards experimental study in lab backed with field work for energy efficient cooking devices based on wood as main fuel.**

***Keywords* – Baffles, Combustion Chamber, Temperature Distribution, Thermocouples, Water Boiling Test.**

I. INTRODUCTION

Four out of every five rural and one out of every five urban households primarily depend on direct burning of solid biomass [1] fuel like wood, crop residue and cattle dung in traditional mud stove or three stone fire for cooking. Such traditional cooking practice is characterized by incomplete combustion of biomass fuels resulting in emission of toxic smoke. A novel fuel-efficient stove was developed that requires no external power, costs $5, [2] and vents nearly all of the smoke that is produced in the process of cooking. A design of profiled conical funnel with a truncated tip was sought after that evacuates smoke through a connected "ventilation pipe" and breathes oxygen from an angled "air inlet" in its lower base, while heating a vessel that sits atop the structure. Since the fire is completely contained within this structure, the device harnesses the convective energies of the smoke toward the productive goal of ventilation. Smoke is driven down its energy gradient (up the ventilation duct and out of the house) by natural convection. By elevating the upper duct, small transient wind currents that create a small pressure gradient help force smoke out of the duct naturally.

II. LITERATURE REVIEW

There have been many research and development in many parts of the world for improving the design of wood stoves. All these designs focus on reducing the emission, fuel consumption, increasing the efficiency and making the system cheaper, portable and convenient to use. Few of the innovations that have already been carried out in an efficient stove and these stoves are as follows :

i. Jayprakash's Portable Energy Efficient Wood Stove
ii. Annapurna Unnat Chulha (TERI SPT 0610)
iii. Oorja Stove
iv. CTARA wood stove [3]

III. DESIGN AND COMPONENT MODEL

A. Design Description

The wood stove is circular in section and consists of a cylindrical clay pot as combustion chamber, a top section and a base. The hearth of the combustion chamber is made of clay, the outside of which is lined with fiberglass and encased in a mild steel casing. The grate or fuel bed is at the base of the combustion chamber [7]. There is a gap between the bottom of combustion chamber and base of the steel casing. At the base of steel casing a simple AC Fan of 10 CFM is attached. The combustion chamber rests on the plate that has eight holes around its annulus.

B. Design Specifications

Based on the choice of a domestic-size stove, the following parameters are selected for the design:

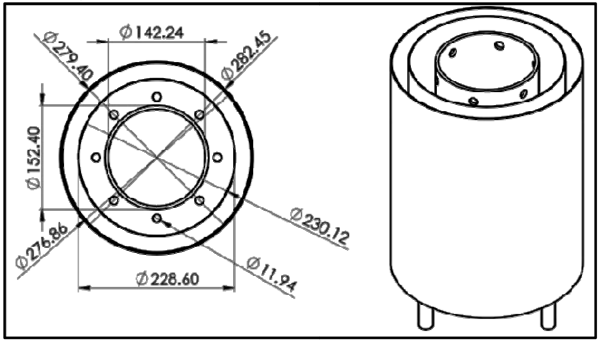


Fig. 1. Top view of stove model

Height of the combustion chamber, Lcc = 228.6 mm;
Internal diameter of combustion chamber, D_1 = 142.24mm;
Thickness of combustion chamber, t_{cc} = 10.16 mm;
Internal diameter of casing = 276.86 mm;
Insulation thickness = 46.74 mm;
Inner diameter of annulus =228.6 mm;
Thickness of annulus = 1.52 mm;
Diameter of holes on base plate = 11.94 mm;

C. Design Calculations

After calculations [3], we get:
A/F = 5.7 kg of Air/kg of fuel

For an actual air supply which is 20% in excess of stoichiometry actual air/fuel ratio, [7]

$A/F_{actual} = 1.2 \times 5.7$
$A/F_{actual} = 6.84$

The wood species considered for the design calculation is pine wood.

$m^{II} = 3.80 g/m^2 s$

Wood is considered to be cut into pieces of cube of dimension 3 x 3 x 3 cm^3
Therefore surface area of wood piece = 9 cm^2
Diameter of combustion chamber is restricted to 13.2 cm.
Cross section area of combustion chamber = 137 cm^2
Therefore number of wood pieces that can accommodate in combustion chamber = $\frac{137}{9}$ = 15

Approximately 14 pieces of wood is taken which is equivalent to 0.267 kg.

Thus, surface areas exposed to burning = 14 x(5x9)=630 cm^2 (assuming only five faces of cube is exposed to burning)

Mass flow rate of fuel $m^I = m^{II} x\ surface\ area = 3.80\ x\ 630\ x\ 10^{-4}$ =0.2394 g/s

Therefore, heat released $=m^I$x calorific value = 0.2394 x 10^{-3} x 16.8131 x 10^6 = 4.025kW

Mass flow rate of air m_{air}= $(A/F)_{actual}$xm^I= 6.84 x 0.2394 x 10^{-3} = 1.63x10^{-3} kg/s

Volume flow rate of air = $\frac{mair}{\rho} = \frac{1.63\ x\ 10^\wedge{-3}}{1.23}$=1.325 x 10^{-3} m^3/s(ρ is the density of air =1.23kg/m^3)

For a fan of blade diameter = 8 cm

Area of air passage = $\frac{\pi}{4}$ x 0.08^2 = 5.026 x 10^{-3} m^2

Therefore, required velocity of air = $\frac{volume\ flow\ rate\ of\ air}{area\ of\ air\ passage}$

$= \frac{1.325\ x\ 10^{-3}}{5.026\ x\ 10^{-3}}$ = 0.263 m/s

Volume flow rate of air = Area of air opening x Velocity of air

1.325 x 10^{-3} = Area of air opening x 0.683

Therefore, Area of air opening = 1.939 x 10^{-3} m^2

As air inlet openings are in the form of circular holes,

Area of air opening = 6 x $\frac{\pi}{4}$ x d^2 = 1.939 x 10^{-3} m^2 (6 holes are provided on the periphery of the combustion chamber)

Therefore, d = 2.02 cm (approx.)

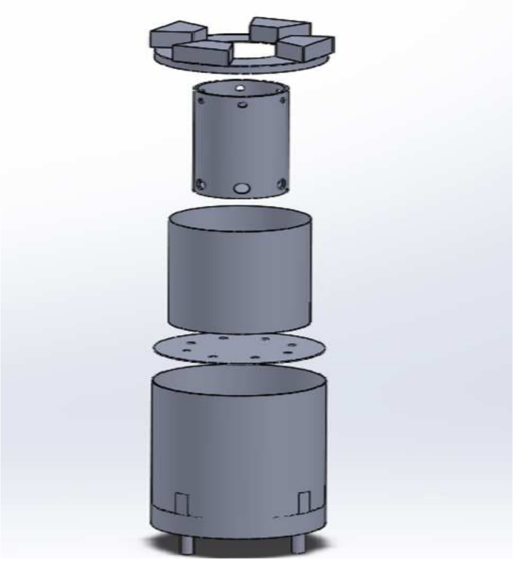


Fig. 2. Exploded view of the project model

IV. TESTING PROCEDURE

A. Method of Testing used for this Project (Water Boiling test) [7]

The stove and vessel are thoroughly cleaned and dried. The test is conducted in an enclosed kitchen environment. A measured amount of fuel wood was weighed out for each test. The same type of wood is used for the series of tests; it is therefore ensured that there was sufficient fuel wood available for the tests, stored in the same place so as to have uniform moisture content. The vessel, lid, and thermocouple are weighed, and then a measured amount of water by volume (about two-thirds the pot capacity) is added to the vessel and weighed again to determine the weight of the water. This was repeated for each test.

The already weighed fuel wood is introduced into the combustion chamber and about 15ml of kerosene is sprinkled on it to initiate burning. The vessel is placed on the stove the moment the sprinkled kerosene got burnt out. The time of the day, the environmental conditions (ambient temperature) and the initial temperature of the water are recorded. Thereafter the commencement of the test the temperature of the water was recorded at intervals of five minutes until the moment the water came to a vigorous boil. The vessel is then removed from the stove and the fire immediately put out with the help of dry sand. The final weight of the remaining water, charcoal and the final temperature of water were then measured and recorded.

The tests were carried out on the 21, 24 and 28 of March, 2016 starting at about 2:30 pm.

Fig. 3. Stove with thermocouples attached

B. Calculations [10]

Thermal efficiency of the stove shall be calculated as follows:

In S.I. units,

If w = mass of water in vessel = 0.5 kg;

W = mass of vessel complete with lid and stirrer = 0.4 kg;

X = mass of fuel consumed = 0.11kg;

c_1 = calorific value of wood = 1671.92 kcal/kg;

x = volume of kerosene consumed = 8 ml;

c_2 = calorific value of kerosene = 2460.113kcal/kg;

d = density of kerosene = .810 g/cc;

f_1 = initial temperature of water in degree Celsius = 24C;

f_2 = final temperature of water, in degree Celsius;

f_3 = final temperature of water in last vessel at the completion of test = 100C;

n = total number of vessels used =1.

(Specific heat of aluminium = 0.896 kJ/kg degree Celsius).

(1 kcal = 4.1868 kJ)

Heat utilized = (n - 1)(W x 0.896 + w x 4.186 8) $(f_2 - f_1)$ + (Wx0.896 + w x 4.186 8) $(f_3 - f_1)$ KJ

H.U = (0.4x0.896+0.5x4.1868)(100-24)

= 186.33KJ

$$\underline{\text{Heat produced}} = 4.1868\ [(X * c_1) + (\frac{xd}{1000}\ x\ c_2)]\ KJ$$

$$H.P = 4.1868[(0.11x1671.92)+(\frac{8\ x\ 0.810}{1000}x2460.113)]$$

$$= 836.73\ KJ$$

$$\underline{\text{Thermal efficiency}} = \frac{\text{Heat utilized}}{\text{Heat produced}}\ x\ 100\ \text{percent}$$

$$\frac{(n-1)(W\ x\ 0.896 + w\ x\ 4.186\ 8).(f2 - f1) + (W\ x\ 0.896 + w\ x\ 4.186\ 8).(f3\ -\ f1)}{4.1868\ [(X * c1) + (\frac{xd}{1000}\ x\ c2)]}$$

$$= \frac{186.33}{836.73}$$

$$= 22.27\%$$

<u>Power Output Rating</u>

$$POR\ = \frac{(F\ x\ CV)}{(860\ x\ 100)} * \eta thermalKW$$

$$= \frac{(0.11\ x\ \frac{60}{7}\ x\ \ 1671.92)}{(860\ )}\ x\ 0.2227$$

$$= 408.21W$$

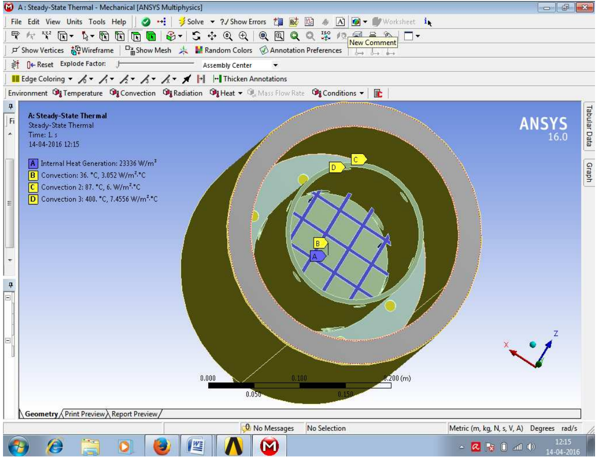
Where,
F = quantity of fuel wood burnt, kg/h;
CV = calorific value of fuel wood, kcal/kg; and = thermal efficiency of the stove, as calculated above.

V. ANALYSIS AND RESULTS

(Thermal Analysis is Conducted to Validate the Readings Taken on 4/04/2016)

Materials taken for ansys analysis were as per [4], [5] and [6]

A. Boundary conditions (for reading taken at 10 minutes)

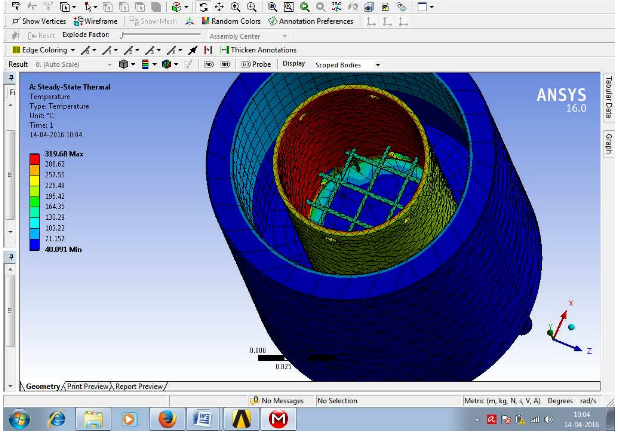

A : Steady-State Thermal - Mechanical [ANSYS Multiphysics]

A: Steady-State Thermal
Steady-State Thermal
Time: 1. s
14-04-2016 12:15

A Internal Heat Generation: 23336 W/m³
B Convection: 36. °C, 3.052 W/m²·°C
C Convection 2: 87. °C, 6. W/m²·°C
D Convection 3: 400. °C, 7.4556 W/m²·°C

Fig. 4. Boundary conditions (for readings taken at 10 minutes)

B. Results Obtained from Simulation


A : Steady-State Thermal - Mechanical [ANSYS Multiphysics]

A: Steady-State Thermal
Temperature
Type: Temperature
Unit: °C
Time: 1
14-04-2016 10:04

319.68 Max
288.62
257.55
226.48
195.42
164.35
133.29
102.22
71.157
40.091 Min

Fig. 5. Temperature distribution along the layer of stove

C. Observation of the Results (for Conditions after 10 minutes)

Table 1: Results from simulation

Sr. No.	Position	Experimental Reading (in °C)	Software Reading (in°C)
1	Inside wall of combustion chamber	322	319
2	Outside wall of combustion chamber	130	220
3	Space between outside wall of combustion chamber and annulus	87	87
4	Outer wall of annulus(where ceramic wool is inserted)	101	110
5	Outermost Wall	42	40.091

Graphical analysis
On X – axis, location of thermocouple
On Y – axis, Temperature in C
For readings at 10 minutes

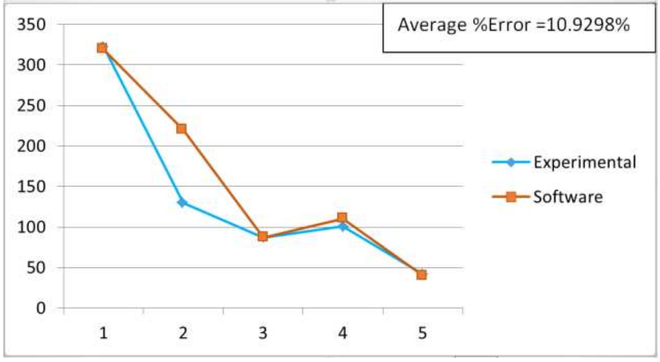


Fig. 6. Temperature distribution graph along the layer of stove

D. Inference

The Ansys results of the temperatures at different positions are generally greater than the Experimental results. The average %error in the readings has a decreasing trend as the time elapses. That is, at higher temperatures the errors are found to be lower. In every reading, it is seen that the temperatures at positions beyond the combustion chamber reduces drastically. This may be due to the effect of radiation and flow of hot gases directly into the space between combustion chamber and annulus from the primary and secondary holes. These effects and flows are not compatible with ansys steady state thermal analysis.

VI. CONCLUSION

It would be seen that the modifications made in providing insulation around the combustion chamber and sizable air inlet to admit adequate quantity of air for combustion, incorporating smoke rings to seal the annulus between the pot and the pothole, and redesigning the configuration of the pot seat and the position of the flue gas exit port, have served to increase the thermal efficiency and therefore the percentage heat utilization of the stove. There has also been a drastic reduction in the smokiness of the stove, making it to be more user-friendly in health, comfort and convenience.

A. Future Scope

Wood stove modifications and retrofit could include:

1) Improved draft controls using barometric dampers. [8]
2) Imparting turbulence by using swirling devices.
3) Employing afterburners and catalysts. [8]
4) Material of combustion chamber (Vernacular Insulative Ceramic). [9]
5) Improved baffles.
6) Use of Solar DC powered fan.

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AUTHOR'S PROFILE

Pavan Hegde obtained his bachelor's degree in Mechanical Engineering in 2016 from University of Mumbai, India.