ISSN 2229-5518

A Case Study on Modifications made in Traditional Indian Biomass Cookstove to Increase its Thermal Efficiency

Nikhil Dixit, Rushiraj Mantri, Omkar Aranke, Ashwin Godbole
Department of Mechanical Engineering, NBN Sinhgad School of Engineering,
Savitribai Phule Pune University

Abstract: The need for an energy efficient biomass cookstove which can replace household LPG stoves is eminent in today's energy crisis scenario. Hence the utilization of biomass energy in the form of pellets (sawdust, garden waste, etc.) can be used as a fuel to run the cooking stove to replace conventional fuels (LPG).The previous cookstoves manufactured by various industries in India were less energy efficient.The main objective behind this case study is to modify these stoves in such a way that they would be more energy efficient, less harmful to living beings as well as user friendly.

Due to lack of technology and awareness regarding biomass and its derivatives, this field has not been researched upto its true potential. The biomass pellets are ignited, which thereafter undergo gasification process and are used as a fuel in these biomass cook stoves. The thermal efficiency of these stoves is obtained by performing water boiling test (as per BIS). Therefore, the challenge in this field is not only to develop such stoves but they should also be technologically feasible, environmentally sustainable, economically viable and socially acceptable

Index Terms: Energy efficient, biomass, cookstove, pellets, gasification, thermal efficiency, water boiling test.

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1 Introduction

The greatest challenge the mankind is facing currently is the need for an alternative source of energy. The world energy sources are depleting due to ever increasing demand for fossil fuels. The demand for fossil fuels is of inelastic nature. The global conventional energy prices are increasing. Still the demand grows on day by day. The excessive use of these fossil fuels have affected environment as well.

The quest for an alternative source of energy has led to the increase in the awareness regarding the use of renewable source of energy. One of the potential alternative sources of energy is biomass energy. The biomass can be compressed using suitable processes in the form of pellets and briquettes which can be used as a fuel. One such application where these biomass pellets can be used is the specially designed biomass cooking stove. These cooking stoves work on gasification process and produce almost smokeless flame with very less amount of emissions.

2 Literature Review

2.1 Need for energy efficient cookstoves in India

The use of traditional stoves leads to incomplete combustion of fossil fuel, causing high Black Carbon (BC) emissions. Furthermore, traditional stoves have low combustion efficiency, leading to higher cooking times and inefficient use of fuelwood. Black carbon (BC) exists as particles in the atmosphere and is a major component of soot. Black carbon mainly results from the incomplete combustion of fossil fuels and wood. Complete combustion would turn all carbon in the fuel into carbon dioxide (CO_2). In practice, combustion is never complete and CO_2, carbon monoxide (CO), volatile organic compounds (VOCs), organic carbon (OC) particles and BC particles are all formed. On a global basis, approximately 20% of black carbon is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning. The largest sources of black carbon are Asia, Latin America, and Africa. Some estimates put that China and India together account for 25-35% of global black carbon emissions.

2.2 Harmful Effects on human health

BC contributes to the adverse impacts on human health, ecosystems, and visibility associated with ambient fine particles. Short-term and long-term exposures to BC are associated with a broad range of human health impacts, including respiratory and cardiovascular effects as well as premature death. The World Health Organization (WHO) estimates that indoor smoke from solid fuels is among the top ten major risk factors globally, contributing to approximately 2 million deaths annually. Women and children are particularly at risk.

Indoor air pollution is the major cause of illness and mortality for women and children inhaling Black Carbon

In India, 400,000 premature deaths occur annually due to lung cancer, bronchitis and cardiovascular disease.

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2.3 Past Efforts for the Improved cook stoves in India

It is interesting that though the organized efforts at national and sub-national levels for improved cook stoves started nearly 30 years back, their widespread use and success has not been adequate and consistent. The social scientists, voluntary organizations, academics, policy makers have all done their bit and pieces for the improved cook stoves but they have not been able to design an optimum cookstove.

2.4 Reasons for limited success till now

a) The end-user wanted more versatility in the fuel usage and less time in cooking, while, the improved mud cook stoves were designed by the institutions by emphasizing on the objective of fuel economy and less smoke
b) The rural people were not concerned much about the cooking fuels and deforestation mainly due to lack of awareness and the alternative employment program for women were not established at that time, as a result, the success was much below the expectation level with which it was started.
c) Apart from the traditional cooking practices, the replacement of traditional cook stoves with the improved cook stoves was also influenced by sociocultural factors and other benefits such as space heating by traditional cook stoves.
d) Stove producers were only concerned about government specifications and did not respond to the need of consumers.
e) Failed to target regions where fuel scarcity was especially severe, or where firewood was very expensive.
f) Another reason was the lack of interest of women towards maintenance, as they did not perceive the usefulness of the stove. [1]

Table 1: Challenges and Research Priorities for Improved Cook stove. [2]

Topic	Research Priority
Adoption and Markets	Factors driving clean cook stove purchase, use, and broader aspirational change. End-uses of traditional stoves (cooking and non-cooking) effectiveness of business models, social marketing, and consumer finance strategies. Cost-effective monitoring protocols documenting short and long-term stove use patterns, including stove and fuel combinations.
Cleaner Fuels	Impacts of fuel stacking and switching to gaseous, liquid, pelletized, and renewable fuels. Impacts and efficiency of fuel production. Processed biomass and biofuels, including efficient conversion of agricultural products and residues into pellets, bio char, charcoal and gaseous or liquid fuels.
Health Impacts	Indoor and outdoor air quality and air pollution exposures Impacts on development and child survival. Impacts on adult disease, including respiratory health and cardiovascular disease incidence of severe burns and injuries.
Technology	Improved stove design (materials, heat transfer, design tools), monitoring (sensors, mobile tools, etc.), and related devices (electric cogeneration, fans, cookware, etc.)

3 Materials And Methodology

3.1 Materials

3.1.1 Measuring instruments

Table 2: Instruments used for Tests and Trials

Sr. No	Instrument Name	Range	Least Count	Purpose
1	Thermometer	0-110 °C	1 °C	Temperature measurement
2	Infrared Gun	0-800 °C	0.01 °C	Temperature measurement
3	Stopwatch	-	0.01 s	Time measurement
4	Moisture Balance	0-100 %	0.01 %	Moisture measurement
5	Weighing Machine	0.2-200 kg	10 gm	Weight measurement
6	Sprinkler	0-20 ml	1 ml	Volume measurement
7	Measuring Tape	0-300 cm	1 mm	Linear measurement
8	Vernier Caliper	0-300 mm	0.01 mm	Linear measurement

3.1.2 Details of Fuel (Sawdust Pellets)

Wood pellets are made from dry sawdust compressed under high pressure and extruded through a die. The fuel used for the test is made up of sawdust and Sal Doc. It has 85-90% of sawdust and remaining 10-15% of Sal Doc. Sal Doc is used as a binding material for better compaction of pellets.
These pellets are uniformly sized, easy to store and cheaply available. They come in a range of sizes: for domestic

ISSN 2229-5518

and relatively small scale systems 6mm or 8 mm is typical, while for larger systems 10mm or 12mm are common. The pellets used for the test trials were of 10mm diameter. [3]

Fig. 2: Sawdust Pellets

3.2 Methodology

3.2.1 Specifications of Traditional Cookstove

1. Overall Dimensions = 245 x 245 x 210 mm^3
2. Combustion Chamber OD/ID = 165 mm/104mm
3. Fuel Capacity = 0.700 kg (Batch Type)
4. Battery Specifications = 12V/4.5A-hr
5. Air Discharge through Fan = 35 cFM (Forced Draft)
6. No. of Fans = 1
7. Average Burning Time = 50-55 min

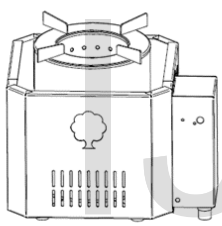

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Fig. 1: Drawing of Cook stove

3.2.2 Working of Cookstove

1. Fill the combustion chamber up to its maximum capacity (700 gm) with pellets.
2. Add 10-15 ml of Kerosene for pre-ignition of pellets.
3. Ignite the pellets with match-stick or suitable equipment.
4. Turn on the fan and keep it at low speed.
5. Wait for 10-15 min till the flame bed is formed.
6. Regulate the fan speed according to the flame intensity.
7. After complete combustion of pellets wait till the cook stove is cooled completely.
8. Remove the ash and clinker with the help of tongs by removing the ash grate.
9. Clean the combustion chamber.

3.2.3 Determination of Burning Capacity Rate

As mentioned in the BIS (IS 13152, Part 2), the procedure for calculating the burning capacity of the stove is as follows:

1. Stack the fuel (sawdust pellets) inside the stove as recommended by the manufacturer.
2. Weigh the cook stove with fuel, let the mass be M_1 kg
3. Sprinkle 10 to 15 ml of kerosene on the fuel from the top of combustion chamber.
4. After half an hour of igniting the fuel, weigh the cook stove with fuel residue (ash), let this mass be M_2 kg
5. Calculate the burning capacity rate as heat input per hour as follows:

Burning Capacity Rate = $2*(M_1 - M_2)$ kg/hr
Heat Input per hour = $2*(M_1 - M_2)*CV$ kcal/hr
{CV=Net calorific value of the test fuel in kcal/kg}

6. Depending upon the burning capacity rate for the cook stove size of the vessel and the quantity of water to be taken for thermal efficiency test is determined. [3]

3.2.4 Determination of Thermal Efficiency using Water Boiling Test

In this method the measured quantity of water at room temperature is kept on the combustion chamber and when it reaches 95°C, the vessel is replaced with the another vessel containing water at room temperature. Likewise number of vessels replaced is recorded and the efficiency is calculated according to the given formulae.

Procedure:-

1. Sprinkle measured quantity 'x' ml (say 10 – 15 ml) of kerosene for easy igniting of the test fuel. As soon as the flame develops, place the vessel on the cookstove and simultaneously start the stopwatch.
2. The water in the vessel will be allowed to warm steadily till it reaches a temperature of 95°C. Note down the time required to heat the water upto final temperature.
3. Remove the first vessel from the cook stove and put the second vessel immediately on the cook stove. Prepare the third vessel for subsequent heating of water.
4. Repeat the procedure by placing the more vessels till there is no visible flame in the combustion chamber of the cook stove. Note down the final temperature of the water in the last vessel. Let it be t_3 °C.

Calculations:-

H_{out} = heat output of the stove i.e. heat utilized in KJ

$$= \{[(n-1)*(w*0.896*0.214+W*4.186)*(t_2-t_1)] + [(w*0.896*0.214+W*4.186)*(t_3-t_1)]\}$$

H_{in} = heat input into the stove i.e. heat produced in KJ

$$= [((X_{fuel}*4400) + (X_k*0.82*10400/1000))*4.186]$$

$$\text{Efficiency, } \eta\ (\%) = \frac{(\text{Heat Utilized} *100)}{(\text{Heat Produced})}$$

Heat utilized = heat output of the stove i.e. heat utilized in KJ

Heat produced = heat input into the stove i.e. heat pro-

ISSN 2229-5518
duced in KJ
w = mass of water in vessel, in kg.
W = mass of vessel with lid, in kg.
X_{fuel} = mass of solid fuel consumed, in kg.
H_{fuel} ='net' calorific value of solid fuel, in KJ/kg;
X_k = mass of kerosene for ignition, in kg.
H_k = calorific value of kerosene, in KJ/kg
t_1 = initial temp of water
t_2 = final temp of water
t_3 = final temp of water in last vessel at the completion of test
n = total no. of vessels used
C_w = specific heat of water i.e. 4.186KJ/kg
C_v = specific heat of the material of the vessel i.e. of Aluminum = 0.896. [4]

4 Experimental Analysis

4.1 Thermal Efficiency tests of Traditional Cookstove

Table 3: Efficiency test results

Test No.	Heat Produced (W)	Heat Utilized (W)	Efficiency (%)
1	3680	1489.18	38.58
2	3680	1441.32	37.34
3	3680	1381.88	35.8
4	3680	1347.91	34.92
5	3680	1432.83	37.12

4.2 Modified Parameters to Increase Efficiency

4.2.1 Thermal Insulation

In order to reduce the heat dissipation due to radiation and convection and to increase the heat utilization, different thermal insulating materials and their respective properties were studied (Rockwool, glasswool, calcium silicate and cerawool). Out of these insulating materials, cerawool was selected due to its low thermal conductivity and high service temperature.

Table 4: Properties of cerawool. [5]

Parameter	Cerawool
Density	64 to 128 kg/m^3
Thermal conductivity	0.11 W/mK
Max. working temperature	1200°C
Tensile strength	Low
Elasticity	High
Applications	Furnace and Boilers

Sr. No	Heat Produced (W)	Heat Utilized (W)	Efficiency (%)
1.	3680	1573.56	42.76
2.	3680	1580.56	42.95
3.	3680	1533.82	41.68
4.	3680	1542.65	41.92
5.	3680	1565.84	42.55

Table 5: Efficiency test results (Insulations)

Fig. 3: Thermal Insulation of Combustion chamber

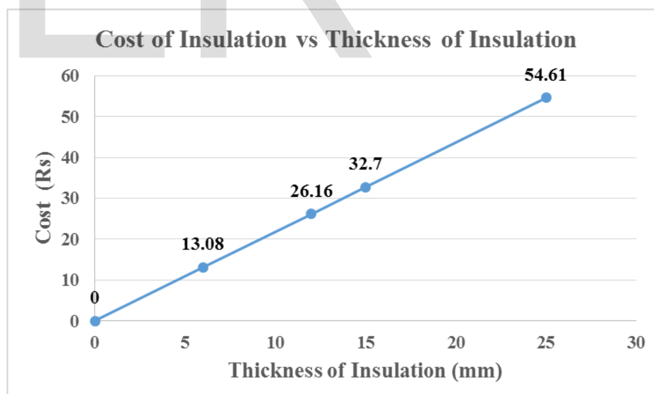

Fig. 4: Variation in cost of insulation with respect to thickness of insulation.

4.2.2 Inlet Air Slot Modification

In forced draft cook stove, the air is supplied through an external source like fan, blowers, etc. Sufficient amount of air is mandatory for complete combustion of fuel (biomass pellets). The air is supplied through two openings viz.
1. Primary air slot: The air supplied through this slot is required for initial combustion (pyrolysis) of the fuel using gasification technology. The air supplied should be in sufficient amount so as to assist the pyrolysis process. In-

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ISSN 2229-5518

sufficient amount of air results in incomplete combustion and ultimately produces unburnt masses.

2. Secondary air slot: The air supplied through this air slot helps in combustion of pyrolised gases which results in the propogation of the flame.

In the modified cook stove the primary air slot area is increased by 200mm^2, considering the stove specifications so as to achieve complete combustion of pellets with minimal unburnt masses.

Table 6: Efficiency Test Results (Inlet Air Slot Modification)

Sr. No	Heat Produced (W)	Heat Utilized (W)	Efficiency (%)
1.	3680	1447.34	39.33
2.	3680	1466.48	39.85
3.	3680	1476.41	40.12
4.	3680	1433.34	38.95
5.	3680	1445.44	39.55

Fig. 5: Modified Air Duct

4.2.3 Material of Combustion Chamber of Cook stove

Mild Steel/Carbon Steel and Stainless Steel are the two types of materials widely used for manufacturing of cookstoves, motors and electrical appliances. Stainless steel (SS) is preferred over mild steel (MS) due to its low thermal conductivity (W/mK) and high ultimate tensile strength (MPa). In this case the use of SS is advisable over MS because of its excellent mechanical as well as thermal properties.

Table 7: Comparison of properties of MS and SS. [6]

Parameter	Mild Steel	Stainless Steel
Tensile Strength (Mpa)	440	515
Yield Strength (Mpa)	370	275
Elastic Modulus (Gpa)	205	207
Poisson's Ratio	0.27-0.30	0.27-0.30
Elongation	15 %	40 %

Sr. No	Heat Produced (W)	Heat Utilized (W)	Efficiency (%)
1.	3680	1476.41	40.12
2.	3680	1416.06	38.48
3.	3680	1373.00	37.31
4.	3680	1351.29	36.72
5.	3680	1409.80	38.31

Table 8: Efficiency Test Results (Use of Stainless Steel)

4.3 Modifications made for Aesthetics and Utility

4.3.1 Upper Covering of Metal Sheet

The sole purpose of providing metal sheet to the cookstove is to give a compact look as well as to prevent the spilling of eatables (solid/liquid food) inside the frame assembly. It also helps in concealing the insulation layers and provides protection to the insulation from external factors like dust, rain, etc. which may affect its chemical properties and in turn may also hamper its overall performance in the long run.

4.3.2 Rockwool Cloth Covering

Rockwool cloth covering is used to hold the shape of the cerawool insulating layer firmly. The added advantage of using rockwool cloth is that it itself acts as an excellent insulator thereby preventing the heat dissipation.

Fig. 6: Modified Cookstove along with Upper covering

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5 Results And Conclusion

5.1 Results

The cumulative results obtained by implementing all the above said modifications are as follows:

Table 9: Cumulative Efficiency Test Results

Sr. No.	Heat Produced (W)	Heat utilized (W)	Final Thermal Efficiency (%)
1	3680	1746.89	47.47
2	3680	1689.48	45.91
3	3680	1710.83	46.49
4	3680	1718.92	46.71
5	3680	1702.00	46.25

5.2 Conclusion

The final outcome of this case study is as follows:
1. The thermal efficiency was increased by making three major modifications viz.
a. The usage of thermal insulation resulted in the increase of thermal efficiency by 4-5%.
b. Providing adequate air flow increased the thermal efficiency by 1-1.5%.
c. Changing the material from MS to SS for the manufacturing of the combustion chamber of the cook stove increased the thermal efficiency by 1-1.5%.

Thus the thermal efficiency of the cook stove can be increased up to 6-8% by implementing the above modifications.

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