ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Development and Performance Evaluation of an Improved Three Pot Cook Stove for Cooking in Rural Uttarakhand, India

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Manuscript Info

Manuscript History:

Received: 23 June 2013
Final Accepted: 30 June 2013
Published Online: July 2013

Key words:
Improved three pot cook stove,
Traditional mud stove,
Emission parameters,
Thermal parameters

Abstract

In this study, an improved three pot cook stove was designed, fabricated and tested to evaluate its performance. The thermal performance of the improved three pot stove was compared with that of traditional mud stove. The results obtained showed a better performance of the improved three pot cook stove than that of the traditional mud stove. The results also showed that the improved three pot stove with wood burning rate of 0.17 kghr–1 can handle fuel more efficiently and economically than traditional mud stove, which has wood burning rate of 0.28 kghr–1. The thermal efficiency of improved three pot cook stove was found to be 28.4%, whilst that of traditional mud stoves was 10.7%. The emission parameters of improved three pot cook stove showed 65.8% SO_2, 70.2% NO_2 and 76.1% TSPM concentration reduction as compare to the traditional mud stove. The actual fuel wood saving was observed 30.0% by using improved three pot cook stove as compared to the traditional mud stove.

Introduction

One third of the world's population of six billion lives in developing countries. Many of these people lack access to modern energy services for economic and social development and some of their present energy system is unsustainable (Smith, 1993). And the emergence of perennial fuel crisis in the developing countries has drawn attention to the need for energy experts to further concentrate on producing viable alternatives and/or complements to kerosene and cooking gas for domestic cooking (Olorunsola, 1999).

Nearly 2 billion people, constituting about a third of humanity, continue to rely on biomass fuels and traditional technologies for cooking and heating (Akinbami, *et al*. 2001; Johansson and Goldemberg 2002).

Traditional fuels such as biomass are quite difficult to burn completely in simple household-sized stove. Combustion of bio-fuels in poorly vented kitchens using poorly functioning stoves leads to the release of very high concentrations of suspended particulate matter and noxious gases. The use of these fuels has a negative impact on the health of household members, especially women and children, when burned indoors without either a proper stove to help control the generation of smoke or a chimney to vent the smoke outside (Smith, 1993). Traditional cook-stoves increases indoor concentrations of important pollutants, such as particulate matter, carbon monoxide, NO_2, SO_2, benzene and formaldehyde which are release from fuel wood burning at the time of cooking. Such exposures are linked to acute respiratory infections, chronic obstructive lung diseases, low birth weights, lung cancer and eyes problems (Kaoma and Kasali ,1994). Therefore, accelerated technological effort is required to improve cook-stove and wood's environmental performance.

Although wood stands out as an affordable, available and safe to store resources that is relatively straightforward to employ for domestic cooking, but the use of wood in inefficient stoves that waste resources and produce substantial amounts of indoor

air pollution would be unsustainable. However, continual technology development will tame wood's disadvantages and allowed wood to be used with much greater efficiency and greatly reduced environmental impact.

The aim of this work is to use locally available materials to develop a more efficient, affordable and safe wood-burning stove in which the use of the stove will result in lesser consumption rates of fuel and reduce the indoor air pollution. This paper also reports the comparative thermal and emission performance of the improved three pot cook stove with a traditional mud stove.

Materials and Methods

Design Considerations The following factors were considered in the design of the three pot cook stove.

Cost of Production The stove was constructed with locally sourced materials mud and rice husk to keep the cost as low as possible to enhance affordability by low-income households.

Ease of Manufacture*:* The design of the stove was such that minimal technical skills required in fabricating the improved three pot stove. Table 1 show the physical parameters of test stoves used in this study.

The procedure and formulae employed in the calculations of burning rate was based on the approach use by Bolaji and Olalusi, 2009.

$$R = \frac{100(Wi - Wf)}{(100 + M)t} \quad (1)$$

where

R=Burning Rate Kg/hr
Wi = Initial weight of fuel at start of test, kg;
Wf =Final weight of fuel at end of test, kg;
M = Moisture content of fuel, %;
t = Total time taking for burning fuel, hr.

The procedure and formulae employed in the calculations of thermal efficiency of the chulha was based on the approach used in Indian Standard on Solid Biomass, chulha – specification 1991.

Thermal efficiency (%) = $\frac{HU}{HP} X 100$ (2)

Where,

HU = Heat utilized
HP = Heat produced,

The procedure and formulae employed in the calculations of power output rating

of the chulha was based on the approach used in Indian Standard on Solid Biomass, chulha – specification 1991.

$$P = \frac{F \times CV \times Te}{860 \times 100} kW \quad (3)$$

where,

P = Power Output Rating, kw
F = Quantity of fuelwood burnt, kg/h;
CV =Calorific value of fuelwood, kcal/kg
Te = Thermal efficiency of the stove, as calculated above.

Description of an improved three pot cook stove

The commonly used traditional mud stove does not contain any features that will help in the effectively burning of the fuel and reduction of indoor pollution. Traditional mud stoves are inefficient and the combustion process in traditional cooking stove is non-ideal and favoring incomplete combustion. An energy efficient improved three pot stove was designed and fabricated to meet the cooking energy requirement of a family having 4–6 persons. The schematic diagram of improved three pot stove and its side view is illustrated in Fig.1 and Fig. 2 respectively. The dimensions of improved three pot stove are shown in Table 2.

Housing: The housing was fabricated from well insulated earthen mixture of clay and crop residue in 3:2 ratio of 7 cm in thickness. It is a three-dimensional form of a trapezium , tilted upward to the rear side. It houses two chambers, the upper one is combustion chamber and lower is ash collection/ flue chamber.

The Flue Chamber*:* Air circulation is important in order to keep the fire burning in the combustion unit. The draught is obtained in the stove with the help of the connection between the chimney, the flue chamber and combustion unit. The combustion units and the chimney pipe are mounted on the chamber as shown in side view of the stove in Fig. 2. The flue chamber consists of adjustable air opening from both the side wall of stove for secondary air circulation. Bricks are used as regulators to control

the volume of air admitted through the openings into the fire-box.

Grate*:* The trapezium grate is a metal frame for holding fuel wood , kept over the flue chamber . It is made from cast iron of 6 mm thick. 3 circular grates were kept at three suitable places to develop 3 pot holes in the improved three pot stove.

The Combustion Chamber*:* The combustion chamber is where fuel wood is burnt and heat is generated. It is mounted on the lower chamber, in which adjustable air openings have been provided from both side walls of stove for secondary air circulation and ash collection. The combustion chamber consists of the fire-box, and pot holes, circular grates and chimney.

Chimney Pipe: The chimney pipe was fabricated from cement at the center of the rear side. It is a hollow pipe of 1360 mm in height and 100 mm in diameter .The height of the chimney can be adjusted according to the height of the room.

Performance evaluation

Test House:

The houses used for this study were the residential, kachcha houses of Indra colony, Pantnagar. The walls of the house were made of bricks and roof was of cemented sheet and the floor was made up of mud. Both the kitchen used for the test were more or less similar. The kitchen having improved three pot cook stove was a, confined structure with a volume of 101.1ft^3 and poor ventilation. The kitchen having traditional mud stove was a, confined structure with a volume of 99.0ft^3 having poor ventilation. The window and outside door was closed during the tests. In the test houses a number of tests have been carried out on both the stoves under similar conditions for comparative performance evaluation. The apparatus used for the tests included three medium-size aluminium pots, a weighing balance, a stopwatch and match box. The sun dried fuel wood of poplar *(Populus deltoides)* was used for test. The calorific value of poplar was 4300kcal/kg. Three trails were taken to carry out the thermal efficiency test of the both cook stoves.

Tests on Burning Rate

Tests on burning rate was carried out with both the stove. Appropriate fuel was charged into each stove and the initial weight of fuel at the start of test, the final weight of fuel at the end of test and the time taken to burn were recorded. This test was repeated two more times for the three stoves and the average burning rate value was calculate for each of the stoves.

Water Boiling Tests

According to Danshehu *et al*. (1992), Water Boiling Tests (WBTs) are short, simple simulations of standard cooking procedures. They measure the fuel consumed and time required for simulated cooking. WBTs are usually employed to investigate the performance of stove under different operating conditions to an expected stove performance. It is used by stove designers, researchers and field workers for quick comparison of the performance of stoves. The data obtained were used to compute the thermal efficiency for each stove using Eq. (2).

Power output rate

The power output rating of a chulha is a measure of total useful energy produced during one hour burning of fuel wood. The data of thermal efficiency and calorific value of fuel wood obtained were used to compute the power output rate for each stove using Eq. (3).

Indoor air quality monitoring

Indoor air pollution levels were monitored by using Handy air sampler (APM 821, Envirotech, Delhi, India). The handy air sampler was used to monitor SPM, SO_2 and NO_2 concentration in the kitchen of test house having traditional and improved three pot cook stove. Handy Air Sampler kept 1.5 m above the floor (the "breathing zone" level) and 1 m from the stove in kitchen.

The total particulate matter monitoring was computed by difference in the filter paper weight and volume of air sample. However, two attached impingers used to monitor the gaseous pollutants. For the gaseous pollutant (SO_2 and $NO_{2)}$ monitoring was done by bubbling indoor air through the respective liquid absorbing medium. Improved West & Gaeke method with Potassium-tetra choloromercurate (K-TCM) as absorbing medium (BIS, 2001) was used to determine SO_2 concentrations. However, for determination of NO_2, modified Jacob and Hocheiser method (BIS, 2006) with absorbing solution of sodium hydroxide and sodium arsenite was used.

Table 1: Physical Parameters of Test Stove

Parameter	Traditional mud stove	Improved three pot cook stove
Type	Fixed	Fixed
Main Body	Mud and stone	Mixture of mud and crop residue(3:2) and brick
Triangular grate	Absent	Metal
No. of pot hole	2	3
Circular grates	Absent	Metal
Wall thickness	4.5cm	7.0 cm
Ht from grate to pot bottom	13cm	10cm for front two pots and 8cm for last pot
Chimney	Absent	Cemented (10cm inner diameter)

Table 2: Dimensions of Improved Three Pot Cook Stove

Parameters	Abbreviation	Dimension
Length of stove	AB=EF	60cm
Width of stove	AC=BD	50cm
Height of stove (Front)	AE=BF	18cm
Height of stove(Back side)	DG	22cm
Fuel entrance gate height	KN=ML	10cm
Fuel entrance gate length	MN=KL	15cm
First pot hole diameter	O	20cm
Second pot hole diameter	P	16cm
Third pot hole diameter	Q	12cm
Fuel collection	HI	15cm
Chimney diameter	RS	10cm
Chimney length(According to the height of test room)	T	136cm

Result and discussion

The burning rate obtained for the both stoves were 0.17 kghr–1 and 0.28 kghr–1 for improved three pot cook stove and traditional mud stove respectively. This result shows that the traditional mud stove had a higher burning rate than improved three pot cook stove. The higher the burning rate the shorter the life span of the fuel, therefore, burning rate determines the life span of the fuel during combustion. It is often disadvantageous to have too high a burning rate. Hence the lower burning rates obtained from the improved three pot cook stove show that the two stoves handled fuel economically. The burning rate obtained in traditional mud stove was close to the 0.21 kghr–1 obtained by Kaoma and Kasali (1994) from the test of coal briquettes in a Zambian clay stove. These results show that biomass as fuel using rural population need a more efficient stove for cooking to replace the traditional stoves.

The thermal efficiencies obtained from the improved three pot cook stove and traditional mud stove were 28.4% and 10.7%, respectively. The higher thermal efficiency of improved three pot cook stove was due to the minimal loss of convective heat current in the two stoves. Also, the higher burning rate of fuel in traditional mud stove lower the thermal efficiency of the stove since both parameters are inversely proportional to each other.

Fig. 3 shows the temperature rise versus time relationship obtained from the water-boiling test carried out with the three stoves. The result showed better performance of improved three pot cook stove than traditional mud stove. It took 13 min for 2 litres of water to boil on the improved three pot cook stove, while the same quantity of water took 20 min to boil on traditional mud stoves respectively.

The mean power output rate obtained for the traditional mud stove and improved three pot cook stove. This result shows that the traditional mud stove had a less power output rate than improved three pot improved cook stove. The average power output rate of improved three pot cook stove was 2.8 kW and power output rate of traditional mud stove was observed 1.0kW. Similar study conducted by Joshi *et al*. (1989) on emission from burning biomass in cook stove and their results revealed that average power output of conventional stove and improved stove i.e. 'Priyangi' stove was 3.93 kW and 4.64kW and the average thermal efficiency of these stove was 15.0% and 26.0% respectively. Fig. 4 illustrate the comparison of thermal parameter of traditional mud stove and improved three pot cook stove.

Fig. 1. Schematic Diagram of Improved Three Pot Cook Stove.

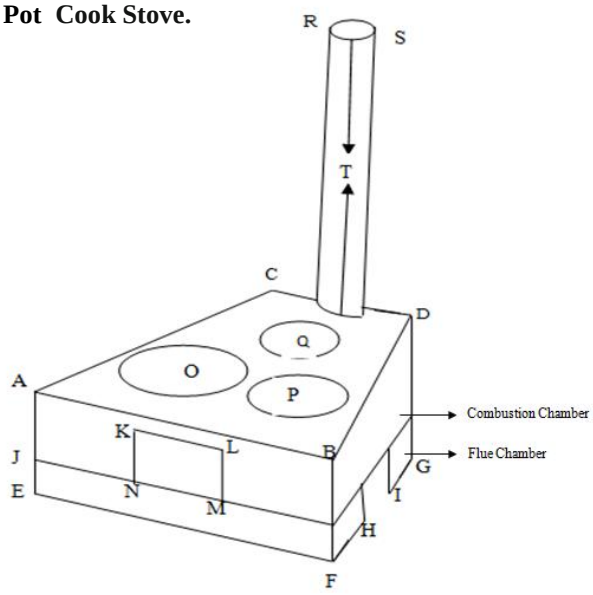


Fig. 2: Side View of Improved Three Pot Cook Stove.

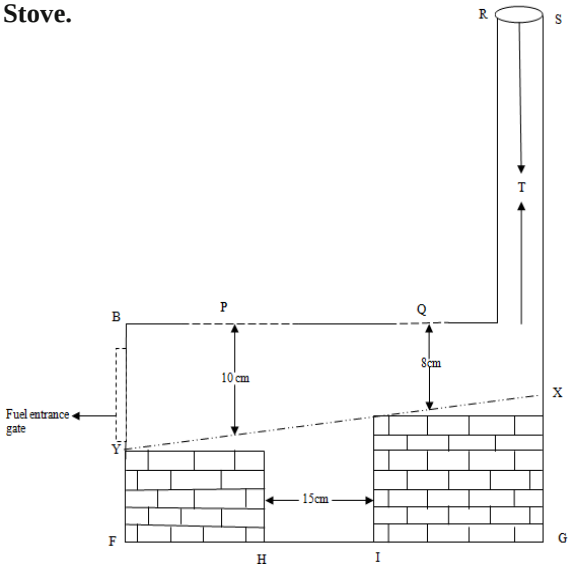


Fig. 3: Rate of Temperature Rise of Water Using Improved Three Pot Cook Stove and Traditional Stove

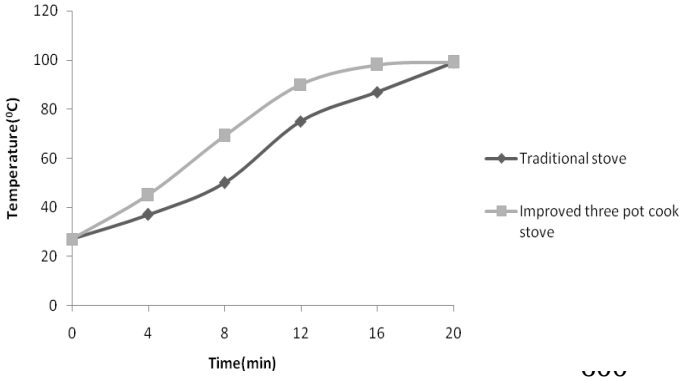
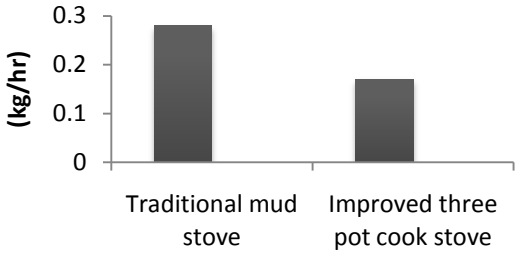


Fig. 4: Comparison of Thermal parameter of Traditional Mud Stove and Improved Three Pot Cook Stove.

(A)Burning Rate



(B) Thermal Efficiency

(C) Power Output Rate

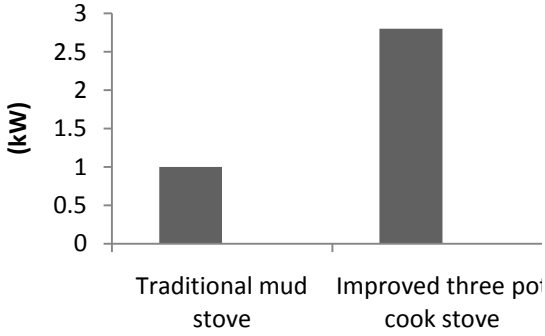
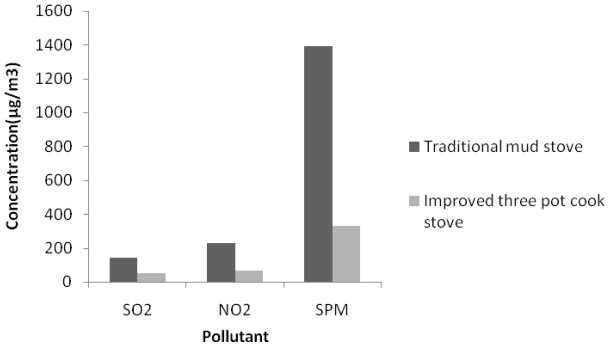


Fig. 5: Comparative Emission of Air Pollutant Concentration in Traditional Mud Stove and Improved Three Pot Cook Stove.



Both the models of wood-burning stoves were tested to determine their contribution to indoor air pollution. The measurements under household conditions revealed that the improved three pot cook stove had much lower pollutant emissions than the traditional mud stove. Fig. 5 illustrates the comparative emission of air pollutant concentration in traditional mud stove and improved three pot cook stove

The average SO_2 NO_2 and particulate matter concentrations were 49.0 µg/m^3, 67.6 µg/m^3 and 332.0 µg/m^3 in kitchen while average pollutant concentration emission from traditional mud stove in the present investigation were SO_2 NO_2 and particulate matter concentrations were 143.3 µg/m^3, 227.5 µg/m^3 and 1389.7 µg/m^3 in kitchen. The emission parameters of improved three pot cook stove showed 65.8% SO_2, 70.2% NO_2 and 76.1% TSPM concentration reduction as compare to the traditional mud stove. Almost similar results were observed by Albalak *et al*. (2001) in rural Guatemala for twenty-four hour PM concentrations for open fire cook stove and an improved three pot cook stove. Average PM concentration was observed 1560 µg/m^3 and 280 µg/m^3 while cooking on a traditional mud stove and improved cook stove 'Mejorada' respectively. The 'Mejorada' showed an 82.5% reduction in PM concentrations as compared to the traditional cook stove.

It was observed that the average fuel consumption for boiling the same amount of water through improved three pot cook stove was less as compared with the traditional mud stove. The actual fuel wood saving was recorded 30.0% by using improved three pot cook stove as compared to traditional mud stove. It comes out approximately 547.5 kg of fuel wood saving per average size family of five persons per year.

Conclusion

Larger percentage of the rural population in developing countries relies on biomass fuels and traditional technologies for cooking and heating. And the burning of biomass fuels in the traditional and inefficient mud-stoves has a negative impact on the health of household members. Therefore, in this study a more efficient wood-burning stove was designed, fabricated and the thermal and emission performance of the stove was compared with that of traditional mud stove.

The results obtained showed that the improved three pot cook stove with fuel burning rate of 0.17 kghr−1 can handle fuel more economically than traditional mud stove, which has fuel burning rate of 0.28 kghr−1. The results also showed a better performance of the improved three pot cook stove in terms of thermal efficiencies and power output rate than that of traditional mud stove. The thermal efficiencies of the improved three pot cook stove and traditional mud stove were found to be 28.4% and 10.7%, respectively. Apart from this, the emission parameters of improved three pot cook stove showed 65.8% SO_2, 70.2% NO_2 and 76.1% TSPM concentration reduction as compare to the traditional mud stove.

Acknowledgement

The authors would like to thank Dean, College of Basic Sciences and Humanities and Head, Department of Environmental. Sciences for providing the necessary facilities throughout the period of this research work. The research fellowship provided by University Grant Commission , India during the course of this study is duly acknowledged.

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