EXPERIMENTAL STUDY OF TRADITIONAL COOK STOVES AND VARIOUS IMPROVED COOK STOVES USING BIOMASS

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Abstract- Biomass resources are effortlessly found in the world resulting in its quantum usage for cooking and heating since the origin of human civilization. Large number of population of rural areas in developing countries including India depend on biomass resources for cooking and heating purposes. For these purposes, half of the world's population uses poorly functioning traditional cook stoves which causes several health effects in women and children as well as affecting the environment. In this experimental study, a comparison of thermal efficiency and power output of traditional and improved cook stoves were made. The experiment conducted was done using Water Boiling Test as per BIS standards. It was also aimed to compare the emission levels based on CO_2 reduction potential. Results indicated that the thermal efficiency of improved cook stoves is higher than the traditional cook stove. In addition, the commenced research proved that the improved cook stoves reduces the CO_2 emissions.

Keywords- Biomass, Improved Cook Stoves, Power Output, Thermal Efficiency, Traditional Cook Stove, Water Boiling Test.

I. INTRODUCTION

Open fires and primitive stoves have been instrumental in cooking since the beginning of mankind. They occured in different sizes and styles, having been modified to myriad cultures and food preparation methods. As the time changed, more advanced cook stove models have been developed. The modern kitchen in today's world reflect the many types of standard based and specialized cooking devices available, from coffee and tea pots to toasters and gas cooktops. But still around 2.7 billion people around the world today depend on traditional biomass such as fuelwood, charcoal or crop residues for cooking,heating and other purposes; and over 1.4 billion people do not have access to electricity [1].About 2.5 billion of this 2.7 billion are in developing countries [2]. In rural areas of developing countries, 90% of the household energy consumption is overcome by the traditional biomass fuels [2].The number of people relying on biomass will increase to 2.7 billion by 2030 because of population growth and in the absence of new policies.

This leads to the fact that one-third of the world's population will still count on these fuels [2].Traditional cook stoves or *chulhas* of thermal efficiencies below 10% emit large amount of pollutants and are used in the developing countries for cooking applications by the rural population. A lot of time is spent in collecting fuels as of poor thermal efficiencies, traditional cook stoves consumelarge quantity of fuel wood. Moreover, women and children health are affected from high levels of pollutants, for 3–7 h daily for manyyears due to these in rural areas [3]. As stated by Smith et al. [4], the burning of biomass fuels results in emission of very high levels of smoke containing hazardous pollutants. This includes respirable suspended particulate matters (SPM),carbon monoxide (CO), nitrogen oxides (No_x), sulfur oxides (SO_x),and a host of organic compounds, some of which (e.g. benzo(a)pyrene) are commonly known ashuman carcinogen.The evidence that biomass fuels burned in traditional ways leads to a buildup of greenhouse gases (GHGs) [5], as well as black carbon (BC), in the atmosphere [6]. As reported by World Health Organization (WHO), approximately 1.6 million premature die every year from these exposure of emissions [7].

Cook stoves with improved efficiency have been introduced in developing countries since 1970.A number of improved wood-burning cookstoves (ICS) models known as second generation flued cook stoves (SGF), were developed. These cookstoves were designed and manufactured based on the engineering principlesand hence, were more efficient and durable. The aim of these designs and modifications was to increase the efficiency with the idea todecrease the fuel wood consumption to reduce the deforestation as well as to decrease the drudgery with the emphasis on smoke reduction [8]. ICS are cooking stoves that use biomass (charcoal, wood, paper) and are designed to maximise the thermal efficiency, fuel wood efficiency, operate safely and minimise harmful emissions to human health [9]. Evidence suggests that widespread distribution of Cookstoves technology with improvements in energy andcombustion efficiencies is potentially useful to mitigate adverse human health, and environmental consequences [10].

This paper deals with comparative efficiency and power output of traditional cook stove (chulha) and

different models of ICSs named as Improved cook stove 1 (ICS1), Improved cook stove 2 (ICS 2) and Improved cook stove 3 (ICS 3) using the laboratory based Water Boiling Test (WBT) along with, emission reduction analysis of improved cookstoves using biomass. It is found that thermal efficiency of ICSs is much more than traditional cook stove. Further, it is also found that ICSs showed highest amount of CO_2 reduction.

II. DETAILS EXPERIMENTAL

2.1. Materials and Methods

For this study, the comparative efficiency and power output of traditional and different models of improved cook stoves has been carried out for which the following materials were used.

Materials

In this experimental study, wood was collected from nearby village for testing cook stoves. Traditional cook stove and three different models of improved cook stoves were available at SardarSwaran Singh National Institute of Renewable Energy (SSS- NIRE), Kapurthala.

The water boiling test (WBT), as per the Bureau of Indian Standards [11] was performed to calculate the efficiency of four cook stoves and the following instruments or equipments have been used:

a) Bomb Calorimeter
b) Thermometer
c) Stopwatch/time measuring device
d) Glass cylinder for measuring water
e) Wood fuel
f) Different models of cook stoves
g) Kerosene oil
h) Platform balance
i) Match stick
j) Aluminium vessels as per BIS standard

Experimental Methods

Thermal efficiency of a cook stove may be defined as the ratio of heat utilized to the heat produced by complete combustion of a given quantity of fuel wood which is based on the net calorific value of fuel wood. The few measurements to carry out thermal efficiency of different cook stoves were carried out as below:

Determination of Burning Capacity Rate, vessel size and quantity of water

The method described below need to be used to determine the burning capacity in order to choose the cooking pot and the amount of water to be taken in the pot as per BIS standards. For this, we arranged the combustion chamber with test fuel in honey comb fashion up to three fourth of the height of the cook stove in the pattern recommended. 10 to 15 ml of kerosene has been sprinkled on the fuel from the top of the cook stove to ignite the fire. Before igniting the fire the weight of the cook stove was measured and again after half an hour of lighting it was measured again as per BIS standards [11]. The burning capacity rate of the cook stove was calculated by the following equation [11]:

$$\text{Heat Input Rate per hour} = 2(M_1 - M_2) \times CV \text{ kcal/h} \quad (1)$$

Where M_1 = the initial mass of the cook stove with test fuel in kg, M_2 = the mass of the cook stove, after burning the test for half an hour in kg, CV = calorific value of the test fuel in kcal/kg.

For thermal efficiency test, the size of the vessel and the quantity of water to be taken shall be selected from the table given in BIS standards depending upon the burning capacity rate of cook stove. After doing the calculations for both traditional and improved cook stoves using Eq. 1, it is found that the quantity of water in pot to be taken for WBT is to be 24 kg for traditional cook stove, 8 kg for ICS 2 and 10 kg for both ICS 1 and ICS 3.

Thermal Efficiency calculation

$$\text{Thermal Efficiency (\%)} = (\text{Heat utilized/Heat produced}) \times 100 \quad (2)$$

$$\text{Heat utilized} = (n\text{-}1)\,(W \times 0.896 + w \times 4.1868)\,(T_2 - T_1) + (W \times 0.896 + w \times 4.1868)\,(T_3 - T_1)\ \text{kJ} \quad (3)$$

$$\text{Heat Produced} = 4.1868\,[(X \times c_1) + (x d\, c_2/1000)]\ \text{kJ} \quad (4)$$

$$\text{Thermal Efficiency } (\eta) = [\{(n-1)\,(W \times 0.896 + w \times 4.1868)\,(T_2 - T_1) + (W \times 0.896 + w \times 4.1868)\,(T_3 - T_1)\} \times 100\} / [\{4.1868\,[(X \times c_1) + (x d\, c_2/1000)\}] \quad (5)$$

Power output Rating

The power output rating of a cook stove is a measure of total useful energy produced during one hour burning of fuel wood.

$$\text{Power output rating} = [(F \times CV \times \eta) / (86000)]\ \text{kW} \quad (6)$$

The parameters used in the above equation of thermal efficiency are defined as: w is mass of water in vessel, in kg; W is mass of vessel with lid and stirrer, in kg; X is mass of consumed fuel, in kg; c_1 is calorific value of wood, in kcal/kg; x is volume of consumed kerosene, in ml; c_2 is calorific value of kerosene, kcal/kg; d is density of kerosene, g/cc; T_1 is initial temperature of water in °C; T_2 is final temperature of water in °C; T_3 is final temperature of water in last vessel at the end of test in °C and n is total number of vessels used. 0.896 kJ/kg °C is taken as the specific heat of aluminium. The parameters used in the above equation of power output rating are defined as: F is the quantity of fuel wood burnt, kg/h; CV is calorific value of fuel wood, kcal/kg.

Method used for calculating emission reduction [12]

$$ER_y = B_{y,\,savings} \times f_{NRB,\,y} \times NCV_{biomass} \times EF_{Projected_fossilfuel} \quad (7)$$

Where ER_y is emission reduction during the year y in tCO_2; $B_{y,\ savings}$ is quantity of woody biomass that is saved in tonnes; $f_{NRB,\ y}$ is fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass; $NCV_{biomass}$ is net calorific value of the non-renewable woody biomass that is substituted (IPCC default for wood fuel, 0.015 TJ/tonne); $EF_{Projected_\ fossilfuel}$ is emission factor for the substitution of non-renewable woody biomass (Use value 81.6 tCO_2/TJ); $B_{y,\ savings} = B_{old}\ [1-(\eta_{old}/\eta_{new})]$ where B_{old} is quantity of woody biomass used in the absence of project activity in tonnes; η_{old}= 0.10 may be taken if the replaced system is three stone fire or a system with no improved combustion; η_{new} is efficiency of the system being used in the project activity, determined using the WBT.

III. RESULTS AND DISCUSSION

Four cook stoves namely traditional stove (chulha) and improved cook stoves (ICS 1, ICS 2 and ICS 3) were used to perform thermal efficiency, power output rating and emission reduction at SSS-NIRE laboratory. The large use of traditional cook stove (chulha) in developing countries is the reason behind the selection of this cook stove. It would also give a good basis of comparison with other cook stoves. The different models of improved cook stoves used in this work are highly recommendable ICS nowadays because of their high performance. These all four cook stoves were tested twice and their results were registered on the WBT tables. The photographic view of both traditional cook stove and ICS is shown in Fig.1.

Thermal Efficiency and Power output of cook stoves using WBT

The thermal efficiency of traditional cook stove was tested with 3 kg wood, 24 kg of water whereas for ICS 1 it was tested with 3 kg wood and 8 kg water as per BIS standards. Both ICS 2 and ICS 3 was tested with 3 kg wood and 10 kg water as per BIS protocol. At an interval of 5 minutes, the temperature of water, pot, plate and cook stove was measured. Thermal efficiency of traditional cook stoves and ICSs were evaluated using WBT and are shown in Table 1.

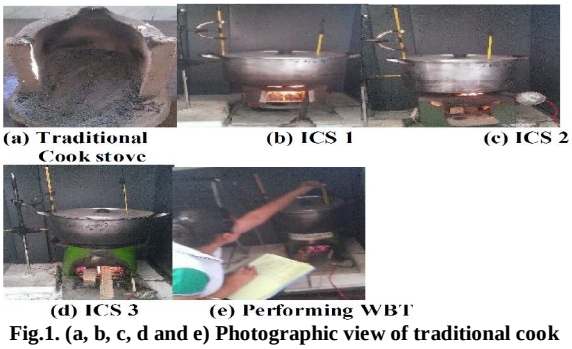


Fig.1. (a, b, c, d and e) Photographic view of traditional cook stove and ICSs models during WBT experiment.

Table 1.Thermal Efficiency of traditional and ICS models

Cook stoves Models	Thermal Efficiency (WBT1)	Thermal Efficiency (WBT2)	Average Thermal Efficiency
Traditional cook stove (chulha)	20.9%	23.6%	22.25%
ICS 1	26.9%	30.6%	28.75%
ICS 2	25.7%	28.5%	27.1%
ICS 3	41.5%	39.6%	40.55%

Putting the above values of thermal efficiency in Eq. 6, the power output of different cook stoves was calculated. The power output of traditional cook stove is 3.21kW. The power output of ICS 1, ICS2 and ICS 3 is 4.15kW, 3.91kW and 5.86kW respectively. Fig.2. shows the variation of thermal efficiency of traditional and various improved cook stoves used in this study.

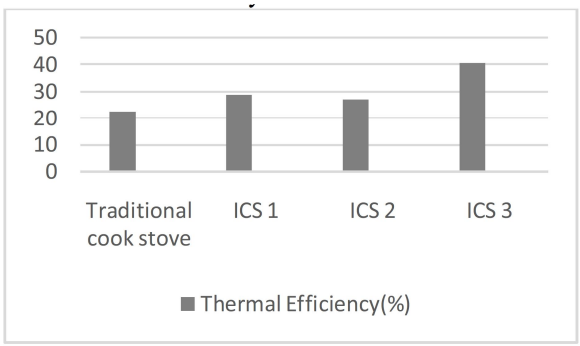


Fig.2. Variation of thermal efficiency and power output of traditional and ICS models.

Emission Reduction values of ICS models

The emission reduction values of different ICS models is calculated using Eq. 7. Fig.3. shows the variation of CO_2 emission reduction values of different ICS models. ICS 3 shows best results and gives a large amount of emission reduction value of 2.57 tCO_2/household/year. This value of emission reduction means that if approximately 10,000 ICS 3 cook stoves are given to the consumers, it would save approximately 25,700 tonnes of CO_2 in one year. Fig.3. shows the variation of various ICS emission reduction values.

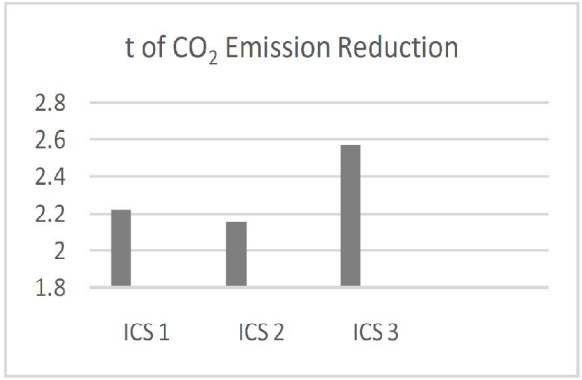


Fig.3. CO_2 Emission Reduction values of ICS models

CONCLUSIONS

Experimental study was done to compare the thermal efficiency and power output of Traditional and improved cook stoves using biomass. The study was also done to show the CO_2 reduction potential of improved cook stoves. Based on the observations of study, major conclusions are drawn:

1. The improved cook stoves gave good results with thermal efficiency and power output as compared to traditional cook stoves.
2. It was observed from Water Boiling Test that improved cook stove i.e. ICS 3 has the highest thermal efficiency followed by ICS 1 and ICS 2 as compared to traditional cook stove (chulha). The thermal efficiency of improved cook stove was 40.55% whereas for traditional cook stove it was only 22.25%. It was also observed that ICS 3 showed the highest amount of CO_2 reduction i.e. 2.57 tCO_2/household/year.

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