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Effects of Retrofit on Thermal Performance and Emission Level of Wood-Fired Cook Stove

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Abstract:- In the present research an attempt has been made to improve the efficiency and emission level of a traditional wood fired cook stove. Quantity of wood required to boil 1 kg of water in a standard pot of 2l capacity was taken as input process parameter. A number of experiments were conducted on three different cook-stove with and without twisted tapes as retrofits. The thermal efficiency and emission levels in terms of gram of emission per kg of wood burned were measured. Thermal efficiency of the three cook-stoves i.e., 3-Brick stove, Mud Stove and Improved cook stove without and with twisted tapes were found to be 15±2%, 17±2%, 18±3%, 21±4%, 23±2%, 26±2% respectively. It was also observed that the emission factor (g/kg) for carbon monoxide was considerably reduced with the use of twisted tapes in all the three stoves as 65±8%, 51±9%, 87±6%, 72±5%, 49±8%, 37±7% respectively.

***Keywords**:- Wood-Fired; Stove; Thermal Efficiency; Emission; Retrofit.*

I. INTRODUCTION

In the rural areas of the developing countries, people mostly use traditional cook stoves which consume more fuel and emit high emission level. Because of such a high emission level in the indoor air, a large number of household women and children suffer from respiratory disease and proved fatal to many of them. To reduce emission level, traditional cook-stove can be replaced by improved stoves. Almost two third of the world population[1] is still dependent on biomass fuels such as wood, cow dung, charcoal, crop residue, dry leaves etc. for their cooking energy requirement and uses traditional inefficient cook stove for cooking their meal because the acceptability of improved cook-stove is very less in the rural areas[2] because of higher cost as compared to traditional stove. Cooking is mostly done on traditional cook-stove within a confined area which is subjected to the exposure of emissions from inefficient combustion of biomass fuels. These emissions cause about more than 1.6 million deaths every year[3] and are responsible for the respiratory diseases to the household women and young children and also for the pollution of our environment. In India alone, almost a million people die of diseases caused by indoor air pollution[2]. Also, inefficient combustion and inefficient heat transfer lead to increased pollution and excessive consumption of biomass fuels causing the faster depletion of forest[4]. Earlier on rapid deforestation in the developing countries was the main motivatiing factor for the development of improved cook stoves[5]. Later on, studies revealed that pollutants emitted by the combustion of solid fuel from traditional cook stoves have an adverse impact on the environment and human health[1]. Thus, a well-designed cook stove that emits fewer pollutants and consumes less fuel can well serve the purpose of end-users.

Only introduction of improved cook stove will not serve the purpose. Utilizing the improved cook stove to reduce the negative impacts of burning solid fuel involves firstly cost-effective design of stoves so that they are available at affordable price in the market and secondly introduction of the improved stoves into the kitchen. Cost of improved cook stove can be drastically reduced if instead of designing a new stove some kind of cheaper retrofits such as twisted tapes is introduced into the existing traditional stoves after identifying the causes of pollutant emission and lower efficiency. Higher emission and lower efficiency are the direct consequence of poor combustion of solid fuel in the combustion chamber and insufficient heat transfer to the cooking pot[6]. Poor combustion of a solid fuel occurs due to the insufficient air intake and lesser residence time of air inside the combustion chamber[7]. Twisted tapes can be used as a retrofit in the traditional cook stoves[8] to increase the turbulence and hence air residence time in the combustion chamber. Twisted tapes also direct the flame of fire to the cooking pot and consequently, heat transfer loss decreases. McCracken et al investigated the effect of long term exposure of smoke to the household women's health in Guatemala and found that less exposure of smoke reduces blood pressure [3].

In the present work water boiling tests have been conducted on three different stoves with twisted tapes (wtt) and without twisted tapes (wott) in the laboratory and their performance in terms of thermal efficiency and emission level is computed to determine the effectiveness of the retrofit.

II. METHODOLOGY

A. Thermal Performance Testing

There are several protocols for performance testing of stoves all around the world. Testing is basically done to make a relative assessment among stoves. Performance testing of stove includes both thermal performance and emission level. Thermal performance accounts for the amount of fuel and time used to cook food on stove in one cycle. Measurement of emission level from stove is done in view of indoor air quality and climate changes caused by emissions.

Water boiling test (WBT) is a simplified simulation of the cooking process[9] and it is intended to estimate how efficiently a cook stove uses fuel to boil water in a cooking pot and the quantity of emissions produced during cooking. The WBT is conducted in highly controlled conditions where variability is less and hence even small changes can be detected in this test. But actual cooking is done in an uncontrolled condition. So, this test does not represent the actual cooking activity. Therefore, lab based test helps us to differentiate between stoves whereas field based tests allow us to better assess the performance of cook stoves.

The WBT consists of three phases[9] that are conducted immediately one after another. A detail discussion about these phases has been done below. The entire WBT test should be conducted at least three times for each type of stove.

➢ *Cold Start High Power Phase*

This phase starts with the stove at room temperature and a known weight of bundle of wood is used to boil a known quantity of water in a standard pot and at the end of this phase the boiled water is replaced with a fresh pot containing fresh water at ambient temperature to conduct the next phase.

➢ *Hot Start High Power Phase*

This phase is performed immediately after the first phase when the stove is still hot. Again, this phase begins with a pre-weighed bundle of wood fuel to boil a measured quantity of water in a standard pot. This phase helps us to identify the differences in performance between a cold stove and a hot stove.

➢ *Simmer Phase*

This phase helps us to determine the amount of wood fuel required to simmer a measured quantity of water at a temperature just below the boiling point for 45 minutes.

The Fig. 1 below shows the variation of water temperature with time for three phases of water boiling test.

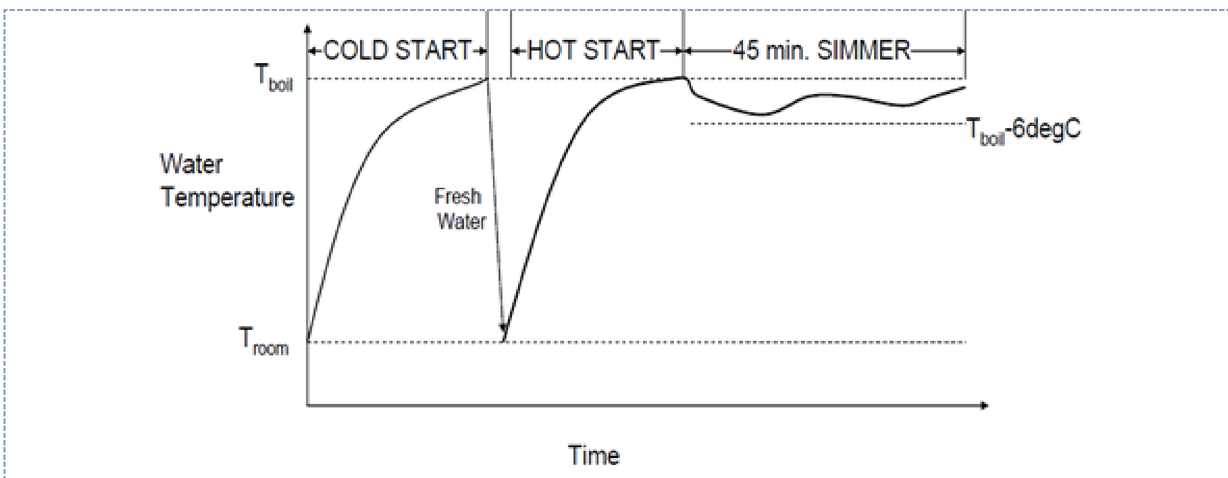

Fig 1:- Variation in water temperature with time during three phases of WBT [9]

B. Emission Testing

Earlier on fuel saving was the primary deriving force for the performance testing of a cook stove. But with the increasing effects of emissions emanating by the combustion of solid fuels in the stove on health and global environment, emission testing has become an equally important task. Measurement of thermal performance of a stove is easier but emission measurement is relatively complicated because of the involvement of a lot of challenges[10]. Emission is measured by putting a hood directly over the stove to collect the exhaust gases emanating from it as shown in the Fig. 2 as shown below[9]. The hood is connected with a GI duct at one end and the other end of the duct is connected with a blower to blow the exhaust gases through the hood and duct system and finally the exhaust gas exits to the atmosphere. Pollutants like carbon monoxide, carbon dioxide, and particulate matter are measured by emission measuring sensors fitted with the duct by means of a sample line pipe. The sensors give real-time measurement of emission components and the data is stored in the computer for further analysis.

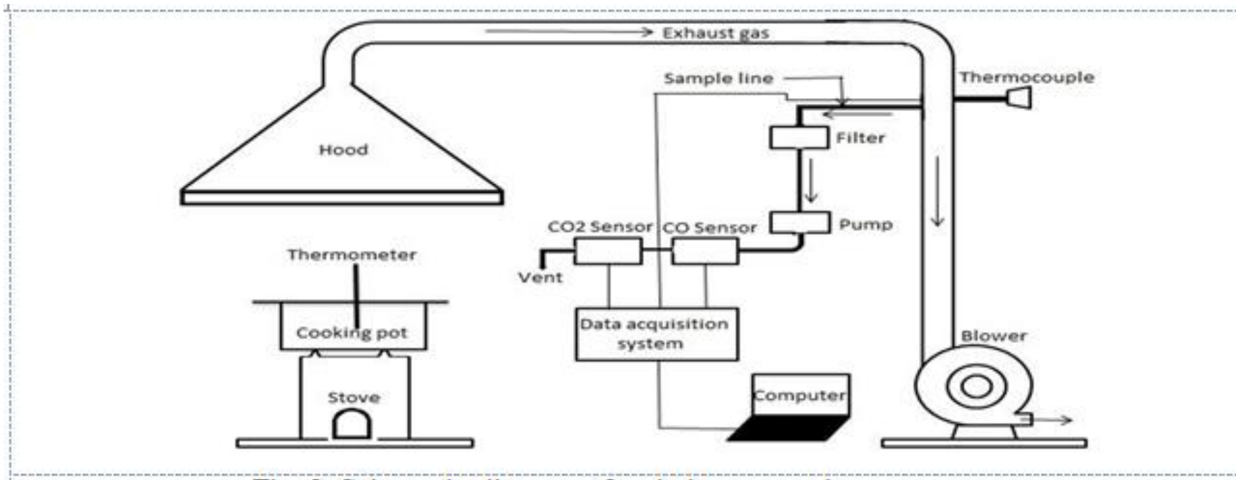

Fig 2:- Schematic diagram of emission measuring test set-up

C. Indian Standard For Cook Stoves

Considering the international practice for the measurement of the emissions and particulates emitting from the combustion of biomass fuel and responsible for health hazards, the revised standard has replaced the performance parameters CO/CO_2 ratio and total suspended particles (TSP) by CO (g/MJd) and TPM (mg/MJd) respectively[2]. The emissions are measured in terms of Mega Joule energy delivered to the pot. The cook stoves satisfying the standard performance parameters are considered for the approval by MNRE. The standard performance parameters developed by BIS in August, 2013 are as given in Table1 below.

Type of biomass cook stove	**Standard performance parameters**		
	Thermal efficiency (%)	CO (g/MJd)	PM (mg/MJd)
Natural draft	Not less than 25	≤5	≤350
Forced draft	Not less than 35	≤5	≤150

Table 1:- Indian standards for cook stove [2]

III. EXPERIMENTAL SEQUENCE

Water boiling test is conducted in the laboratory for three different stoves without and with retrofits (a set of twisted tapes) to measure simultaneously thermal efficiency and emission levels.

Two and half kilograms of water was boiled in a flat-bottomed aluminum pot of 5 liters capacity with a thermometer inserted into a wooden probe holder to measure the water temperature continuously. A certain amount of wood was used as fuel to boil water and keep it boiling for 5 minutes. The wood and water were weighed on a digital weighing machine. The stove with pot of water was kept under the hood. A known amount of kerosene was sprayed over the wood to initiate the firing. The emission measuring system was turned on as the wood was set on fire. With the help of emission measuring sensors and data logger, the concentration levels of CO and CO_2 were recorded every minute. The exhaust temperature was measured by means of a thermocouple with probe inserted into the exhaust duct. The thermocouple was connected to the data logger to get the temperature reading in every minute. A U-tube manometer was used to measure the exhaust pressure in the duct. The starting time and the time when water came to boil were noted down. The ambient temperature and pressure were recorded. When the water boiling test came to an end, the emission measuring system was switched off. The boiled water and the unburned wood were reweighed to get how much water was evaporated and how much wood was burned. The charcoal was collected carefully on a tray and weighed. The experiment was repeated 3 times for each type of stove. After the test was over, all the test data were analyzed further to evaluate the thermal efficiency and the emission levels.

IV. RESULTS AND ANALYSIS

Laboratory-based water boiling test was conducted three times for each type of stove without twisted tapes (wott) and with twisted tapes (wtt) (a set of twisted tapes, shown in Fig.3). Figure 4 shows the variation in thermal efficiency. Emission level for carbon dioxide and carbon monoxide was determined in terms of gram per kg of wood burned and gram per MJ of energy delivered to the cooking pot. The results thus obtained were plotted and shown in the figures 5, 6, 7 and 8.

Fig 3:- Three types of stove

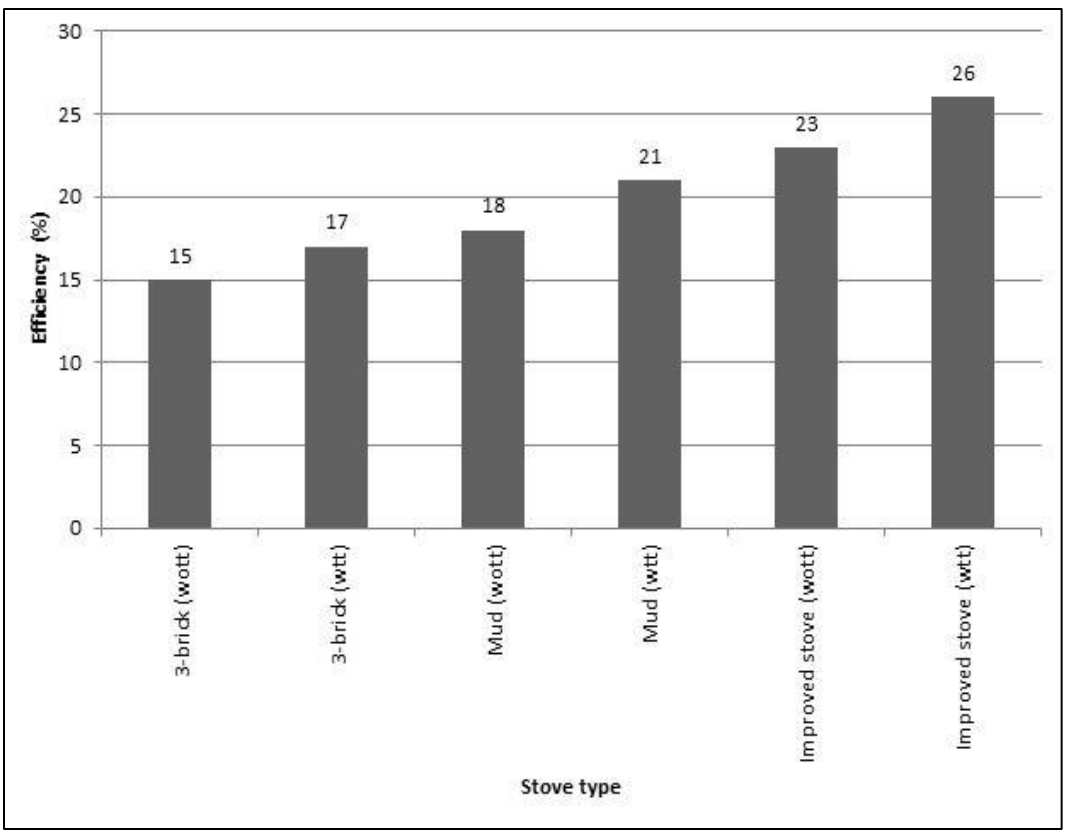

Fig 4:- **Error! No text of specified style in document.**. Variation of thermal efficiency with stove type

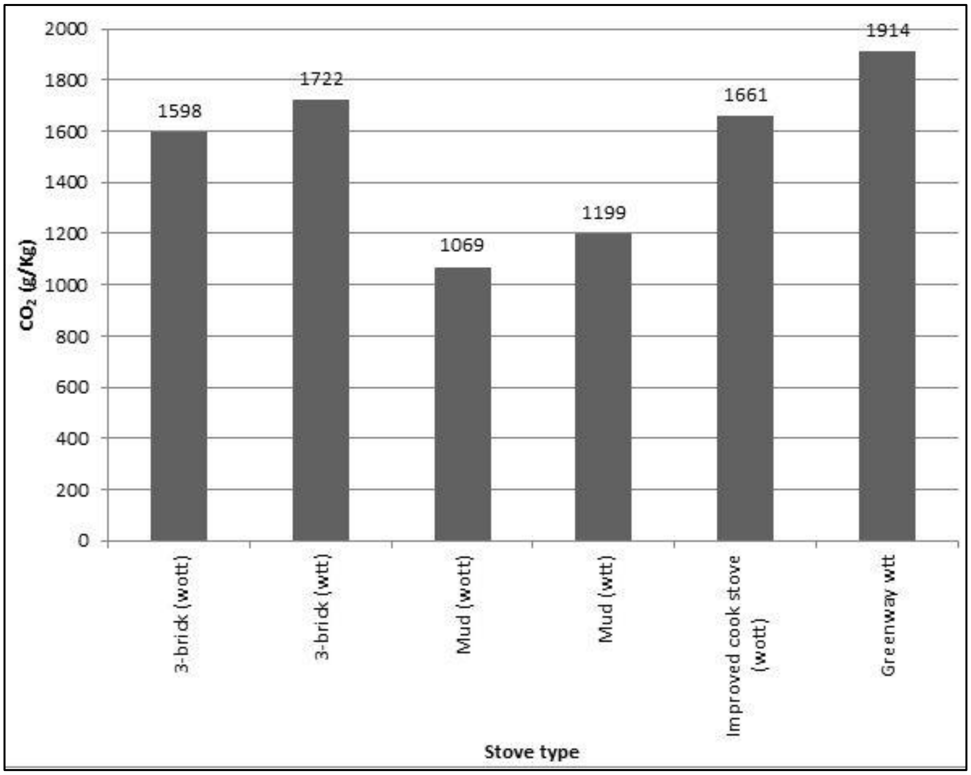

Fig 5:- Variation in CO_2 emission factor with stove type

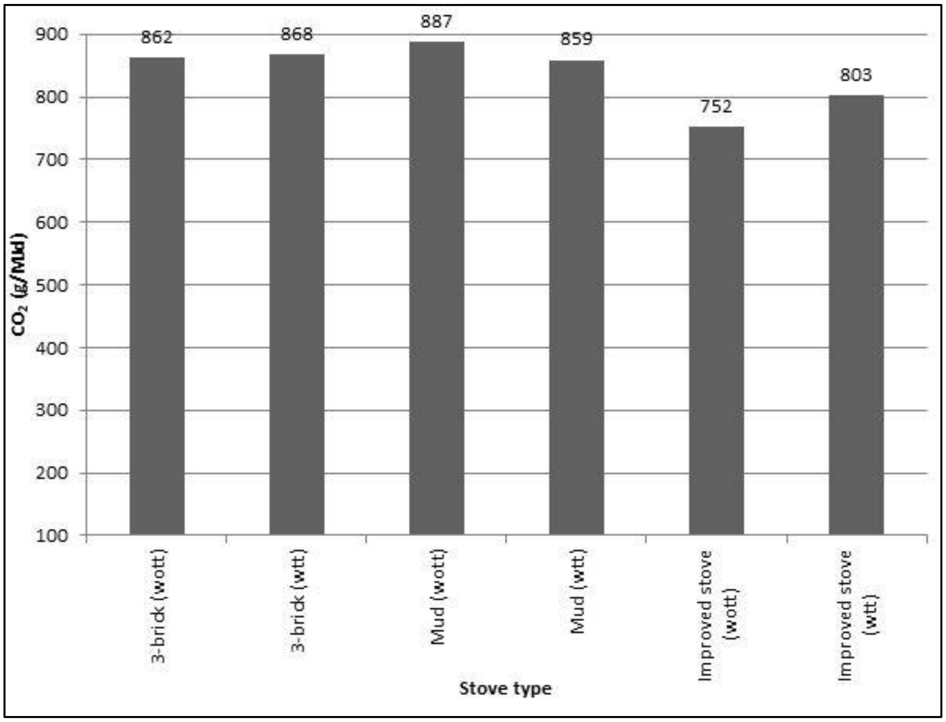

Fig 6:- Variation in grams of CO_2 per MJ delivered to the pot with stove type

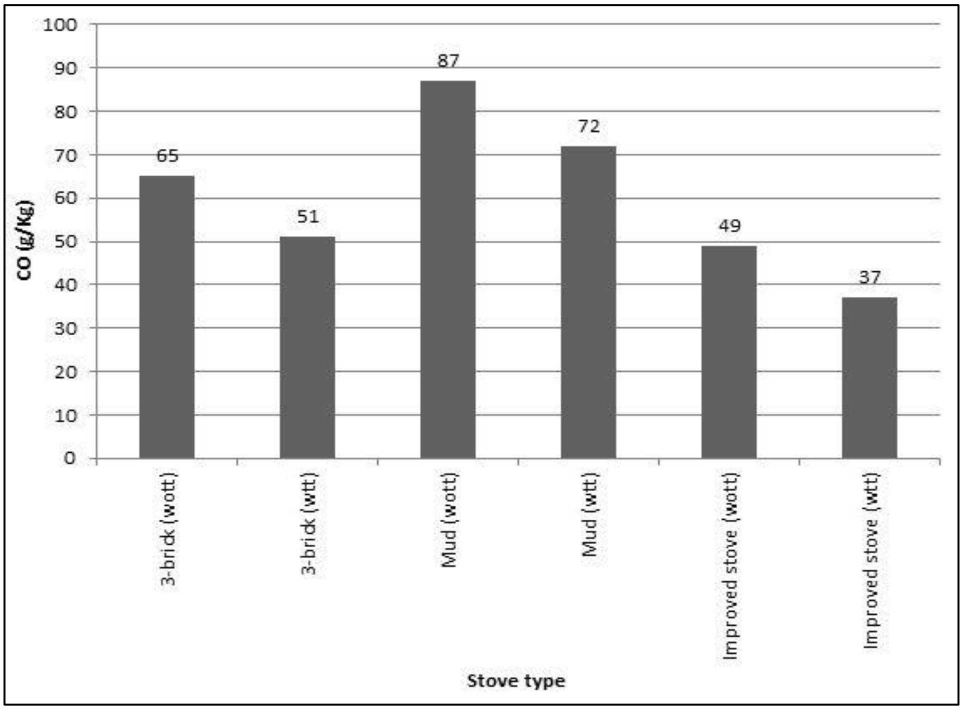

Fig 7:- Variation in CO emission factor with stove type

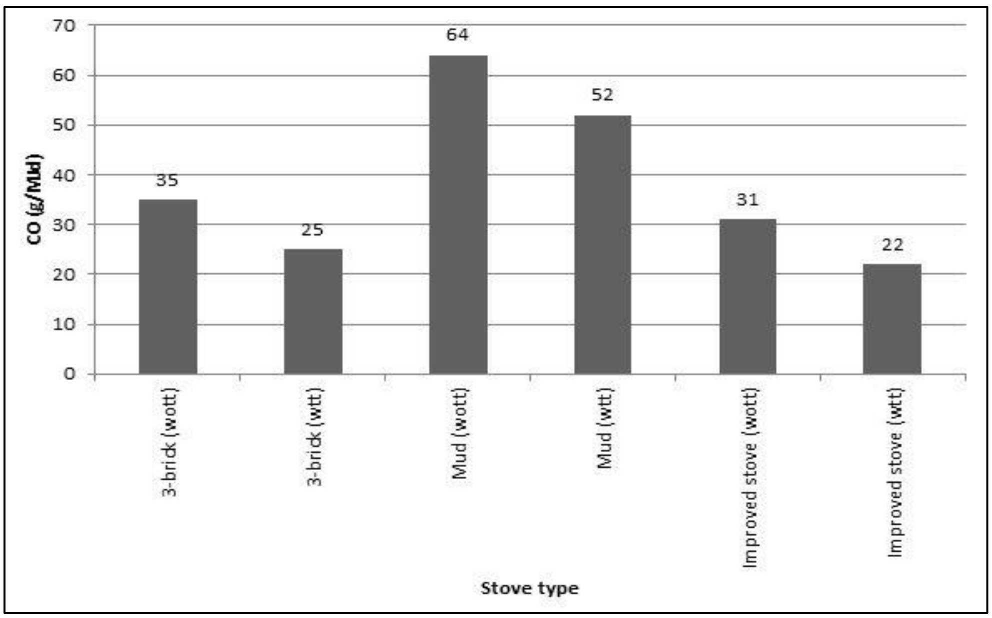

Fig 8:- Variation in grams of CO per MJ delivered to the pot with stove type

Note:-

1. *wott* – without retrofit
2. *wtt* – with retrofit
3. *MJd* – Mega joule of energy delivered to the pot
4. Emission factor – mass of emission emitted per Kg of wood burned

1. CO_2 emission factor (g/kg of fuel burned) in case of 3-brick stove and Improved cook stove is higher as compared to mud stove as shown in Fig.4 because in 3-brick and Improved cook stove stove combustion of fuel takes place properly due to the availability of sufficient air in the combustion chamber but in case of mud stove air is not inducted sufficiently in the combustion chamber due to the small opening of the fuel feeding gate. Similar is the case with grams of CO_2 emitted per mega joule of energy delivered to the pot (as shown in Fig.5). But by using a set of twisted tapes with the stoves CO_2 emission factor and grams of CO_2 per mega joule of energy delivered to the pot is

increased due to increase in residence time of air in the combustion chamber.

2. CO emission factor (g/kg of fuel burned) and grams of CO per mega joule of energy delivered in case of 3-brick and Improved cook stove stoves are less as compared to mud stove as shown in Fig.6 and Fig.7. This is because in 3-brick and Improved cook stove stoves combustion of fuel takes place relatively in a proper way due to the induction of sufficient amount of air in the combustion chamber. But with the addition of twisted tapes slight reduction of CO emission factor (g/kg) and grams of CO delivered to the pot is observed.

3. The efficiency of 3-brick stove is the lowest as compared to the other two stoves (as shown in Fig.8) because in case of 3-brick stove a large part of input heat energy is lost to the surrounding air and to the ground. Similarly the efficiency of the mud stove is less than the improved cook stove stove because larger part of the energy is lost to the stove wall due to its bulky size. But with the addition of twisted tapes the efficiency of all the three stoves is increased due to increase in residence time of air and also twisted tapes help to direct the fire flame to the pot hence reduction in the heat energy lost to the surrounding air. The overall performance results have been summarized below in the table 2.

stove type	CO_2 (g/Kg)	CO_2 (g/MJd)	CO (g/Kg)	CO (g/MJd)	Efficiency (%)
3-brick wott	1598±9%	862±9%	65±8%	35± 6%	15±2%
3-brick wtt	1722±8%	868±6%	51±9%	25±8%	17±2%
Mud wott	1069±5%	887±6%	87±6%	64±7%	18±3%
Mud wtt	1199±9%	859±5%	72±5%	52±5%	21±4%
Improved cook stove wott	1661±5%	752±8%	49±8%	31±9%	23±2%
Improved cook stove wtt	1914±8%	803±5%	37±7%	22±6%	26±2%

Table 2:- Overall performance of cook stoves

V. CONCLUSIONS

The above discussion offers a step-by-step approach for the performance analysis of three different wood fired stoves in terms of emission level and thermal efficiency. Water boiling tests were conducted under controlled environment on the three different stoves with and without twisted tapes and thermal efficiency and emission level was determined. It was observed that by the use of twisted tapes the thermal efficiency of three brick stove, mud stove and improved stove increased from 15±2% to 17±2%, 18±3% to 21±4%, and 23±2% to 26±2% respectively and the emission level for CO (in gram of CO emitted per kg of wood burned) decreased from 65±8% to 51±9%, 87±6% to 72±5%, and 49±8% to 37±7% respectively. Hence it is concluded that twisted tapes have favorable impact on the thermal performance and the emission level of the stoves.

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