Performance Test of Modified Mud Improved Cook Stove

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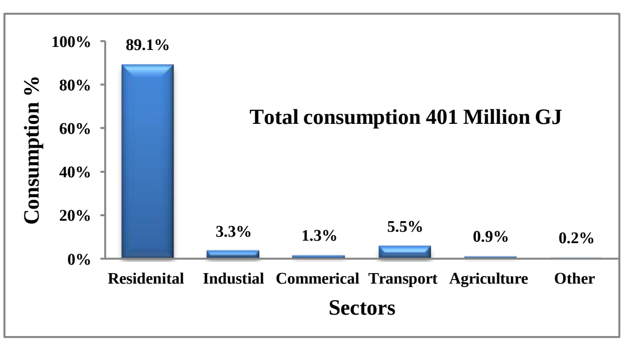
Abstract: Rural people of Nepal are highly dependent on fuelwood for cooking purpose. Government of Nepal (GoN) recently announced "Clean Cooking Solutions for All" by 2017 and is promoting chimney operated Mud and Metallic Improved Cook Stove (ICS) throughout the country. GoN has already been promoted 897,745 Mud ICS and 16,314 Metallic ICS till July 2014 and target to install 2,700,000 Mud ICS in the coming year. Mud ICS are widely promoting in the rural Terai and Mid Hill areas of Nepal. With the promotion of efficient and hygienic cook stove contributes positively in economy, health and environment. Increase of efficiency of the heavily promoted Mud ICS has great important in the context of Nepal. Use of air gap and proper chimney height are the few ways to increase the thermal efficiency of ICS. Thermal efficiency of Mud ICS using bricks with two cylindrical holes has been found 19.3% in cold start, 21.3% in hot start and 19.5% in simmering which is 2.67% higher in average than the existing stove without air gap. Thermal efficiency of Mud ICS with decreases by 3.78% during increase of chimney height from 39" to 48".

Keywords: Mud ICS; fuelwood; chimney; air gap; hot start; cold start; simmering

1. Introduction

Biomass accounts for a large fraction of the domestic energy needs in the developing countries. Fuelwood is the main source of energy in the residential sector of Nepal. It has also little contribution in the commercial and industrial sectors also. Main source of fuelwood are direct forest, agro process, industrial process and other recovered process. Fuelwood consist of woody biomass whose primary source is both forest land (natural forest, shrub, wood and timber, grass, non cultivation etc.) and non forest land (agricultural, roadside, garden etc.) (WECS, 2010).

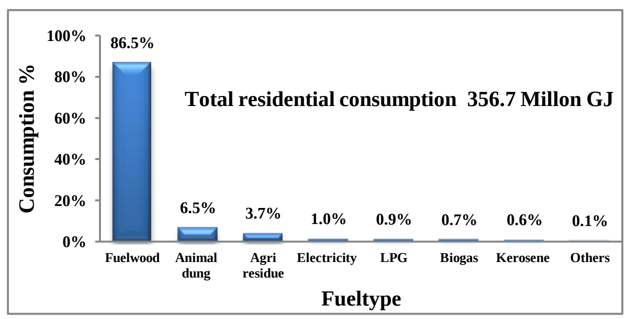
Energy consumption status of Nepal as shown in figure 1 shows that 89.1% energy consumed in residential sector. Main purpose of energy use in residential sector is for cooking and space heating.



(WECS, 2010)

Figure 1: Sector wise energy consumption of Nepal in 2008/09

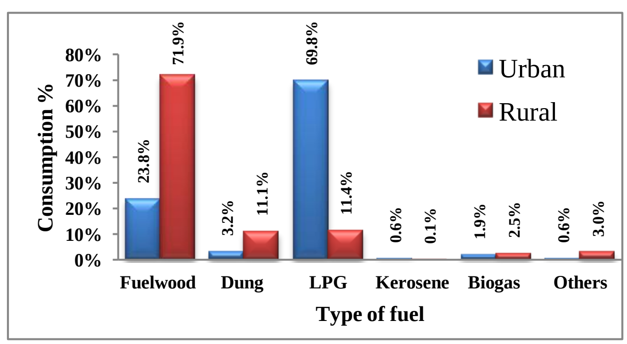
Fuelwood is the main source of fuel in the residential sector. Figure 2 shows that 86.5% residential sector energy requirement is fulfilled by fuelwood.



(WECS,2010)

Figure 2: Residential sector energy consumption of Nepal by fueltype in 2008/09

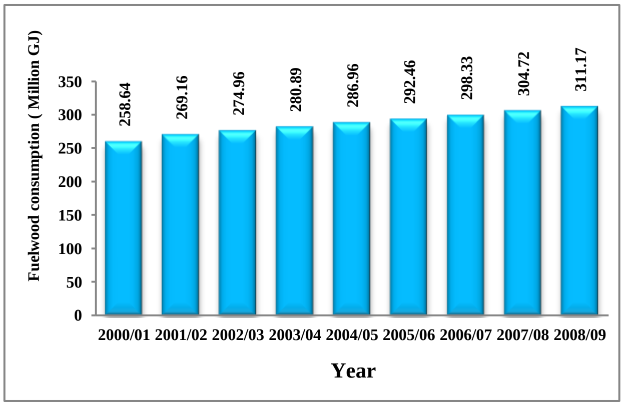
Figure 3 shows that 71.9% rural household and 23.8% urban household use fuelwood for cooking purpose.



(CBS, 2013)

Figure 3: Source of cooking fuel in residential sector

Fuelwood consumption trend shown in figure 4 is increasing about 2% per year which is exerting immense pressure on the forest resources of the country with negative impacts on environment.



(WECS,2010)

Figure 4: Fuelwood consumption trend

Increasing trend of fuelwood consumption is also affecting adversely for the sustainability of fuelwood resources. Table 1 shows that the sustainable fuelwood supply is only 60.28% of the total consumption in the year 2008/09.

Table 1: Sustainable biomass potential and consumption trend in 2008/09

(Unit in 000 GJ)

S.N.	Description	Sustainable supply	Consumption
1.	Fuelwood	187,599.0	311,167.3
2.	Agriculture residue	243,812.5	14,684.7

(WECS, 2010)

Table 1 shows that fuelwood consumption rate is higher than sustainable supply resulting deforestation rate is increasing. On the other hand, there is huge scope for the use of agriculture residue as fuel.

More than 2.5 billion people all over the world cook with biomass based solid fuel in open fires. Besides consuming high amounts of fuel, these fires are main source of indoor air pollution, responsible for an estimated 4 million annual premature deaths (Lim et al, 2010).

However, very often biomass is burnt inefficiently in open three-stone fire and traditional cook stoves for cooking and heating applications which causes severe health problems in women and children and also affects the environment. Many efforts have been made worldwide to increase the dissemination of improved cook stove but have not succeeded in their targets. The successful cook stove dissemination programs can lead to the sustainable development of the rural areas besides helping in the commercialization of cook stove.

Promoters of ICS argue they provide the "triple benefits" of improving health outcomes, preserving local ecosystems, and reducing green house gas emissions. (Christopher, 2013).

In Nepal, biomass energy (fuelwood, agro-residue and animal dung) is used for cooking and heating purposes. Use of traditional stoves such as *"agenu" (*open fireplace*)* and *"chulo" (*rudimentary stoves*)* consumes more fuelwood. Use of biomass energy and low-grade biomass fuels lead to excessive levels of indoor smoke/air pollution. This is one of the reasons for higher rates of infant mortality and morbidity and other unhealthy living conditions. Release of incomplete burn carbon gas and other harmful particles in the atmosphere due to poor combustion of biomass fuels in rudimentary stoves results indoor air pollution as well as Green House Gas emission.

Government of Nepal (GoN) through Alternative Energy Promotion Center (AEPC) is promoting both Mud and Metallic ICS throughout the county. In these stove, the combustion gases exit through the chimney and are exhausted outside of the kitchen.

Mud ICS is used for cooking purpose which is widely promoting in the rural area of Terai to Mid Hill of the Nepal. Metallic ICS is used for cooking and space heating purpose which is promoting upper higher hill and mountain regions.

GoN recently announced "Clean Cooking Solutions for All" by 2017 by promoting chimney operated Mud ICS and Metallic ICS throughout the country. AEPC has already promoted 897,745 Mud ICS and 16,314 Metallic ICS till July 2014, it has also targeted to install 350,000 Mud ICS and 7,000 Metallic ICS in the year 2014/15. It has total targeted 2,700,000 Mud ICS installation in the coming years (AEPC, 2014).

Socio economics status of Nepal indicates that Nepal has to depend on biomass resources in the coming few decades too. National energy consumption status, biomass supply and consumption status, government plan and user's requirement indicate that there is necessary for the detail study to develop socially acceptable and efficient cook stove. Among them, efficient Mud ICS promotion will contribute more in the context of Nepal.

The main aim of this paper is to perform the thermal efficiency test of modified Mud ICS which is made by using brick with air gap and also to find the effect of chimney height on thermal efficiency.

2. Materials and methods

2.1 Material selection

For the construction of brick, clay is mixed with adhesive, insulating and supporting materials. The materials used for the fabrication cook stove are made in the following proportion:

- Clay (4 part)
- Dung (1 part)
- Rice husk (2 part)
- Sugar (3 kg)
- Salt (1kg)
- Iron rods

2.2 Mold selection and fabrication of brick

In general practice, rectangular mold is used for the fabrication of brick as shown in figure 5 from which brick fabrication is easy and strength of brick is also high.

Figure 5: Commonly used mold for bricks

For the construction of brick with air gap, rectangular mold has been selected with two solid cylinders fixed on the base each of diameters 1.5’’ and height equal to brick as shown in figure 6. This mold produces rectangular brick with two circular holes. Selection of such mold has been done by viewing fabrication and strength factors.

Figure 6: Mold selection for brick with air gap

Brick has been fabricated by using the mold by technician with using material as per standard proportion as shown the figure 7.

Figure 7: Fabrication of brick with two circular holes

2.3 Cook stove selection and fabrication

"Raised two pot mud cook stove" has been selected for the performance test which is one of model promoted by AEPC.

For the performance test of existing Mud ICS, already constructed Mud ICS in Renewable Energy Test Station (RETS) has been taken which was made by trained manpower by using material as per standard proportion.

Modified Mud ICS, stove has been fabricated by using brick with cylindrical holes as shown is figure 9.

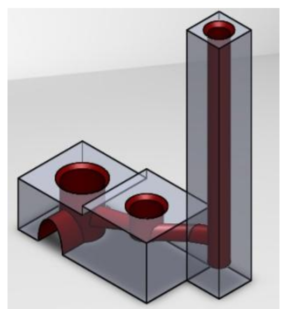


Figure 8: Isometric view of two pot raised cook stove

Figure 9: Fabricated two pot raised cook stove with modified brick

2.4 Estimation of thermal efficiency

To evaluate the performance of stoves, Water Boiling Test (WBT) has been used. The WBT is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking pot. The entire WBT has been conducted at least three times for each stove, which constitutes a WBT test set.

$$\eta = \frac{Amount\ of\ heat\ gain\ by\ water}{Equivalent\ dry\ fuel\ consumed \times \mathrm{LHV}}$$

LHV = Lower Heating Value

Three types of water boiling tests has been formed (a) Cold start (b) hot start and (c) Simmering which are shown in figure 10.

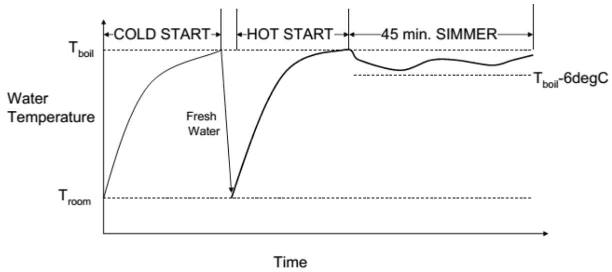


Figure 10: Temperature during the three phases of the water boiling test

a. For cold-start high-power phase, the tester begins with the stove at room temperature and uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot. The tester then replaces the boiled water with a fresh pot of ambient-temperature water to perform the second phase.
b. The hot-start high-power phase is conducted after the first phase while stove is still hot. Again, the tester uses fuel from a pre-weighed bundle of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass, since these stoves may be kept warm in practice.
c. The simmer phase provides the amount of fuel required to simmer a measured amount of water at just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout much of the world.

(Cleancookstove, 2014)

All the stove construction work and performance testing work was done in RETS, Khumaltar Lalitpur Nepal.

3. Findings and Discussion

3.1 Effects of various factors for the promotion of ICS

Although use of ICS has various advantages as compared to traditional cook stove. But still there are number of people who are using traditional cooks stove and government agency and promoter are also lagging for the successful promotion of ICS. The recent development of ICS is focused upon possible social, economic, technical and environmental factors in optimal way.

Table 2: Factor for the promotion of ICS

Factors	Description
Social	Users need and availability of the local resources Comfort Safety and health Needs
Economic	Cost affordability Fuel economy
Environmental	Reduction of smoke Reduction of deforestation
Technical	Heat transfer Fluid flow Material science Power output Thermal and combustion efficiency

3.2 Thermal efficiency test for different stoves

The thermal efficiency of existing and modified Mud ICS with air gap has been found determined. During experiment chimney height 39” by using WBT is presented in Table 3.

Table 3: Thermal efficiency test of existing and modified Mud ICS

Test type	Type of stove	Thermal efficiency (%)	S.D.	COV
Cold Start	Existing	14.70	2	14.2
	Modified	19.30	2	8.4
Hot Start	Existing	20.60	2	9.4
	Modified	21.30	3	15.8
Simmering	Existing	15.47	2	14.3
	Modified	19.50	6	15.0

S.D. = Standard Deviation; COV = Covariance

Test result shows that thermal efficiency of the cook stove has been increased in the modified stove by 4.60 % in cold start, 0.70% in hot start and 4.03% in simmering test respectively.

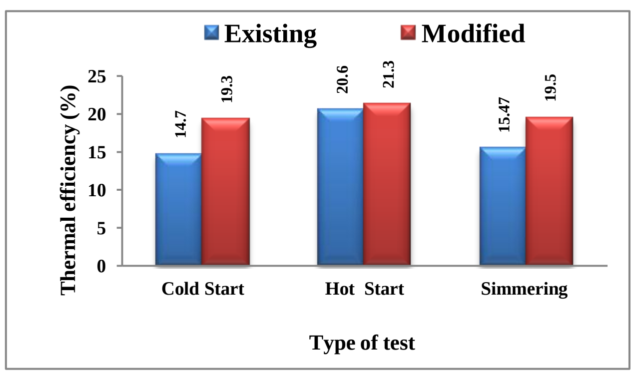


Figure 11: Comparison of thermal efficiency between existing and modified stove

Experiment result show that there is increase of efficiency of modified stove with air gap by an average 2.67%.

Theoretically use of air gap within the wall increase the thermal resistance and reduce the heat flow through the wall. Experiment results show that here is possibility to increase thermal efficiency by using air gap either in brick or within the wall of the stove.

Detail analysis of heat flow by using brick with the optimum size of air gap without affecting strength may give significant result to increase thermal efficiency.

3.3 Thermal efficiency test with variation of chimney height

It is always best practice to add a chimney to any wood burning cook stove. Chimneys that take smoke and other emissions out of the living space protect the family by reducing exposure to pollutants and health risks. Even cleaner burning stoves without a chimney can create unhealthy levels of indoor air pollution. (Aprovecho, 2014)

Chimney creates draft and volumetric flow of flue gas changes as square root of its height and square of diameter with other parameters remaining constant. Generally, change in diameter is used to control the volumetric flux (FAO, 1993).

Proper design of chimney is important. Draft will increased due to large diameter and long distance will result in faster combustion which in turn will result in large flue gas losses. On the other hand, insufficient draft due to small diameter chimney, bend and obstruction in the flow path will result backflow. Average velocity of flue gas in the chimney should be 0.4 to 1 m/s (FAO, 1993).

Table 4: Thermal efficiency test of modified cook stove with different chimney height

Type of stove	Height of chimney	Thermal efficiency	SD	COV %
Cold Start	39"	19.30	2	8.4
	48"	14.41	0	2.8
Hot Start	39"	21.3	3	15.8
	45"	18.85	2	8.3
Simmering	39 "	19.5	6	16.3
	48"	16.10	2	14.4

Experiment results performed on modified Mud ICS has shown that thermal efficiency decreases with the increase of chimney height from 39 " to 48" by 4.89 % in cold start, 2.45% in hot start and 3.4% in simmering test respectively.

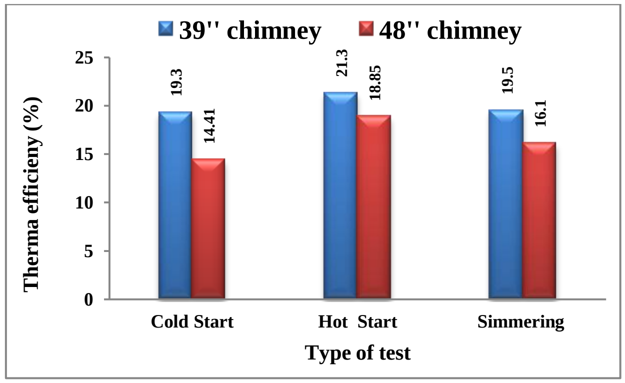


Figure 12: Comparison of thermal efficiency Modified ICS by using 39 '' to 48'' chimney

Here, due to increase in height of chimney, draft has been increased which increases losses of heat through the flue gases and ultimately efficiency decreased. For the given size, 39 " chimney is more appropriate but still there is need to find optimum height for given diameter. For the practical case also, training should be given to the cook stove installer, to install the chimney per site condition.

3.4 Wall temperature of stove

Wall temperature of the cook stove helps to find out heat loss by convection and radiation from wall and heat loss in thermal mass. On the other side, it also increase the temperature of combustion chamber which leads to better combustion and thermal efficiency.

Here initial wall temperature of existing and modified Mud ICS are 26 ºC and 28.33 ºC respectively.

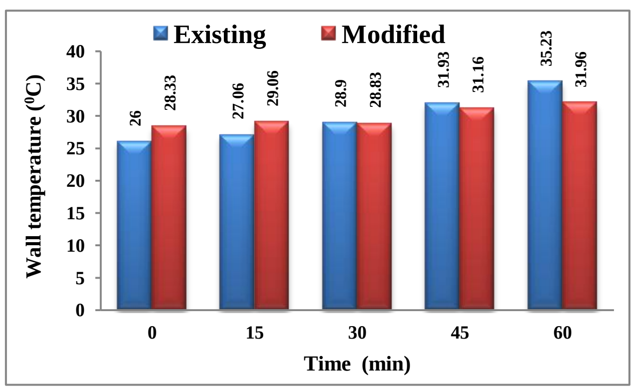


Figure 13 : Comparison of average rear side wall temperature of two ICS at different times

Experimental results shows that average rear wall temperature of existing and modified Mud ICS (as shown in figure 13) changes from 26 ºC to 35.23 ºC and 28.33 ºC to 31.96 ºC during 60 minutes cooking time respectively. Here, net change in temperature of existing and modified cook stove are 9.23 ºC and 3.63 ºC.

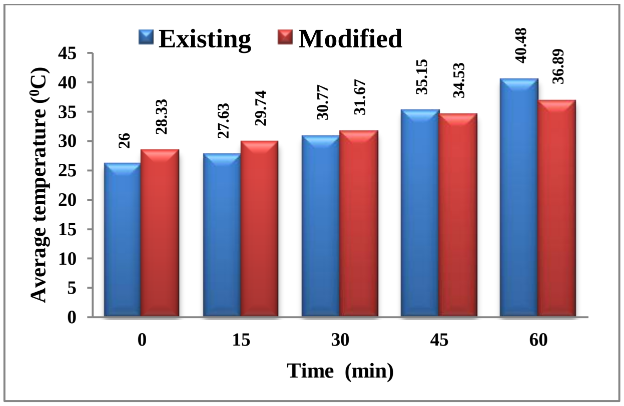


Figure 14: Comparison of average front side wall temperature of two ICS at different times

Similarly, average front wall temperature of existing and modified Mud ICS changes from 26 ºC to 40.48 ºC and 28.33 ºC to 36.89 ºC during 60 minutes cooking time respectively as shown in figure 14.

Here, net change in temperature of existing and modified cook stove are 14.48 ºC and 8.53 ºC.

For both front and rear side, net increase in temperature of modified Mud ICS is more during one hour time which indicates there is less heat loss in modified ICS in comparison to existing one.

3.5 Limitations of the experiment

These two stoves are made by two different technicians at different time.

Environment temperatures are different during experiment in two cook stoves.

Wall temperature reading has been taken for only 60 minutes. Steady state condition result has not achieved.

4. Conclusion and recommendation

4.1 Conclusions

- The thermal efficiency of Modified Mud ICS is found to be 19.3% in cold start, 21.3% in hot start and 19.5% in simmering respectively which is 2.67% higher in average.
- Efficiency of the Mud ICS has been decreased by 3.78% on changing chimney height from 39 " to 48".
- The surface temperature of outer walls of Modified Mud ICS has been reduced significantly.

4.2 Recommendations

Followings studies are recommended

- Emission test should be carried out to determine the overall performance
- Heat loss from wall surface, loss in thermal mass, change of temperature of combustion chamber, change in thermal efficiency with changing air gap should be done
- Effects of air gap on thermal stress and strength should be carried out
- Determination of optimum chimney size on the exiting Mud ICS and develop different chimney diameter as per changing the height and layout

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