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# Assessment and Optimization of Thermal Efficiency of Two Pot Raised Mud Improved Cookstove with Variation of Different Parameters

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**Abstract:** Millions of people around the world are using biomass fuels to satisfy their energy requirement for cooking. Two pot raised mud Improved Cookstove (ICS) is one of the most promoted cookstoves in Nepal. There is a need to study the effects of different parameters on two pot raised mud ICS for its optimum performance. The goal of this work is to study the effect of variation of different parameters for two pot raised mud ICS and identify parameters for optimum performance. Power test for cookstove, specially focusing thermal efficiency has been performed by changing different parameters. Effect of varying fuel feeding rate, chimney height, opening area of air fuel inlet, inlet area of interconnecting tunnel, combustion chamber height, grate height and insulating material on thermal efficiency has been studied and cookstove has been modified for its optimum performance. The thermal efficiency of optimized cookstove, using 2 cm grate and insulation has shown an increase of 6.70 from 18%.

**Key words:** Firepower, grate, combustion chamber height, interconnecting tunnel, air fuel opening area, chimney, insulation

## INTRODUCTION

Globally, more than 2.5 billion people are dependent on biomass based fuel for cooking and heating purposes (Lim *et al*., 2013). About 16 million hector of forests is being consumed as cooking fuel yearly. Fuelwood consumption and subsequent environmental pollution can be reduced by improving the thermal efficiency of cookstove and through optimum use of biomass fuel (Sedighi and Salarian, 2017). Currently, about one-third of the world population lacks clean cooking facilities and trends indicate that this problem will continue till 2030 (Kshirsagar and Kalamkar, 2014). Use of improved cookstove by improving thermal efficiency and combustion performance can reduce adverse human health effects, reduce energy consumption and contribute for environmental aspects (Smith, 1994). In the context of Nepal, almost 80% of people rely on biomass (WECS, 2010). Traditional stoves are used by most of them but adoption of improved cookstove, disseminated by Government of Nepal has been increased over last decade. The mud ICS disseminated still requires further technical assessment for the optimum performance (Agrawal *et al*., 2016).

Around the world, numerous variety of cookstoves are available with different design and performance (Kshirsagar and Kalamkar, 2014; Sutar *et al*., 2015). Parameters affecting cookstove performance has been studied by researchers Agenbroad *et al*. (2011a, b), Kshirsagar and Kalamkar (2014) and different design aspects by MacCarty and Bryden (2015). Among the research done, most of them are focused on single pot cookstove. Limited research is available on multi-pot cookstove (MacCarty and Bryden, 2015). This paper aims to study the effect of variation of different parameters for two pot raised mud ICS and identify parameters value for optimum performance.

For this, from the literature review, the following parameters have been identified as vital for cookstove performance.

**Optimum firepower:** Many researchers have found thermal efficiency vs. firepower characteristics in the shape of shallow inverted bowl (Kandpal *et al*., 1994; Sutar *et al*., 2015). Thermal efficiency is highly influenced by fuel feeding rate and has maximum value at a certain range.

**Chimney height:** Chimney not only serves as ventilation of combustion products but also, controls the mass flow rate of incoming air (Prapas *et al*., 2014). Theoretically, stoichiometric air is sufficient for complete combustion but practically, excess air is required for complete combustion and better performance of the cookstove.

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Suction created by chimney largely affects the cookstove performance. Chimney with high suction (excess chimney height) leads to quenching of flame. On the other hand, chimney with low suction (not sufficient chimney height) leads to less excess air and incomplete combustion.

**Combustion chamber height:** Considering the design of cookstove, height of the combustion chamber should be equal or slightly greater than flame height. If the height of the combustion chamber is less than the flame height, the flame will touch the cold pot which will result in quenching of flame, incomplete combustion of fuel, deposition of soot at the bottom of the pot and increase in the emission of pollutants (Bussmann and Prasad, 1986). On the other hand, if combustion chamber's height is too high, there is possibility of less heat transfer to the pot due to quenching of the flame.

**Side opening:** A side opening in the stove has the purpose of air and fuel inlet. Fuel burning rate, temperature of combustion chamber and air supply is controlled by side opening. There is also, loss of heat through radiation and convection by opening. Thus, a side opening has a profound influence on the efficiency of the cookstove (FAO, 1993).

**Interconnecting tunnel:** Interconnecting tunnel is the path way from first combustion chamber to second combustion chamber for flame and flue gases. Shape and size of the interconnecting tunnel affects the draft of air flow, turbulence of flue gases and combustion process of the cookstove. Diverging and converging tunnels have more resistance to flow of flue gases and flame. It also, creates more turbulence on the flue gases. On the other hand, tunnels with small diameter creates more pressure drop. Purpose of modification of pathway to second pot is to increase the efficiency of heat transfer to second pot, swirling of incoming air and flue gases. Swirling in incoming air increases the turbulence of air in combustion chamber resulting in increase of thermal efficiency (Sutar *et al*., 2015).

**Insulation material:** Insulation material greatly affects the performance of ICS. Use of insulation layer in the combustion chamber reduces the heat transfer to walls of cookstove. This results in high combustion chamber temperature which increases combustion efficiency and ultimately thermal efficiency. Most of the metal cookstoves use ceramics in the internal parts of combustion chamber to increase the performance of cookstove (Sutar *et al*., 2015). A heavy cookstove such as mud brick absorbs 30-40% of heat during the cooking period (Claus and Sulilatum, 1982).

**Grate:** Use of the grate increases the thermal efficiency of cookstove. The primary air coming from below the grate is heated from the char and ash. Grate also, aids in proper burning of char (Sutar *et al*., 2015). Thermal efficiency of cookstove can be improved by 3-5% by using grate (Gusain, 1990).

## MATERIALS AND METHODS

**Fabrication of cookstove:** Two pot raised mud ICS of size 82×40×28cm has been fabricated by using solid bricks, supporting structure parts and additives. Mud used for the fabrication of brick was composed up of 5/8 fraction clay or local mud, 2/8 fraction rice husk or saw dust and 1/8 fraction cow or buffalo dung parts by volume.

Rectangular shaped bricks have been fabricated for wall of cookstove and square shape bricks for chimney by using moulds (Fig. 1). The details of materials required for cookstove fabrication is presented in Table 1.

Fabrication of cookstove was done by trained stove master. Schematic view and fabricated photograph of cookstove are shown in Fig. 2.

**Experimental analysis:** For the analysis of cookstove parameters, experiment has been performed at Stove Lab of Pulchowk Campus, Institute of Engineering, Tribhuvan University, Lalitpur, Nepal. Power test was done for the

Fig. 1: Fabricated square and rectangular bricks

Table 1: Material for the cookstove fabrication

| Material | Dimension/specification | Quantity |
|---|---|---|
| Brick for wall | 20×10×5 cm | 40 bricks |
| Brick for chimney | 20×20×5 cm brick with a hole of 8 cm diameter | 22 bricks |
| Iron frame | Rectangular rod (15×3 mm cross section) | |
| | 20 cm length | 2 No.s |
| | 25 cm length | 2 No.s |
| | 30 cm length | 2 No.s |
| | Frame to support to opening for air fuel inlet | 1 No |
| Mud with additives | Mud | Asrequired |
| | Salts | 1 kg |
| | Wheat flour | 1 kg |
| | Sugar | 1 kg |
| Water | Clean | Asrequired |

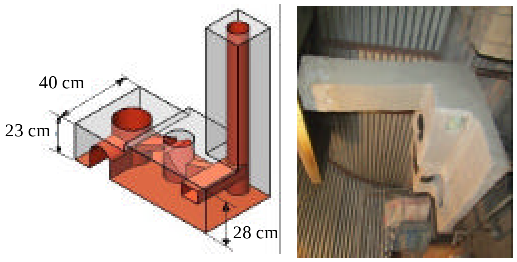


Fig. 2: Schematic diagram for the variation of geometrical parameters

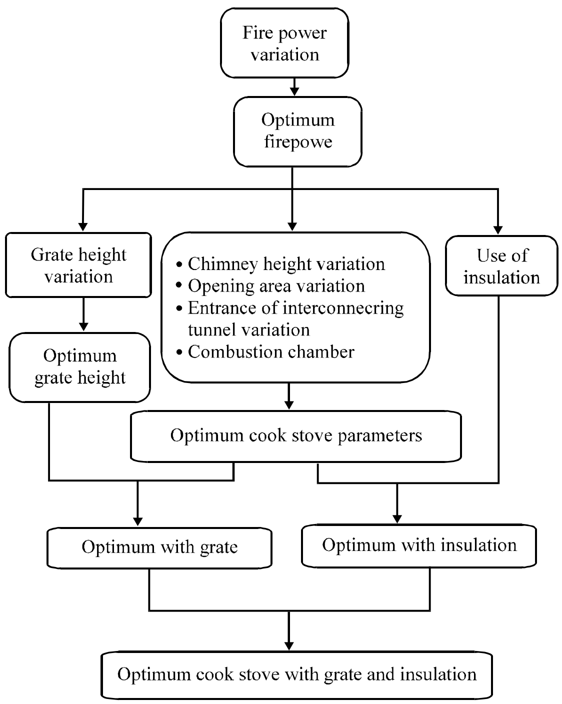


Fig. 3: Performance test steps to find optimum cookstove

evaluation of thermal efficiency and optimum cookstove was obtained using the experimental methodology as shown in Fig. 3.

**Thermal efficiency test procedure:** Thermal efficiency of cookstove has been calculated by using "Power Test". Maintaining constant power during Water Boiling Test (WBT) is difficult and power variation result in data with high standard deviation and variance. The stove power varies according to, the person supplying fuelwood to cookstove and for the same person it depends on the steadiness of fuelwood feeding. To remedy this problem, power test was devised. While most of the procedures are similar to cold start of WBT, some aspects are considered differently. First of all, the test has been conducted for 1 h and secondly, constant fuel feeding rate has been

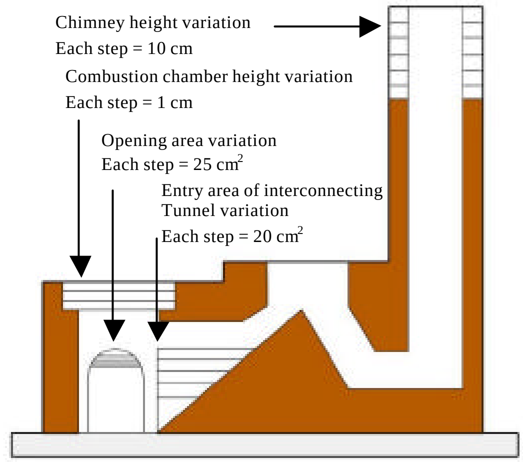


Fig. 4: Schematic diagram for the variation of geometrical parameters

maintained. The amount of wood to be supplied is divided in different batches of equal weight and is fed to stove at constant time intervals. All other protocols for testing were of Water Boiling Test 4.2.3 Version. For the calculation of thermal efficiency of cookstove, excel sheet provided by Global Alliance for Clean cookstove has been used.

**Methodology for thermal efficiency test:** Thermal efficiency test has been performed using the methodology shown in Fig. 3. First firepower was varied to obtain optimum firepower. Maintaining optimum firepower, power test for each parameter has been performed keeping other parameters constant and optimum value for each parameter has been obtained. Additionally, thermal efficiency test for grate and insulation material has been performed. Finally, test for optimized cookstove with grate only, insulation only and grate-insulation combined has been performed.

**Variation of different geometrical parameter**: Geometrical parameters viz. chimney height, combustion chamber height, opening area of air fuel inlet and entry area of interconnecting tunnel has been changed as shown in Fig. 4.

## RESULTS AND DISCUSSION

**Thermal efficiency at different firepower:** Input fuel feeding rate has been varied considering fire power range from 3.3-6.6 kW to find the optimum feeding rate as shown in Fig. 5.

As the fuel feeding rate increases, the efficiency first increases, reaches maximum value and then decreases. The reason for low efficiency at lower fuel feeding rate is

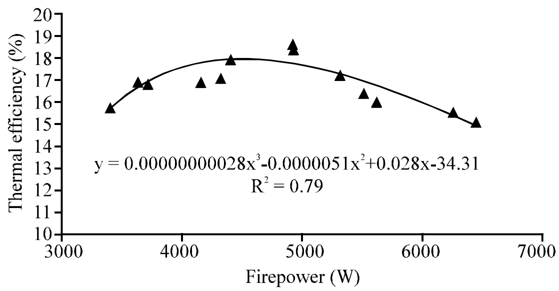


Fig. 5: Thermal efficiency of cookstove at different firepower

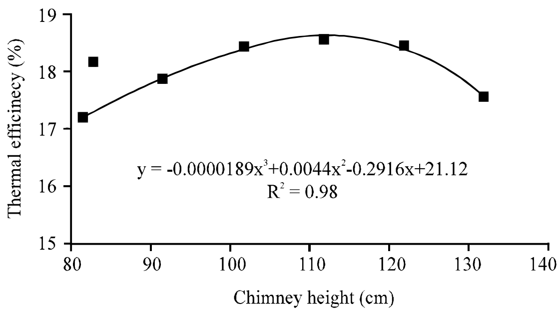


Fig. 6: Thermal efficiency of cookstove at different chimney height

due to quenching of flame because of high excess air ratio. For higher fuel feeding rate, there is lack of air for complete combustion because of which the efficiency decreases. The shape of the graph is inverted bowl shape which is in accordance with the literature (Kandpal and Maheshwari, 1995; Sutar *et al*., 2015). From polynomial equation of the graph, its maximum value has been found at value 4.5 kW and corresponding thermal efficiency 18%. Feeding rate for further experiments has been maintained as per optimum firepower.

**Thermal efficiency at different chimney height:** Chimney height of the cookstove has been varied from 81-132 cm with fixed chimney hole diameter of 10 cm. The nature of thermal efficiency vs. chimney height has been found concave downward as shown in Fig. 6.

The graph for chimney height vs. firepower has been found as bell shape. For shorter chimney height, the draft created due to stack effect is less which results in lower suction of air. This decreases the efficiency of cookstove. For higher chimney height, the suction is excess leading to higher Excess Air Ratio (EAR) higher losses of heat through flue gas and reduction of temperature of combustion chamber which results in lower thermal efficiency. The polynomial equation gives optimum efficiency 18.16% at chimney height 112 cm.

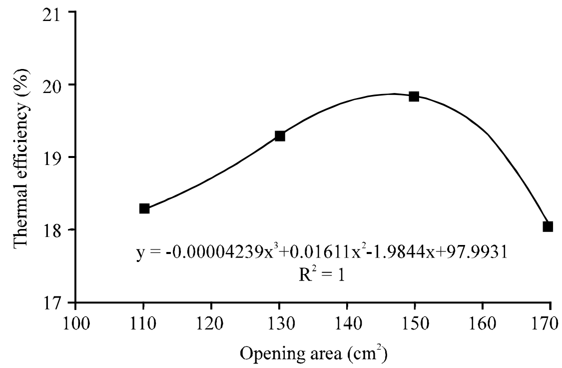


Fig. 7: Thermal efficiency of cookstove at different opening

**Thermal efficiency at different opening area of air fuel inlet:** Size of opening inflences the air flow entering into the combustion chamber and convetion and radiation heat losses. Social factor such as size of fuelwood used, also, influence the size of the opening (Sharma and Dralami, 2016). Thermal efficiency of cookstove has been obtained by varying the area of opening from 110-170 cm$^2$ as shown in Fig. 7.

Nature of the graph has been found concave downwards. Polynomial equation gives maximum efficiency of 19.85% at opening area of 148 cm$^2$. The cause of low thermal efficiency at smaller opening due to more space occupied by fuelwood and less space available for incoming air which results in insufficient air for complete combustion. At larger opening, supply of excess air causes quenching of flame and at the same time more convection and radiation heat losses through openings. From design aspect, minimum opening area of combustion chamber should maintain with the capacity to accommodate at highest firepower (Kshirsagar and Kalamkar, 2016). Considering social viability (Sharma and Dralami, 2016) and design aspect, 148 cm$^2$ area is suitable for optimum performance.

**Thermal efficiency at different size of entry area of inter connecting tunnel**: Thermal efficiency test has been performed by varying entry area for the interconnecting tunnel from 139-14 cm$^2$ as shown in Fig. 8. The reduction of area has been done as shown in Fig. 4. Rectangular wall has been raised from bottom of the entry hole to reduce area.

As area of interconnecting tunnel decreases, turbulence of air entering the second combustion chamber increases and overall contact time of flue gas increases. Hence, thermal efficiency increases. Further, reduction of entry area of interconnecting tunnel, results in lack of the area for flow of flue gas. Because of this, insufficient air

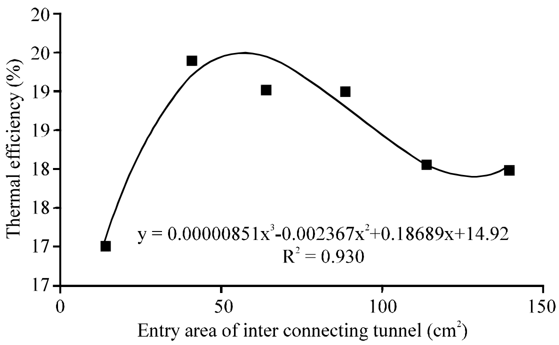


Fig. 8: Thermal efficiency of cookstove at different entry area of inter connecting tunnel

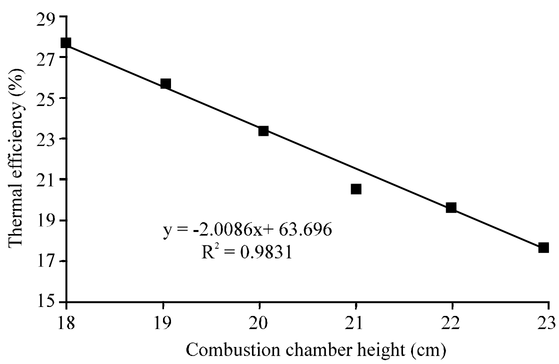


Fig. 9: Thermal efficiency of cookstove at different combustion chamber height

enters the combustion chamber leading to incomplete combustion and decreased thermal efficiency. Equation of the graph gives maximum thermal efficiency 19.46% for an area of 56.95 cm$^2$.

**Thermal efficiency at different combustion chamber height:** Thermal efficiency test of cookstove has been performed by varying combustion chamber height 18-23 cm as shown Fig. 9.

Result shows that there is linear relationship between thermal efficiency and combustion chamber height. As the combustion chamber height decreases, thermal efficiency increases. This is because the flame directly comes in contact with the pot, transferring more heat to the pot and increasing the thermal efficiency. But the combustion chamber height can be reduced upto a certain limit only. Below the limit, the combustion is incomplete and high soot deposits are formed on the bottom of the pot. Higher combustion chamber height causes quenching of flame and results in decrease of thermal efficiency (Bussmann and Prasad, 1986).

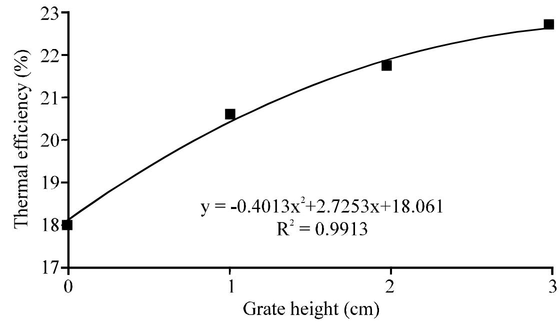


Fig. 10: Thermal efficiency of cookstove at different grate height

From design aspect, combustion chamber height should be slighty greater than flame height. Height of the flame has been calculated by using Herwijn empirical formula as follows:

$$H_f = C\times P^{\frac{2}{5}} \tag{1}$$

Where:

P = The Power output
C = A Constant

Values of this constant are: 110 mm/kW$^{0.4}$ for a fire without grate (Herwijn, 1984). By using Herwijn empirical formulae, height of the flame for the stove without grate has been found 19.98 cm in which thermal efficiency has been found 21.93%. In this condition, combustion process was found normal and there was no exess soot formation on the pot. For the 18cm height combustion chamber, i.e., 2 cm less than flame height, thermal efficiency has been found 27.83%. This is due to shorter distance between bed of combustion chamber and bottom of the pot, shape factor increases and pot receives more heat at high temperature and thermal efficiency increases. But this leads to increased deposition of soot on the pot, incomplete combustion and increased emission pollutants.

**Thermal efficiency with the use of grate:** Use of grate increases the thermal efficiency of the cookstove (Kshirsagar and Kalamkar, 2014). Thermal efficiency of cookstove by using grate of height of 1, 2 and 3 cm have been found 20.61, 21.69 and 22.70%, respectively as shown Fig. 10. This shows that thermal efficiency has been increased by 2.62% (from 18-20.61%) by using grate of height 1 cm. Similarly, thermal efficiency increased by 1.08 and 1.01% by increasing subsequent each 1 cm grate height, respectively.

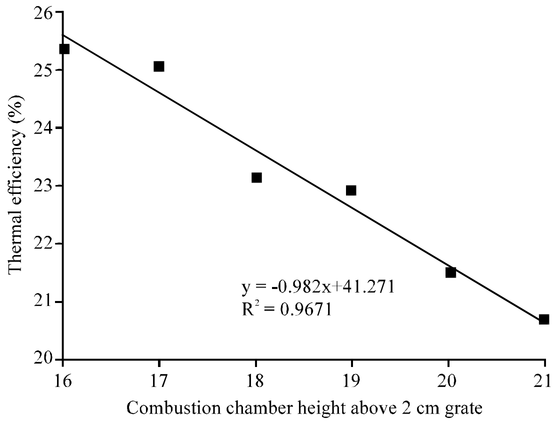


Fig. 11: Thermal efficiency of cookstove with use of 2 cm grate and variation of combustion chamber height

Use of grate supplies primary air from bed which carries heat from combusted ash and results in improvement of combustion quality. Preheating of incoming air improves quality of combustion and improves thermal efficiency (Bryden *et al*., 2005).

Grate height has not been increased more than 3 cm due to size of opening area, size of the fuelwood used and social factor. Here, thermal efficiency has been increased from 17.85-22.69%, i.e. with net increase of 4.71% with the use of 3 cm grate but for 3 cm grate height, the fuelwood has to be cut into small pieces and considering social aspects 3 cm grate is not a viable option. It has been found that thermal efficiency has been increased by 3.83% with the use of 2 cm grate. Socially, technically and geomtrically, grate height has been fixed 2 cm.

Combustion chamber height above the grate has been varied from 16-21 cm. Thermal efficiency of cookstove at different combustion chamber height has linear relation to combustion chamber height as shown in Fig. 11. Thermal efficiency of cookstove has been increased with reduction of combustion chamber height.

**Thermal efficiency with the use of insulation:** Inner layer of the combustion chamber has been coated by insulating material and effect on efficiency has been observed. Composition of insulating material were ash 5/12, saw dust 3/12, talcom powder 1/12, fire clay 1/12 and bulk clay 2/12 parts by volume. The main reason for use of this material for insulation is consideration of social aspects. This stove is a nationwide disseminated cookstove and the insulation material should also be locally manufacturable.

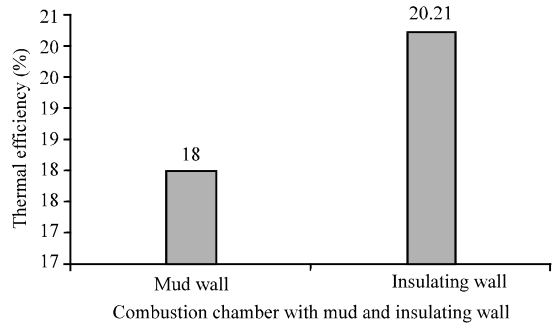


Fig. 12: Thermal efficiency of cookstove with use insulating material

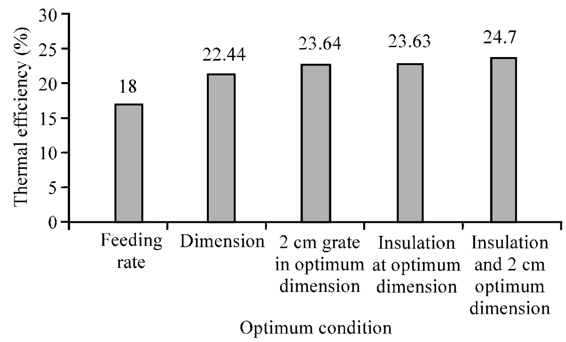


Fig. 13: Thermal efficiency at optimum condition

Thermal efficiency of cookstove with insulating layer increased from 18-20.21%, i.e., 2.21% increase in thermal efficiency as shown in Fig. 12. This is due to decrease in conductivity which results in less heat transfer to the wall. Also, the temperature of flame increases and ultimately, thermal efficiency increases (De Lepeleire and Christiaens, 1983).

**Thermal efficiency at optimized condition:** Experimental results show that optimum thermal efficiency has been found at fire power 4.5 kW, i.e., at feeding rate 1.2 kg/h. Similarly, optimum dimension such as chimney height, air fuel inlet opening, entry area of interconnecting tunnel and combustion chamber height has been found 112.88 cm, 148 $cm^2$, 56.95 $cm^2$ and 20 cm, respectively. Thermal efficiency of cookstove at overall optimum dimensions have been found at 22.45%. This value is 0.51% more than individual optimum value at combustion chamber height 20 cm. Experimental results show that combustion chamber height is most sensitive parameter for the thermal efficiency (Fig. 13).

For the optimum dimension, with the use of 2 cm grate, thermal efficiency increased from 22.45-23.86%, i.e., net increase of 1.41%.

Thermal efficiency of cookstove with the use of insulation on the inner layer of combustion chamber at optimum dimension has been found 23.63% which is 1.19% more than in case without use of insulating material.

Furthermore, using 2 cm grate on the cookstove fabricated in optimum dimension with insulation in the inner layer of combustion chamber, thermal efficiency has been found 24.70% which is 1.07% higher than in the case of without use of grate.

## CONCLUSION

In this study, effect of firepower variation, different geometrical parameters variation, grate use and insulation used has been studied for two pot raised mud ICS.

Optimum efficiency 18% has been found at firepower 4.45 kW, i.e., 1.2 kg/h feeding rate for the existing cook stove. Optimum chimney height, air fuel inlet opening, entry area of interconnecting tunnel and combustion chamber height have been found as 112.88 cm, 148 $cm^2$, 56.95 $cm^2$ and 20 cm, respectively. Thermal efficiencies with the use of 1-3 cm grate increases by 2.62, 3.7 and 4.71%, respectively. Socially and technically 2 cm grate height is better.

Thermal efficiency of cookstove at optimum dimension has been found 22.44% and thermal efficiency increased by 1.2% on using 2 cm grate on it. Thermal efficiency of cookstove has been found 23.63% with the use of insulating material (without grate) in optimum dimension. For optimized cookstove with 2 cm grate and insulation in the inner lining of combustion chamber, thermal efficiency reaches to 24.70% which is 1.07% more than in the case of without use of grate. Thermal efficiency of cookstove has been increased from 18-24.70%, i.e., 6.70% increment.

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## REFERENCES

Agenbroad, J., M. DeFoort, A. Kirkpatrick and C. Kreutzer, 2011. A simplified model for understanding natural convection driven biomass cooking stoves-Part 1: Setup and baseline validation. Energy Sustainable Dev., 15: 160-168.

Agenbroad, J., M. DeFoort, A. Kirkpatrick and C. Kreutzer, 2011. A simplified model for understanding natural convection driven biomass cooking stoves-Part 2: With cook piece operation and the dimensionless form. Energy Sustainable Dev., 15: 169-175.

Agrawal, S., A. Parajuli, J.K. Tharu and A. Kamat, 2016. Development of mathematical model for 2-pot enclosed cookstove and its experimental validation. Msc Thesis, Tribhuvan University, Kirtipur, Nepal.

Bryden, M., D. Still, P. Scott, G. Hoffa, D. Ogle, R. Bailis and K. Goyer, 2005. Design principles for wood burning cook stoves. Aprovecho Research Center, Shell Foundation. http://www.ewb-usa.org/files/2015/05/PrinciplesWoodBurningCookStoves.pdf.

Bussmann, P. and K.K. Prasad, 1986. Parameter analysis of a simple woodburning cookstove. Pan, 16: 1-20.

Claus, J. and W.F. Sulilatu, 1982. A comparison of the performance of three woodstoves. Proc. Indian Acad. Sci. Sect. C. Eng. Sci., 5: 343-359.

De Lepeleire, G. and M. Christiaens, 1983. Heat transfer and cooking woodstove modelling. Proc. Indian Acad. Sci. Sect. C. Eng. Sci., 6: 35-46.

FAO, 1993. Improved solid biomass burning cookstoves: A development manual. Regional Wood Energy Development, Russia. http://wgbis.ces.iisc.ernet.in/energy/HC270799/RWEDP/acrobat/fd44.pdf

Gusain, P.P.S., 1990. Cooking Energy in India. Vikas Publishing House Private Limited, New Delhi, India, Pages: 127.

Herwijn, A.J.M., 1984. An experimental investigation into the heat transfer from a wood-fire to a pan. Master Thesis, Eindhoven University of Technology, Eindhoven, Netherlands.

Kandpal, J.B. and R.C. Maheshwari, 1995. Combustion of biomass fuels in two cookstoves for their conservation. Energy Convers. Manage., 36: 1015-1021.

Kandpal, J.B., R.C. Maheshwari and T.C. Kandpal, 1994. Air pollution from biomass combustion in domestic cookstove. Renewable Energy, 4: 545-549.

Kshirsagar, M.P. and V.R. Kalamkar, 2014. A comprehensive review on biomass cookstoves and a systematic approach for modern cookstove design. Renewable Sustainable Energy Rev., 30: 580-603.

Kshirsagar, M.P. and V.R. Kalamkar, 2016. User-centric approach for the design and sizing of natural convection biomass cookstoves for lower emissions. Energy, 115: 1202-1215.

Lim, S.S., T. Vos, A.D. Flaxman, G. Danaei and K. Shibuya *et al*., 2013. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. Lancet, 380: 2224-2260.

MacCarty, N.A. and K.M. Bryden, 2015. Modeling of household biomass cookstoves: A review. Energy Sustainable Dev., 26: 1-13.

Prapas, J., M.E. Baumgardner, A.J. Marchese, B. Willson and M. DeFoort, 2014. Influence of chimneys on combustion characteristics of buoyantly driven biomass stoves. Energy Sustainable Dev., 23: 286-293.

Sedighi, M. and H. Salarian, 2017. A comprehensive review of technical aspects of biomass cookstoves. Renewable Sustainable Energy Rev., 70: 656-665.

Sharma, U. and H.B. Dralami, 2016. Performance assessment and analysis for potential promotion of improved cookstoves in nepal under market/non-market mechanism. Proc. IOE. Graduate Conf., 1: 221-231.

Smith, K.R., 1994. Health, energy and greenhouse-gas impacts of biomass combustion in household stoves. Energy Sustainable Dev., 1: 23-29.

Sutar, K.B., S. Kohli, M.R. Ravi and A. Ray, 2015. Biomass cookstoves: A review of technical aspects. Renewable Sustainable Energy Rev., 41: 1128-1166.

WECS, 2010. Water and energy commission secreteriate. Nepal, South Asia. http://www.scirp. org/(S(351jmbntvnsjt1aadkposzje))/reference/References Papers.aspx?ReferenceID=949294