Cooking Devices and their Thermal Efficiencies in the Context of Nepal: A Review

Hari Bahadur Darlami[1*], Ravikant Chaudhary[2] Bishnu Kumari Budha[3]

[1,2] Tribhuvan University, Institute of Engineering,Pulchwok Campus, Lalitpur, Nepal
[3]National Basic School, Kathmandu, Nepal
Corresponding Email: haridarlami@ioe.edu.np*

Abstract: Cooking energy is the basis energy for the human society. According to availability of resources and technology, different cooking devices are used. Performance assessment of cooking device gives the idea for selection of cooking devices. Use of clean and efficient cookstove keeps importance environmentally, economically and socially. Poor people are using lower grade fuel and traditional technology such as use of loose biomass and cow dung in traditional cookstove. With increase of economic status people, they are using biomass based improved cookstove, biogas, Liquefied Petroleum Gas (LPG) and induction stove in the context of Nepal. The present article aims at bringing together thermal efficiencies of cooking device that are using in Nepal.

Keywords: Cookstove, thermal efficiency

1. Introduction

Cooking of food is the basic energy needed for the human society. It is estimated from the historical evidences that fire has been used for cooking of meals for about 100,000 years [1]. About 2.6 billion people do not have access to clean cooking facilities; and if predictions are believed the approximately same number will still be so in 2030 [2]. Pollutants emitted from cookstoves cause serious indoor air pollution and have a negative impact on health of people [3]. Biomass based cookstove is widely used in the rural area. Among them, loose biomass and dung cake are used by poor family to fulfil their energy demand need. Biogas technology is another source of renewable energy which can be installed by even the middle class family, who owns agricultural land and animal farming. Now a day, most of the urban people use LPG whereas rural people also have LPG with biomass based cooking device. Electric stove also used by higher class family. Induction cookstove is newly emerged technology. Now about 2.7 billion people in developing countries are dependent on biomass based fuel including wood, loose biomass, agricultural residues and animal dung for cooking [4]. The traditional cookstoves are inefficient and produce high emissions which may cause respiratory disease and other health problems. Despite these high emission devices have adverse impact on the lives of the people, the design and development of these cookstoves have received relatively less attention from the scientific and technical community of the world. Consequently, despite a concerted effort by many groups at the grassroots level, the problem is still far from resolved.

Study of cooking devices and their performances at different parametric condition keeps importance for the selection cooking devices as per availability of resources and economic status of people. Energy efficiency is the main component to achieve energy savings, allowing to obtain the same or better quality service or device with lower power consumption [16].

2. Cooking devices in Nepal

In Nepal about 89% of energy is used in household sector. Among them, 86.5% energy is fulfilled by fuelwood, 6.5% animal dung, 3.7% argicultral residue, 1% electricity, 0.9% LPG, 0.1% other. The household uses fuelwood in urban and rural are 23.8% and 17.9% respectively. Similarly LPG user households in urban and rural are 69.8% and 11.4% respectively [5] . As per AEPC report, around 1.3 million improved cookstoves have been disseminated to date, and more than 2 million people are still using traditional cookstove.

Biomass energy is one of the readily available sources of renewable energy that has been using for the purpose of cooking and space heating. About 60.9% of Nepalese people are using fuelwood for cooking purposes [6]. People are using traditional types cooking stove that has been started from many thousands years ago to modern type of cooking devices. Type of use cooking devices in the households depends upon the availability and reliability of fuel supply, availability of cooking device, social acceptance and economic status of the people. Government and non-governmental sectors are trying to replace traditional cookstove by clean fuel and efficient technology. Improved Cookstove fabrication training, subsidy for the promotion of Metallic Improved Cookstove, Rocket stove, gassifier stoves, induction stove etc. Government of Nepal has subsidy policy for installation of biogas plant to promote clean renewable energy. Government of Nepal has subsidy for LPG gas. Now large numbers of people are attracted towards Induction cookstove where electricity is available with appropriate size of conductor and meter. Different local levels have introduced subsidy policy for induction cookstove in order to shift toward clean cooking energy.

3. Hierarchy of cooking devices and their thermal efficiencies

Biomass based cooksoves have widely used in the rural area in the context of Nepal. The reason is biomass is readily available, cultural practice, lack of alternate source of cooking in rural area, economic status of cooking fuel etc. Use of higher level of cooking energy and devices depend upon the availability and economic status of people. In the context of Nepal, the hierarchy of cookstove has been shown in Figure 1. Still most of lower status rural people are using biomass based fuel such as fuelwood, dung cake, agriculture residue and loose biomass in traditional cookstove. In most of terai and hilly region people are using chimney mud improved cookstove (ICS). Governmnet of Nepal and different institutions are working for the promotion of such smokeless improved cookstove by giving subsidy, improved cookstove fabrication training at local level etc. In higher hill and mountain region, government of Nepal is promoting chimney metallic ICS for cooking and space heating purposes by giving subsidy. Rocket stove is more efficient cookstove which is widely using by rural people as additional cooking device. Use of natural draft rocket stove is more in comparison to force draft. Force draft rocket stove requires electricity which is not available in all rural area. LPG is the higher hierarchy fuel in the context of Nepal. Most of the urban people and road access rural people are using LPG. Induction cookstove is emerging technology which is clean and efficient.

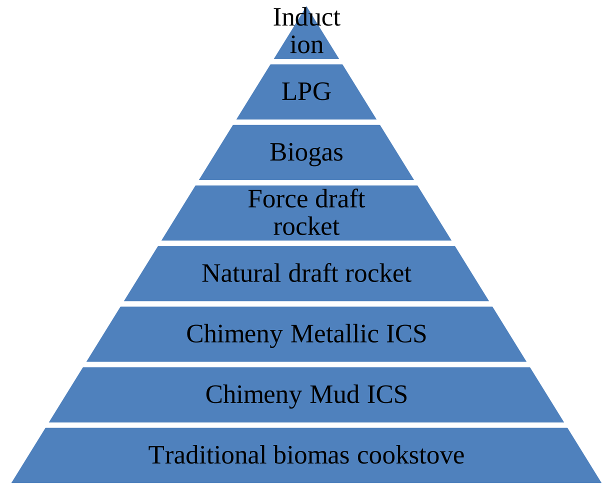

Figure 1: Hierarchy of efficiency of cookstoves

3.1.1 Biomass based cookstoves

Biomass based cookstove uses fuelwood, cow dungs, agricultural residues etc. with caloric value of about 21 MJ/kg as the fuel sources [7]. Water Boiling Test of biomass cookstove has confirmed the average thermal efficiency varies in the range of 11-17%[8]. Thermal efficiency of biomass cookstove can be increase by optimum side opening for air fuel mixture inlet[13], optimum combustion chamber height for complete combustion [9]. Cookstoves have multiple advantages such as carbon credits, their contribution to climate-change mitigation as well as yield significant co-benefits in terms of energy access for the poor people. Furthermore, they can result in improved rural health, environmental, agricultural and economic benefits [10].

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 [11]. Usage of the grate also increases the thermal efficiency of cookstove. The primary air coming from below the grate is heated by the heat of char and ash. Grate also aids in proper burning of char [4]. Thermal efficiency of cookstove can be improved by 3% to 5% by using grate [12]. Secondary air ensure proper and complete combustion of fuel. It increases thermal efficiency and improves quality of emission parameters [13].

By improving the thermal efficiency of cookstove, optimal use of the biomass fuel, and fuelwood consumption can subsequently mitigate environmental pollution [14]. By enhancing thermal efficiency and combustion performance, the use of improved cookstove can reduce energy consumption, contribute to environmental aspects and human health [15]. Design of cookstoves with provision of better secondary air and smaller thermal mass will increase the thermal efficiency of cookstove and reduce emissions. Solid fuels with higher energy content when used in ICS may result in high efficiency but will contribute to significantly higher emissions. Development of cookstove with proper analysis of heat and mass transfer with use of computational fluid dynamics helps for development of efficient cookstove [7].

Its thermal efficiency can be increased by shielding the combustion chamber. Combustion of biomass base fuel in close chamber reduces the heat loss from surrounding, directs heat into the pot and increase the combustion performance.

3.1.2 Traditional cookstove

According to the hierarcy, Traditional Cookstove is the lowest level of cookstove technology. It burns loose biomass, dung cake and fuelwood in open fire. In Terai area most of the people are using loose biomass and dung cake to fulfill their energy need. Thermal efficiency of cookstove with using loose biomass is lesser than 10% that means only 10% of heat produced on burning loose biomass is utilized for cooking purpose while remaining energy are wasted. However, with use of fuelwood, the overall thermal efficiency of traditional cookstove increases above 10% [17].

Performance of traditional cookstove can be increased with the use of smaller chunks of fuelwood, dried fuel, and proper handling of fuel.

3.1.3 Mud chimney improved cookstove

It is widely used in rural part of middle hill and Terai region. It is generally made up of one or two pot hole. They use agriculture residue and fuelwood as a fuel. It consists of combustion chamber, air fuel inlet, chimney. As per NIBC standard for biomass cookstove minimum thermal efficiency of cookstove have been set 20%. During test of two pot raised mud cookstove in 2016 in RETS, high thermal efficiency has been found as 25.5% [18].

Thermal efficiency of mud cookstove can be increased by using grate, insulation material, secondary air supply, turbulence of flowing air, force draft, appropriate dimension, appropriate feeding.

3.1.4 Metallic chimney improved cookstove

The Metallic cook stoves are the less considered type of improved cook stoves in Nepal. They are not so highly demanded as they contribute heavy metal parts which eventually increase the cost of the stove. Yet the metallic cooking stoves can be highly preferred in the colder zones of Nepal which includes the mountainous regions. The major characteristic of the metallic cooking stove is its space heating feature which makes it most practical among the colder regions. This cookstove have two to 3 pot holes. It consists of combustion chamber, air fuel opening with door, baffle and damper. Renewable Energy Test Station (RETS) has bench mark for thermal efficiency of this type of cookstov is 18%. Alternative Energy Promotion Center has developed two pot holes and three pot hole metallic chimney stove for the purpose of cooking and space heating in the higher altitude which thermal efficiencies have been found 18.17% and 22.35% respectively. Life of metallic stove is major factor. Its thickness and material keeps importance for durability of cookstove. Its wall and cooking surface are made from 1.5mm and 4mm MS sheets.

Thermal efficiency of metallic chimney cookstove can be increased by using grate, secondary air supply, turbulence of flowing air, appropriate dimension, appropriate feeding.

3.1.5 Rocket stove

Rocket stoves are efficient cooking devices that utilize high-temperature combustion chambers containing insulated vertical chimneys to ensure the complete combustion of small chunks of wood. Natural draft cookstove consists of either well insulated wall around the vertical drafting tube flow path or hole around the flow path combustion. Insulation in combustion chamber increase the temperature of combustion chamber and increase the combustion as well thermal efficiency. For the rocket cookstove which supply secondary air helps to complete combustion of fuel. The elbow, a key feature in the design, can be constructed using a metal pipe or ceramic and cookware.

The average thermal efficiency of rocket cookstove is about 30% which can further be increased upto 35% by changing the configuration that includes riser area, height of pot supporter, combustion chamber [19].

3.1.5.1 Natural draft

Natural draft rocket cookstove is widely used cookstove in the context of Nepal. In general, height of chimney is three times of diameter for sufficient draft. Minimum bench mark for thermal efficiency of this type of cookstove is 25%. Thermal efficiency of rocket stove made by Husk Power Nepal and Chaitya Metal Workshop has been found as 30.29% and 29.10% respectively. Henan Sencer, China has developed a natural draft rocket stove which has thermal efficiency of 31.51% [18].

3.1.5.2 Force draft

Force draft rocket stove have higher thermal efficiency than natural draft. Turbulence of air is created by fan which is usually operated by electric power. Minimum bench mark for thermal efficiency of this type of cookstove is 35%. Husk power developed a gassifier rocket stove with thermal efficiency of 41.24%. Thermal efficiency of Mini Moto force draft roket stove developed by Minimoto BV, The Netherlands has been found 49.39%. Shengzhuo Stove Develove by Ganlin Town, Shengzhou, China has developed a force draft single pot hole rocket stove have high power thermal 50.89% which is the highest performance stove as tested in RETS laboratory [18].

Thermal efficiency of cookstove can be increased with appropriate dimension and skirt, well insulation, supply of appropriate secondary air.

3.1.6 Biogas cooksove

Biogas is a high grade fuel that can be used for the purpose of both thermal and electricity generation. The performance of the biogas plants depend on the quality of construction and quality standards of biogas appliances. Along with speed up dissemination, the accuracy and efficiency of the appliances is much needed to be increased along with quality construction that in turn would help in the reliability of the technology. Practically, thermal efficiency of locally made biogas cookstove has been found 30% to 40% in the context of Nepal.

Thermal efficiency has been found up to 54.8 % overall efficiency at higher flame intensity and 43.6% for lower intensity [20].

Thermal efficiency of biogas stove can be increased with proper design of burner cap center, equal spacing and appropriate sizing of burner hole, size of burner nozzle, diameter and size of side holes, reduction of heat loss from pan support.

3.1.7 LPG stove

LPG is found with very wide application in a large variety of domestic, industrial, commercial uses. Thermal efficiency of LPG burner is measured for a wide range of parameters such as loading height, pot diameter, and loading weight. The maximum thermal efficiency of 61.66% could be achieved with the present burner [21]. The thermal efficiency of LPG stove for regular cast iron burner was found to be 48%. When flat and flower face burners were used, thermal efficiency of LPG stove improved. When flat face brass burner was used maximum thermal efficiency of 58% was achieved. While thermal efficiency of 50% was observed when face brass flower burner was used. Further, it was experimentally found out that thermal efficiency of LPG stove using regular brass burner was 4% higher as compared to regular cast iron burner [22].

3.1.8 Induction cookstove

Induction cooking is often considered one of the most efficient technologies for cooking purpose as it ranks at the top of hierarchy. Induction cookstove works based on the principle of magnetic induction, where eddy currents are excited in a ferromagnetic cookware in the presence of an oscillating magnetic field. The induced currents dissipate heat by the Joule effect, generating the heat directly in the cooking pot. Villacis et al. in 2015 studied the energy efficiency of induction cookstove by using different material for cookware has found that efficiency has found higher than 80% in all cases [23]. This technology also consumes comparatively less time for cooking purpose.

However, this requires higher size of conductor and MCB switch as per number of devices. In context of Nepal, these problem would be challenges for induction users.

4. Conclusions

Following conclusions have been drawn from the study

- Biomass based cookstove is lowest hierarchy level cookstove with lower thermal efficiency. Thermal efficiencies range of of traditional, chimney metallic ICS, Chimney Mud ICS, Natural draft rocket and force draft rocket stove have been found 5-10%, 18-22%, 20-26%, 25-31% and 35-51% respectively.
- Biogas lies in higher hierachy which is clean renewable energy and thermal efficiency range. Thermal efficiency of locally made stove have range 30-40% and imported stove have upto 55%.
- LPG stove is widely used cooking device which thermal efficiency range from 48 to 58%.
- Induction coookstove is highest hierarchy cooking device and it thermal efficiency has range from 80-90%.

References

[1] J. Bronowski, *The Ascent of Man*. Little, Brown & Company, 1973.

[2] IEA, "International Energy Agency. World Energy

Outlook 2012-Executive Summary. France, November 2012. ⟨http://www.iea.org/publications/freepublications/publication/English.pdf⟩," 2012.

[3] A. Warwick, H. and Doig, "Smoke: the Killer in the Kitchen, Indoor Air Pollution in Developing Countries, ITDG Publishing, London.," 2004.

[4] K. B. Sutar, S. Kohli, M. R. Ravi, and A. Ray, "Biomass cookstoves: A review of technical aspects," *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1128–1166, 2015, doi: 10.1016/j.rser.2014.09.003.

[5] WECS, "Energy Situation and Supply Conditon of Nepal," *Water Energy Comm. Secreteriate*, 2014.

[6] C. Bureau and O. F. Statistics, "Annual household survey 2015/16," vol. 16, 2016.

[7] A. Gupta, A. N. V Mulukutla, and S. Gautam, "Environmental Technology & Innovation Development of a practical evaluation approach of a typical biomass cookstove," *Environ. Technol. Innov.*, vol. 17, p. 100613, 2020, doi: 10.1016/j.eti.2020.100613.

[8] C. M. Quist, M. R. Jones, and R. S. Lewis, "Energy for Sustainable Development Estimation of transient thermal ef fi ciency of a biomass cookstove," *Energy Sustain. Dev.*, vol. 33, pp. 122–128, 2016, doi: 10.1016/j.esd.2016.06.004.

[9] P. K. K. Bussmann P., "Parameter analysis of a simple wood burning cook stove. In: Proceedings of M. Sedighi, H. Salarian Renewable and Sustainable Energy Reviews 70, 656–665 International Heat Transfer Conference. San Francisco; 1986 p. 3085–3090.," 2017.

[10] J. Gill, "Improved stoves in developing countries. A critique," *Energy Policy*, vol. 15, no. 2, pp. 135–144, 1987, doi: 10.1016/0301-4215(87)90121-2.

[11] J. K. Kumar R, Lokras SS, "Development, analysis and dissemination of a three pan cook stove. Bangalore: Indian Institute of Science.," 1990.

[12] P. Gusain, "Cooking energy in India. Development Alternatives, Vikas Publishing House Pvt. Ltd.;. New Delhi: India," 1990.

[13] B. Thapa, B. Karki, C. Acharya, and R. K. Jha, "Design modification of existing 2-pot MICS for increasing efficiency and social acceptance," 2013.

[14] M. Sedighi and H. Salarian, "A comprehensive review of technical aspects of biomass cookstoves," *Renew. Sustain. Energy Rev.*, vol. 70, no. November 2016, pp. 656–665, 2017, doi: 10.1016/j.rser.2016.11.175.

[15] K. Smith, "Health,energy, and green house-gas impacts of biomass combustion in household stoves.Energy Sustainable Development 1994;1(4):239.," 1994.

[16] B. P., "Editorial. Energy Efficiency, 1(1), 1–3.," 2008.

[17] E. Boy, N. Bruce, K. R. Smith, and R. Hernandez, "Fuel efficiency of an improved wood-burning stove in rural Guatemala : implications for health , environment and development," *Energy Sustain. Dev.*, vol. 4, no. 2, pp. 23–31, 2000, doi: 10.1016/S0973-0826(08)60239-2.

[18] RETS, "Lists of Nepal Interim Benchmark for solid biomass Cook stoves," 2016. Accessed: May 25, 2019. [Online]. Available: http://www.retsnepal.org/uploads/file/20NIBC 2016 approved Cookstoves.pdf.

[19] A. Pundle, B. Sullivan, P. Means, J. D. Posner, and J. C. Kramlich, "Biomass and Bioenergy Predicting and analyzing the performance of biomass-burning natural draft rocket cookstoves using computational fluid dynamics," *Biomass and Bioenergy*, vol. 131, no. November, p. 105402, 2019, doi: 10.1016/j.biombioe.2019.105402.

[20] D. T. N. Shewangizaw W. Demissie, Venkata A.Ramayya, "Design, Fabrication and Testing of Biogas Stove for 'Areke' Distillation:The case of Arsi Negele, Ethiopia, Targeting Reduction of Fuel-Wood Dependence," *Int. J. Eng. Res. Technol.*, vol. 5, no. 3, pp. 354–365, 2016, [Online]. Available: http://www.ijert.org.

[21] P. Agarwal, A. Anand, and R. Gupta, "Performance Analysis of Conventional Lpg Cooking Stove," *Int. J. Appl. Bio-Engineering*, vol. 9, no. 1, pp. 15–19, 2015, doi: 10.18000/ijabeg.10127.

[22] M. Y. Khan and A. Saxena, "Performance Of LPG Cooking Stove Using Different Design Of Burner Heads," *Int. J. Eng. Res. Technol.*, vol. 2, no. 7, pp. 656–659, 2013.

[23] S. Villacís, J. Martínez, A. J. Riofrío, D. F. Carrión, M. A. Orozco, and D. Vaca, "Energy Efficiency Analysis of Different Materials for Cookware Commonly Used in Induction Cookers," *Energy Procedia*, vol. 75, no. September, pp. 925–930, 2015, doi: 10.1016/j.egypro.2015.07.252.