A Review on Design and Performance of Improved Biomass Cook Stoves

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Abstract. Nearly half of the world's population uses solid fuels for their domestic energy needs. Among those who use indoor cooking stoves, the poorest fam ilies living in rural areas most frequently use solid fuels. The use of indoor three stone fire cookers in rural areas of developing countries is known to be detrimental to the health of people. Hence, development of an improved biomass cook stove will be helpful for the betterment of people's lives especially women. This review presents results of studies carried out on improved biomass cook stoves. Traditional cook stove consumes high amount of resulting in higher health risks to people from higher carbon emissions. In order to avoid this health risk as well as reducing fuel consumption number of researchers in our countries could be design, develop and testing of a new improved cook stove. The discussion on the design of improved cook stoves was presented under different classifications with regarding to Air supply system, Fuel type, Operation, Number of pot and Construction material. In addition, results of experimental investigation done by various authors on the performance of cook stoves in terms of efficiency, burning rate, specific fuel consumption and power output is presented. Upon this parameter some of the researchers compare the traditional biomass cook stove with improved cook stove. From experimental test result the improved cook stoves are high performance than traditional stove.

Keywords: Biomass cook stove · Thermoelectric generator cook stove · Thermal efficiency

1 Introduction

Biomass cook stoves are commonly used for cooking and heating of food in rural households. A biomass cook stove is heated by burning wood, charcoal, animal dung or crop residue. So that nearly half of the world's population, approximately 3.5 billion people, uses biomass fuels for their domestic energy needs. Among those who use indoor cooking stoves, the poorest families living in rural areas most frequently use solid fuels, where it continues to be relied on by up to 90% of households [1]. In developing countries households consume significantly less energy than those in developed countries whereby over 50% of the energy is for food preparation purpose. The average rural family spends

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20% or more of its income on purchasing of wood or charcoal for cooking. In urban area also frequently spend a significant portion of their income on the purchase of wood or charcoal. Deforestation and erosion often result from harvesting wood for cooking fuel [2].

Biomass cook stove technology is increasingly being used to address the performance goals of reduction of harmful emission due to incomplete combustion and increasing thermal efficiency, thus reducing fuel consumption. The three stone fire cook stove is the most basic, but still extremely common method for cooking with biomass fuel, and is often used as a benchmark for comparison. The three stone fire cook stove is simply an open fire cook stove, gaining its name from the stones used to hold the cook piece over the fire. Improved biomass cook stoves have been able to reduce Carbone mono oxide and particulate matter emissions by 50–75% and increase the fuel efficiency by 30–50% compared to the three stone fire cook stove configuration [3]. These reductions were accomplished largely by enclosing the fire in a combustion chamber. The primary benefits of chamber enclosure are airflow control (providing better mixing with reduced quenching) and reduced convective and radiative heat transfer losses. The combustion chamber also allows the stove designer to locate the cook piece for reduced emissions and increased heat transfer.

This review paper mainly focused on design and improvement of biomass cook stove. There are a number of researchers that developed biomass cook stone in rural areas as well as in developing countries. As we know in this area people mainly children's are preparing food in traditional mechanism. The traditional mechanism of cooking was on a three-stone cooking fire or on a mud stove. The three-stone fire is the cheapest stove to produce and requiring only three suitable stones of the same height on which a cooking pot can be balanced over a fire. However, this cooking method is known to have the following problems: Biomass fuel smoke is vented into the home, instead of outdoors and also it causing health problems, Fuel is wasted, as heat is allowed to escape into the open air this requires the user to gather more fuel and may result in increased deforestation for wood is used for fuel, during food preparation, people especially women's uses only one cooking pot at a time, the use of an open fire creates a risk of burns and scalds.

Therefore, in order to avoid the above problems a number of researchers tried to develop improved cook stoves. Improved cook stoves are more efficient, which means the stove users spending less time for gathering fuel wood or other fuels, suffer less emphysema and other lung diseases prevalent in smoke filed homes, while reducing deforestation and air pollution.

2 Working Principle and Design Improvement of Cook Stove

Improved cook stove consists of chimney, a grate ash scrapper, combustion chamber and air jacket for flow of air in primary and secondary streams. The combustion air is preheated through the hot surfaces of the stove before it is drawn in to the stove either by natural drafts or forced draft during the burning of the various solid fuels. Improvement of a biomass cook stove done by Nandish et al. [1], Ayo et al. [2], Pavan et al. [4] and Amiebenomo et al. [5] were by design of combustion chamber, proper provision of insulation around the combustion chamber and providing sufficient air for

the combustion chamber. But their overall design structure and models were different from each other. Ayo et al. [2] and Amebomo et al. [5] constructed a proper pot sit and flu gas stack in order to reduce amount of Radiation heat loss and indoor air pollution with smoke emission.

According to their stove chimney construction Ayo et al. [2] constructed large chimney on the right side of the combustion chamber. Whereas Amebomo et al. [5] constructed the chimney at the top of the combustion chamber and its height was very short compared to Ayo et al. [2]. the construction of large chimney was important for reducing environmental pollution but it was not portable and bulky.

Nandish et al. [1] constructed the biomass cook stove without any flue gas stack (chimney) so during combustion process the carbon pollutes the environment. Srivastava et al. [3], Naher et al. [6] and Ezzati et al. [7] compared traditional Cook stove with improved cook stove, however the design improvement techniques they used were found to be widely different. Zongsha et al. [8] carried out experimental investigation in order to compare the thermal performance of improved cook stove with tradition cook stove and reported that the earlier is having a better performance than the latter. Srivastava et al. [3] compared the performance of improved three pot stove with traditional cook stove with his improved cook stove consisting of three pots (making cooking of three meals at once possible and saving cooking time as a result) while Zongsha et al. [8] presented results based on a single pot cook stove. A single pot cook stove was easy to construct, chip and portable compared to three pot cook stove and also its initial cost was cheap compared to three pot stove. The three-pot cook stove constructed in a fixed position and it could not be easily moving from one area to another. The improvement techniques reported in the work of [3, 9] was significant and easy to construct in developing countries.

Pavan et al. [4] claimed a significant heat saving and improved efficiency by incorporating smoke rings to seal the annulus between the pot and the pothole as well as by improving the design of the pot seat and the flue gas exit port position [4]. Amiebenomo et al. [5] also fabricate and evaluate the performance of an improved cook stove. In this study an increased heat transfer efficiency of the stove was claimed by providing a proper pot skirt around the combustion chamber and reducing heat loss [6]. Okafor et al. [9] presented a distinctive study by designing nozzle type improved cook stove whereby the shape of the stove seems like a nozzle. Mirt stoves are a good acceptance for Enjera baking so Dresen et al. [10] and Gizachew et al. [11] studied in detail about mirt stove on the carbon emission reduction as well as fuel wood saving and also, they discuss about the performance of improved cook stove in Ethiopia but Dresen et al. [10] studied in Afromontane forest of Ethiopia. In contrast Gizachew et al. [11] studied in bale eco region of Ethiopia. Risha et al. [12] and Champier et al. [13] studied about design, development and performance evaluation of thermoelectric generator integrated with forced draft cook stove. So, compared to other types of improved cook stove this type of cook stove were helpful for developing country as well as rural area. Because in rural area there is a shortage of electric power for charging mobile battery as well as lighting LED but thermoelectric generator cook stove technology avoid such problems and also it provides multi-functional purpose for rural areas. Inside the combustion chamber there was a high amount of heat, so by using TEG (Thermo electric generator)

in order to recover the waste heat. The aim of this thermo electric generator is converted heat energy in to electrical energy.

3 Advances in Cook Stoves

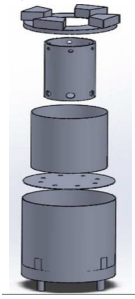
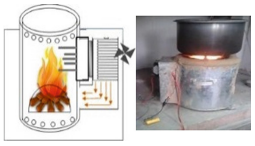
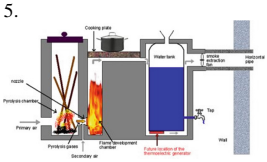
3.1 Thermoelectric Power Generation

Risha et al. [12], Perumal et al. [14], and Champier et al. [13] studied about thermo electric generator incorporates in a multi-functional wood stove but their cook stove arrangement as well as methodology were differed from each other. Risha et al. [12] and Perumal et al. [14] by using water boiling test in order to evaluate the performance of thermo electric generator. Among these two researcher Risha et al. [12] able to boil 6.1 kg of water in 30 min according to this parameter they could get the power generation of TEG 3 to 5 W. Perumal et al. [14] from water boiling test they can get 4.5 W and also the temperature difference of 2400 c. In contrast Champier et al. [13] cook stove compared to the above two researchers stove they developed a permanently installed stove integrated with thermo electric generator. In addition to this, they install the permanent water tank inside the cook stove so this improved cook stove was multi-functional purpose. Experimental test was done by on thermo electric and heat transfer of the model. So, during experimental test compare the electrical power and temperature using thermo electric and heat transfer equation because the performance of generator depends up on heat transfer through the model. This type of stove compared to other type of cook stove in terms of its maintenance cost as well as the total cost, it was more expensive but in terms of functionality it has multi- functional than other types of cook stoves. Champier et al. [13] produced TEG up to 9.5 W.

4 Types of Cook Stove

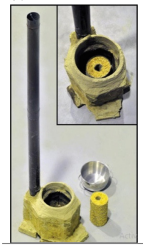
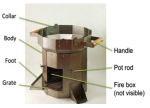
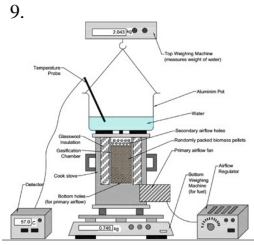
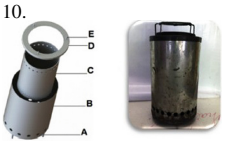
The different types of cook stoves could broadly be classified according to their operation, air supply, exhaust flow, portability, construction materials, fuel types and stove functions. In addition, the stoves could also be categorized as single and multi- pot, based on the number of pots of the stoves. A number of researchers developed new cook stoves and the others were improved the existing one by providing proper insulation around the combustion chamber, by using a proper construction material and by installed thermo electric generator around the cook stove in order to generate electricity for multi-functional purpose. The performance of improved biomass cook stove and traditional three stone cook stove were tested by using water boiling test, controlled cooking test and kitchen performance test So most researchers [3–5, 15–18, 20–23, 25, 26], conducted the performance of cook stove by using water boiling test. Burning rate, specific fuel consumption rate, efficiency and power output were parameters that estimate the performance of cook stove. Most of the studies [8, 11, 13, 19, 21, 23, 24, 27–30], reported the performance of cook stove using controlled cooking test. Reduced carbon emission and minimized fuel consumption are the primary parameters during experimental test. Aashish et al. [31] checked the performance of the improved cook stove using CFD software and temperature distribution along the layer (Table 1).

Table 1. Types of biomass cook stoves

Types of cook stove	Author	Title	Air supply mechanism	Construction material	Thermal efficiency (%)
1. 	Nandish et al. [1]	Performance enhancement of cook stove	Forced draft 12 V AC Fan	Combustion chamber ✓ refractory cement Outer body ✓ Galvanized iron sheet	23%
2. 	Pavan et al. [4]	Energy efficient wood stove	Forced draft 10 V AC Fan	Combustion chamber ✓ clay outside of the combustion chamber ✓ lined by fiber glass Outer body ✓ milled steel	22.27%
3. 	Dresen et al. [10]	Fuel wood saving and carbon emission reduced by the use of ICS in Afromontane forest, Ethiopia	Natural draft	The stove body made from cement and river sand	63%
4. 	Rishia et al. [12]	Design, development and performance evaluation of TEG integrated forced draft biomass cook stove	TEG integrated forced draft	Combustion chamber ✓ Glass wool TEG-sandwiched between the aluminum plate	Thermo electric generator produced 3 to 5 W
5. 	Champier et al. [13]	Study of TEG in corporate in a multifunctional wood stove	Forced draft	Combustion chamber ✓ ceramic The cooking pot and the fire does not directly contact	Thermo electric generator produced up to 9.5 W

(*continued*)

Table 1. (*continued*)

Types of cook stove	Author	Title	Air supply mechanism	Construction material	Thermal efficiency (%)
6. 	Panwar et al. [16]	Design and performance evaluation of 5kw producer gas stove	Natural draft	Combustion chamber ✓ Refractory cement Outer body ✓ milled steel	26.5%
7. 	Simone et al. [17]	Design and performance assessment of a rice husk fueled stove for house hold cooking in typical sub Saharan setting	Natural draft	The body of stove made from mud brick	18%
8. 	Wilson et al. [18]	Avoided emission of fuel efficient BMCS dwarf embodied emission	Natural draft	Outer body of stove made from -Milled steel sheet Fire box made from stainless steel	35%
9. 	Tanmay et al. [19]	Design of energy utilization test for a BMCS formulation of an optimum air flow recipe	Natural draft	Combustion chamber ✓ glass wool insulation Outer body ✓ milled steel	30%
10. 	Mohammadreza et al. [21]	Comparative evaluation of the performance of an improved biomass cookstove and traditional stoves of Iran	Natural draft	Each part of the cook stove made from metal sheet and consists of -cylinder leg -inner cylinder -outer cylinder -outer and inner cylinder coupling	35%

NB. The above all cook stoves could have uses wood as a fuel

5 Conclusions

From the above discussion, it can be concluded that there is a need to replace the traditional and inefficient biomass cooking devices with efficient cooking devices such as the improved and advanced biomass cook stove. Because traditional three stone cook stove follows different health hazard for people especially women during preparation of food as well as it increases environmental pollution. For this reason, in order to reduce this problem a number of researchers to design, developed and investigating a new improved cook stove for rural area of developing countries. In this paper the researcher's improvement techniques can be assessed in two ways. First, in most of the studies to design developed and testing of an improved biomass cook stoves with locally available material and also using different air supply mechanisms. During these improvement techniques all these researchers cannot take in to account wastage of heat on the combustion chamber. However, the other researchers to design and investigate the most fantastic technology for rural area of developing country by designing and recovering the west heat on the combustion chamber using thermo electric generator through the hot surfaces of the stove before it is drawn in to the stove either by natural drafts or forced draft during the burning of the various solid fuels.

6 Recommendation

Almost all researchers to design, developed and testing of small size biomass cook stove. for this reason, still now in developing country especially in Ethiopia almost all institutions like hotels, universities, hospitals and other institutions to prepare food using traditional three stone fire biomass cook stove. So, in order to reduce fuel consumption as well as environmental pollution, anyone who are initiate and expert to this technology to design and developed large size cook stove using locally available material.

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References

1. Nandish, G.: Performance enhancement of cook stove. Int. J. Renew. Energy Environ. Eng. **3**, 95–98 (2015)
2. Samuel, A.A.: Design, construction and testing of an improved wood stove. AU J.T. **13**(1), 12–18 (2009)
3. Joshi, M., Srivastava, R.K.: Development and performance evaluation of an improved three pot cook stove for cooking in rural Uttarakhand, India. Int. J. Adv. Res. **1**, 596–602 (2013)
4. Pavan, H.: Energy efficient wood stove, aloysius Fernandez. Int. J. Eng. Innov. Res. **5**(4), 260–263 (2016)

5. Amiebenomo, S.O.: Fabrication and performance evaluation of an improved biomass cook stove. Int. J. Eng. Res. Technol. (IJERT) **2**(3), 1–9 (2013)
6. Brauer, M., Naeher, M., Lipsett, L.P., Zelikoff, J.T., Simpson, C.D., Koenig, J.Q.: Wood smoke health effects a review. Inhalation Toxicol. **19**, 67–106 (2007)
7. Lopez, A.D., Ezzati, M., Rodgers, A., Vander, H.S., Murray, C.J.: Selected major risk factors and global and regional burden of disease. Lancet **360**, 1347–1360 (2002)
8. Duanmu, L., Wang, Z., Yuan, P., Ning, M., Liu, Y.: Experimental study of thermal performance comparison based on the traditional and multifunctional biomass stoves in China. Procedia Eng. **121**, 845–853 (2015)
9. Okafor, I.F., Unachukwu, G.O.: Performance evaluation of nozzle type improved wood cook stove. Int. J. Sci. Eng. Res. **4**, 1195–1204 (2013)
10. Dresen, E.: Fuelwood savings and carbon emission reductions by the use of improved cooking stoves in an Afromontane Forest, Ethiopia. Land **3**, 1137–1157 (2014)
11. Tolera, M., Gizachew, B.: Adoption and kitchen performance test of improved cook stove in the Bale Eco-Region of Ethiopia. Energy. Sustain. Dev. **45**, 186–189 (2018)
12. Prasad, R., Mala, R., Vijayc, V.K., Vermad, A.R.: The design, development and performance evaluation of thermoelectric generator (TEG) integrated forced draft biomass cookstove. Procedia Comput. Sci. **52**, 723–729 (2015)
13. Champier, D.: Study of a TE (thermoelectric) generator incorporated in a multifunction wood stove. Energy **36**, 1518–1526 (2011)
14. Ram, N.K., Raman, P., Gupta, R.: Development, design and performance analysis of a forced draft clean combustion cookstove powered by a thermo electric generator with multi-utility options. Energy **69**, 813–825 (2014)
15. Rathod, A.P., Motghare, K.A.: Performance Evaluation and Heat transfer studies on Biomass Gasifier cook-stove. Int. J. Appl. Innov. Eng. Manag. (IJAIEM) **4**(5), 353–361 (2015)
16. Panwar, N.L., Rathore, N.S.: Design and performance evaluation of a 5kW producer gas stove. Biomass Bioenerg. **32**, 1349–1352 (2008)
17. Parmigiani, S.P., Vitali, F., Lezzi, A.M., Vaccari, M.: Design and performance assessment of a rice husk fueled stove for household cooking in a typical sub-Saharan setting. Energy. Sustain. Dev. **23**, 15–24 (2014)
18. Wilson, D.L.: Avoided emissions of a fuel-efficient biomass cookstove dwarf embodied emissions. Dev. Eng. **1**, 45–52 (2016)
19. Jain, Tanmay, Sheth, P.N.: Design of energy utilization test for a biomass cook stove: Formulation of an optimum air flow recipe. Energy **166**, 1097–1105 (2019)
20. Paulsen, A.D., Kunsa, T.A., Carpenter, A.L.: Gaseous and particulate emissions from a chimneyless biomass cookstove equipped with a potassium catalyst. Appl. Energy **235**, 369–378 (2019)
21. Amare, D., Endeblhatu, A., Muhabaw, A.: Enhancing biomass energy efficiency in rural households of Ethiopia. J. Energy Nat. Resour. **4**(2), 27–33 (2015)
22. Panwar, N.L., Mehetre, S.A., Sharma, D., Kumar, H.: Improved biomass cookstoves for sustainable development a review. Renew. Sustain. Energy Rev. **73**, 672–687 (2017)
23. Murali, J., Raman, P., Sakthivadivel, D., Vigneswaran, V.S.: Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut shell. Biomass and Bio Energy **49**, 333–340 (2013)
24. Ochieng, C.A., Tonne, C., Vardoulakis, S.: A comparison of fuel use between a low cost, improved wood stove and traditional three-stone stove in rural Kenya. Biomass Bio Energy **58**, 258–266 (2013)
25. Ram, N.P., Kaushik, S.C., Jain, S.K.: Transient heat transfer for liquid boiling with a cookstove: a start of art. Chang Village **6**(6), 411–421 (1984)
26. Rowe, D.M., Nuwayhid, R.Y., Min, G.: Low cost stove-top thermoelectric generator for regions with unreliable electricity supply. Renewable Energy **28**, 205–222 (2003)

27. Vitali, F., Parmigiani, S.: Agricultural waste as household fuel: Techno-economic assessment of a new rice-husk cookstove for developing countries. Waste Manag. **33**, 2762–2770 (2013)
28. Still, D.K., et al.: Laboratory experiments regarding the use of filtration and retained heat to reduce particulate matter emissions from biomass cooking. Energy. Sustain. Dev. **42**, 129–135 (2018)
29. Singh, V.K., Suresh, R., Malik, J.K., Datta, A., Pal, R.C.: Evaluation of the performance of improved biomass cooking stoves with different solid biomass fuel types. Biomass Bioenergy **95**, 27–34 (2016)
30. Li, H., Huangfu, Y., Chen, X., Xue, C., Chen, C., Liu, G.: Effects of moisture content in fuel on thermal performance and emission of biomass semi- gasified cookstove. Energy. Sustain. Dev. **21**, 60–65 (2014)
31. Nagarhalli, M., Gandigudea, A.: Simulation of rocket cook-stove geometrical aspect for its performance improvement. Mater. Today **5**, 3903–3908 (2018)