Design and Optimization of Continuous Type Rice Husk Gas Stove

Bimrew Tamrat(✉), Bisrat Yilma, and Million Asfaw

Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
betselotbim@gmail.com, bisratyilma20@gmail.com, milliyardo@gmail.com

Abstract. Most of the people especially in rural areas of Ethiopia have been using charcoal, firewood and animal dung for many years. Due to these, women can be affected for different respiratory diseases. The country generates huge tonnes of rice husks at different locations. The main aim of this project was to design, manufacture and optimize the continues type rice husk gasifier which will be an efficient and convenient cooking device that produce gaseous flame using rice husk as a fuel Water Boiling Test (WBT) was performed to evaluate the performance of the gasifier stove. The indoor air quality was also tested using indoor air pollution meter. The power source specially to drive the fan was solar photovoltaic (PV). For different inlet air flow rates, WBT was checked. Air flow rate having 6.51 m^3/s delivers better performance of the gasifier. The newly designed model delivers the maximum particulate concentration of 229 $\mu g/m^3$ and the highest CO concentration of 3.8 ppm, and average PM concentration and CO concentrations are 63 $\mu g/m^3$ and 0.42 ppm, respectively. T he thermal efficiency of the gasifier for different in let air flow rates 8.94 m^3/s, 7.74 m^3/s and 6.51 m^3/s were checked and he result comes 36%, 30% and 45%, respectively. The specific fuel consumption for the above-mentioned inlet air flow rates in g/L were 153, 234 and 169, respectively.

Keywords: Gasifier · Air flow rate · Indoor air quality · PV power · Water boiling test

1 Introduction

Biomass fuels continue to play an essential role in domestic for cooking purpose in most of developing countries like Ethiopia an agriculturally based economy and fuel wood is often a major fraction of the total biomass use [1]. Biomass energy also plays a significant role for reduction of green house at the global level and keeping the eco-system clean when it is used in sustainable and efficient manner [2]. However, the majority of households in Ethiopia are using traditional biomass for cooking by traditional and inefficient stoves. Burning of these biomass fuels using inefficient stoves emits harmful

N. G. Habtu et al. (Eds.): ICAST 2019, LNICST 308, pp. 623–633, 2020.
https://doi.org/10.1007/978-3-030-43690-2_47

chemicals and large amounts of particulates. The most common method of cooking in the developing countries including Ethiopia, particularly in the rural areas is an open fire stove as shown in Fig. 1.

Fig. 1. Traditional three stone baking system [9].

Also there is an excessive dependency on only biomass energy due to lack of electric energy sources; this leads to an excessive deforestation and land degradation. Due to this reason, it is very important to search for effective technology for utilization of the biomass energy. The goals of the present project are: to ensure an efficient and user-friendly gasifier product for the users, to replace some of the total fuel wood consumption and thereby to decrease the deforestation and to create a good indoor air ventilation condition.

The highest total exposure too many air pollutants can occur in the rural homes of developing countries where biomass fuel forms the principal energy source for cooking and space heating [1]. Respiratory diseases are linked with poor air quality and lack of proper ventilation. According to a Federal Ministry of Health (FMoH) report it is found that the top ten causes of morbidity in cases of acute upper Respiratory Infections occurred during the 2003 E.C. (2010/11 G.C), which is linked with air pollution. A similar number of pneumonia cases (5%) were also reported during the same period, accounting for 7% of hospital admissions. Moreover, 2% of admissions were due to tuberculosis [6].

Evaluating the efficiency and emission performance is an upright way to compare one fuel stove with another [8]. Water boiling test is commonly utilized in laboratory emission measurement; the detailed procedure varies with various protocols [10].

Gasification is the process that converts carbon containing feedstock into carbon monoxide, hydrogen and carbon dioxide achieved by oxidation the material is kept at high temperature with controlled amount of oxygen. As it is seen from Fig. 2, rice husk can be an energy source in different forms. It can be used to generate fuel, heat, or electricity through thermal, chemical, or bioprocesses. It contains about 30–50% of organic carbon and has high heating value of 13–16 MJ/kg. It has a moisture content of 8 to 10% by weight.

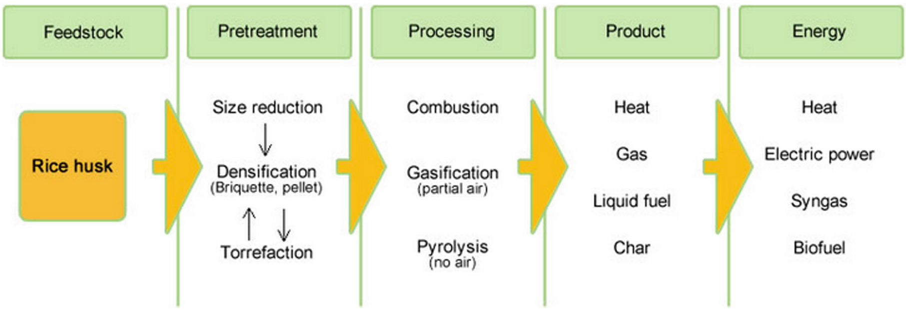

Fig. 2. The energy conversion processes of rice husk [11].

Compared to the traditional cooking stoves, the gasifier stoves are not only fuel efficient but also emission efficient. Owing to their low efficiency, the traditional cook stoves emit more than 10% of their carbon as products of incomplete combustion. In addition, even if, it varies by the type of wood, about 100–180 g of carbon monoxide and 7.8 g of particulate matter are also emitted per kg of used wood. Gases such as methane, total non-methane organic compounds and N_2O are added to this [13].

Nepal Academy of Science and Technology have developed a briquette gasifier stove by adopting the design done by Asian Institute of Technology, Thailand [14]. But this stove is bulky in size and high cost of fabrication for domestic cooking for low income people. The general objective of this paper is to design, develop and optimize to provide low income households an efficient and convenient cooking device that produced gaseous flame using rice husk as fuel.

Rice Husk Gasifier Working Principle

Gasification of rice husks is accomplished in an air sealed chamber which is the reactor. Restricted amount of air is introduced by a fan into the reactor to convert rice husks into high carbon contained char so that by a chemical reaction, it will produce carbon monoxide, hydrogen, and methane gases, which are combustible when ignition is occurred. The fan is driven by the power which is generated from solar photovoltaic power generation system.

Fundamentally, the gas produced during gasification is composed of: carbon monoxide, hydrogen, methane, carbon dioxide, and water vapor. The gasification and the reactions of gases during the process are illustrated below.

$$\text{Combustion}\quad C + O_2 = CO_2 \tag{1}$$

$$\text{Water gas}\quad C + H_2O = CO + H_2 \tag{2}$$

$$\text{Water shift reaction}\quad CO + H_2O = CO_2 + H_2 \tag{3}$$

$$\text{Bounded reaction} \quad C + CO_2 = 2CO \tag{4}$$

$$\text{Methane reaction} \quad C + 2H_2 = CH_4 \tag{5}$$

2 Materials and Methods

The constructed gasifier stove design specification is based on knowledge obtained from field study, literature review and theoretical calculations which are meeting with the needs or requirements of the user nearby Bahir Dar city. The gasifier stove is considered to meet the energy requirement for cooking of average size of 5 family (Fig. 3).

Fig. 3. Gasifier stove while construction.

Laboratory based tests were considered to construct gasifier stove which give an enhanced performance in a controlled environment. The water-boiling test is one of the tests performed under controlled conditions at stove testing room to measure performance metrics of the gasifier such as, time to boil water, thermal efficiency, Specific fuel consumption, and firepower. Water boiling test is a useful tool in the process of cook stove development and to compare different stoves.

A measured amount of same type rice husk of having 700 g was weighed out for each series of tests. The pot and lid weighed, and then a measured amount of water having 1000 g was poured to the pot and weighed again to determine the weight of the water. The weighed rice husk was set into the reactor/combustion chamber and a piece of fired paper is used for ignition. The pot was placed on the gasifier, and the time, the ambient temperature and the initial temperature of the water were recorded using temperature measuring thermocouple. The temperature of the water inside the pan was recorded at an intervals of 20 s until the water reaches the boiling point. The final weight of the remaining water, bio-char, and the final temperature of water were measured and recorded. Repeated tests were conducted in different times with same procedure with different air flow rate to the reactor by controlling the air flow using fan speed controller to know the air-fuel ration that can deliver better and an optimized result. Since air-fuel ratio is one of the major parameters which can affect the gasification process.

Variables that are Directly Measured

f_{hi} Weight of fuel before test (grams)
P_{hi} Weight of pot with water before test
T_{hi} Water temperature before test (ºC)
t_{hi} Time at start of test (min)
C_h Weight of charcoal and container after test (grams)
p_{hf} Weight of pot with water after test (grams)
T_{hf} Water temperature after test (ºC)
t_{hf} Time at end of test (min)

Variables that are Calculated [16]

Temperature adjusted time to boil the water

$$\Delta t_h^T = \left(t_{hf} - t_{hi}\right) \times \frac{75}{(T_{hf} - T_{hi})} \tag{6}$$

Thermal efficiency of the system

$$h_h = \frac{4.186 \times (p_{hi} - p) \times \left(T_{hf} - T_{hi}\right) + 2260(w_{hv})}{f_{hd} \times LHV} \tag{7}$$

Burning rate (grams/min)

$$r_{hb} = \frac{f_{hd}}{t_{hi} - t_{hf}} \tag{8}$$

Specific fuel consumption (grams/grams water)

$$sc_h = \frac{f_{hd}}{p_{hf} - p} \tag{9}$$

Temperature corrected specific consumption

$$sc_h^T = \frac{f_{hd}}{p_{hf} - p} \times \frac{75}{(T_{hf} - T_{hi})} \tag{10}$$

Firepower (W) can be calculated as:

$$FP_h = \frac{f_{hd} \times LHV}{60 \times (t_{hi} - t_{hf})} \tag{11}$$

Where, LHV is net lower calorific value in MJ/kg, P is dry weight of empty pot (grams), w_{hv} Water vaporized (grams) during boiling test, f_{hd} is equivalent rice husk consumed in grams.

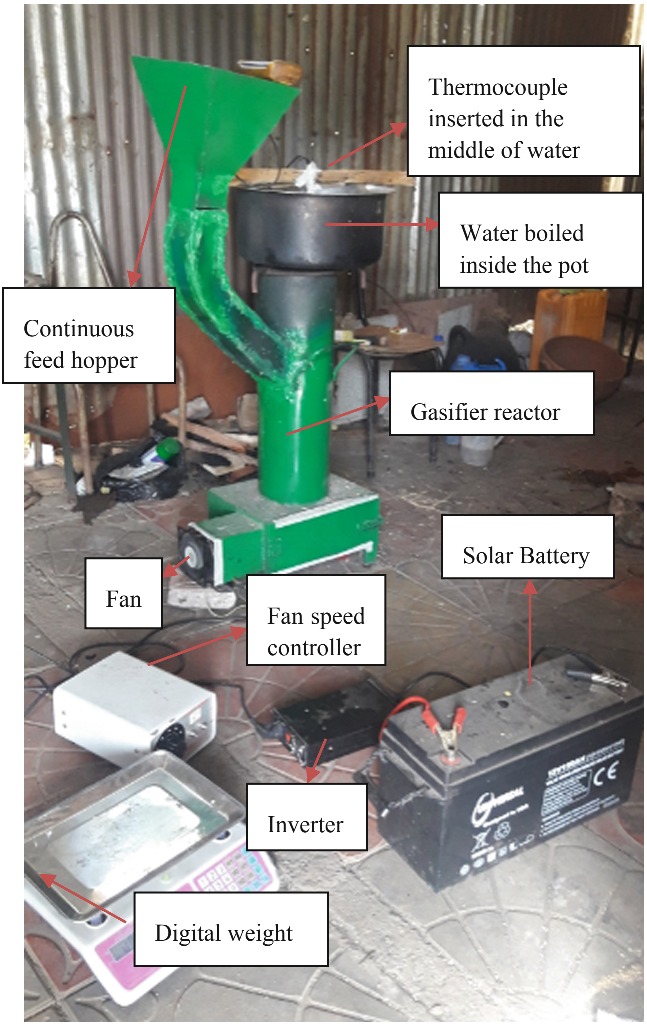

Fig. 4. Water boiling test set-up

The fan is powered by 100 W photovoltaic solar panel which absorbs sunlight as a source of energy since the majorities of rural communities in Ethiopia have low access to electrical energy (Fig. 4).

Beside the water boiling test, emission tests were also performed to measure the indoor air quality using a portable indoor air pollution meter (Figs. 5 and 6).

Fig. 5. A photovoltaic (PV) module.

Fig. 6. Indoor air pollution meter (b)

3 Result and Discussion

Figure (7) shows water boiling test results for different inlet air flow rate. It is observed from the figure, for different air flow rates, the rate of temperature rising varies. Up to 66 °C of water temperature rising, air flow rate having a value 7.74 m^3/s gives better output than the other two inlet air flow rates. This might be due to high production of methane gas for this specific air flow rate. From 67 °C up to the boiling point of water (94.2 °C), 8.94 m^3/s, 7.74 m^3/s and 6.51 m^3/s inlet air flow rates delivers better temperature rising of water with time on the order set in the above. After reaching boiling temperature of water, all the air flow rates gave constant temperature which is at phase change stage.

The moisture content and the freshness of rice husk have impact on the gasification process. The test show the gasification process for rice husk having a year old and moisture content of 10% of the total weight of the rice husk, it was not possible to get the gasification process simpler. When use fresh and a moisture content of about 6% from the total weight of the rice husk get much better gasification process.

Three different tests having the same amount of input energy that is 0.7 kg of rice husk, the same volume of water which is 1 L and the same initial ambient and water temperature 28.5 °C, and 26 °C were performed. The air flow rate which is important for partial burning (pyrolysis) was used. From Table 1 the efficiency of the stove is found 45% for the system operated with 6.51 m^3/s of air flow rate. For this case the total temperature-corrected time taken to get the water boiled is 19 min and the burning rate is 8 g/min, specific fuel consumption 169 g/L. The fire power from this test is found 1788 W. The thermal efficiency of the constructed rice husk gasifier stove for 8.94 m^3/s air flow rate is 36% is less than the efficiency of the system having 6.51 m^3/s inlet air flow rate but greater than with the system having air flow rate of 7.74 m^3/s (30%

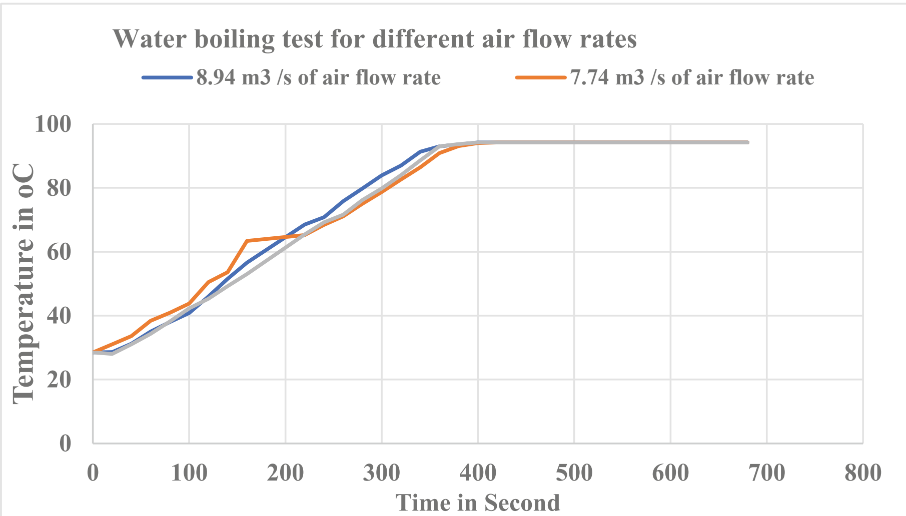

Fig. 7. Water boiling test for different air flow rates.

Table 1. Water boiling test results

High power test	Units	Test 1	Test 2	Test 3
Time to get the water boiled	Minutes	16	15	17
Temp-corrected time to boil	Minutes	18	16	19
Burning rate of the rice husk	g/Minutes	8	12	8
Thermal efficiency of the system	%	36%	30%	45%
Specific fuel consumption of the stove	g/liter	153	234	169
Temp-corrected specific consumption	g/liter	168	256	185
Temp-corrected specific energy cons.	kJ/liter	2,381	3,640	2,632
Firepower	Watts	1,900	2,895	1,788

Table 2. Water boiling test results

Average PM concentration	63	$\mu g/m^3$
Average CO concentration	0.42	ppm
Highest PM concentration	229	$\mu g/m^3$
Highest CO concentration	3.8	ppm

efficiency). The reason is sufficient oxygen is supplied to burn the fuel completely, rather than becoming partial burning of the fuel (pyrolysis), it becomes complete combustion and methane gas might not be generated. The constructed gasifier which is not gives flame for 4.78 m^3/s inlet air flow rate. The supplied air is not sufficient to achieve even partial burning of the fuel and found very dense smoke. From this investigation it is found that the optimum air flow rate to get better output to be given by the constructed rice husk gasifier stove.

Figure 8 show the emission that is the particulate matter (PM) and carbon monoxide (CO) concentration test results of water boiling test by using the designed rise husk gasifies stove for the three air flow amounts 8.94 m^3/s, 7.74 m^3/s and 6.51 m^3/s), mass of fuel of 0.7 kg. From Fig. 8 and Table 2, the maximum particulate matter concentration is 229 $\mu g/m^3$ and the highest CO concentration is 3.8 ppm. The average PM concentration and CO concentrations are 63 $\mu g/m^3$ and 0.42 ppm, respectively. From the existing literature, the indoor air quality which is the PM and CO of the three stone stove cooking system is 3300 $\mu g/m^3$ and 23.5 ppm [16, 17] and the improved modern stove emission test results show that the PM and CO concentration are 1520 $\mu g/m^3$ and 20.5 ppm, respectively. From the experimental emission test results, it is possible to give witness that using rice husk gasifier for cooking purpose gives better indoor air qualities than three stone stove and modern cooking stoves.

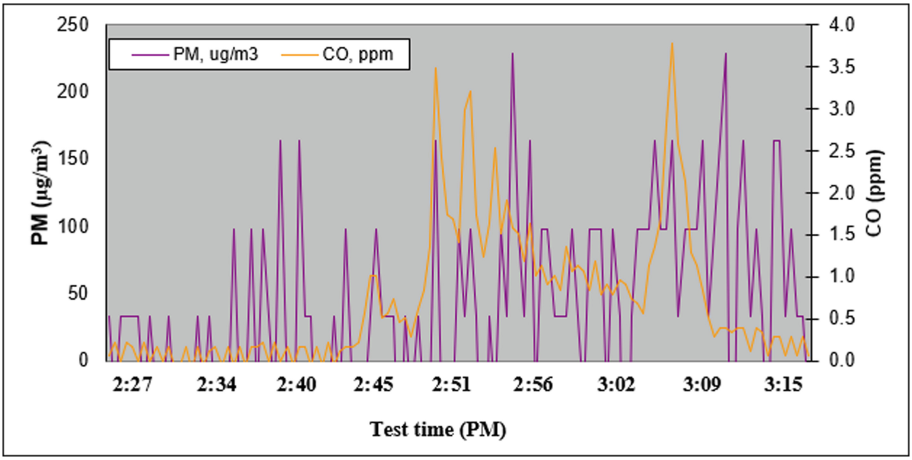

Fig. 8. Carbon monoxide and particulate matter concentration in the testing room.

4 Conclusion

Rice husks brought directly from rice mill or storage area has moisture content. When experiment on gasification is performed, the moisture content is better to reduce at least at the level of 6%. It is possible to reduce the moisture content by open sun drying mechanism or use oven. The freshness of the rice husk has also its own impact on the gasification process as well.

Parameters used to test the designed gasifier were 0.7 kg of rice husk, a litter of water, PV power source to drive the fan, water boiling pan. With the same parameters, input air flow rate of 6.513/s delvers better thermal efficiency (46%) than the other two input air flow rates (8.94 m^3/s and 7.74 m^3/s). The indoor air quality of the gasification is also tested and found much better than the three stone stove (particulate matter of 3300 $\mu g/m^3$ and CO concentration 23.5 ppm) and modern stove cooking mechanisms (particulate matter of 1520 $\mu g/m^3$ and CO concentration of 20.5 ppm). The maximum and the average PM obtained were 229 $\mu g/m^3$ and 63 $\mu g/m^3$ respectively. The maximum and average CO concentration of the test were 3.8 ppm and 0.42 ppm, respectively.

References

1. WHO Household air pollution and health.htm
2. Impact Assessment of Mirt Improved Biomass Injera Stoves Commercialization in Tigray, Amhara and Oromiya National Regional States. Prepared by: MEGEN POWER Ltd. Submitted to: The MoARD/GTZ SUN Energy Programme
3. Guta, D.D.: Assessment of biomass fuel resource potential and utilization in Ethiopia: sourcing strategies for renewable energies. Int. J. Renew. Energy Res. **2**(1), 134–136 (2012)
4. Hammed Suleiman, B.D., Asfaw, A.: Household fuel use and acute respiratory infections among younger children: an exposure assessment in Shebedino Wereda Southern Ethiopia. Afr. J. Health Sci. **18**(2), 32–33 (2011)

5. Njong, M., Johannes, T.A.: An analysis of domestic cooking energy choices in Cameroon. Eur. J. Soc. Sci. **20**(2), 25–36 (2011)
6. Energy Sector Management Assistance Program (ESMAP), Strategy to Alleviate the Pressure of Fuel Demand on National Wood fuel Resources, Haiti (2007)
7. KEY FINDINGS ON THE 2013 NATIONAL LABOUR FORCE SURVEY (CSA, 2013). file:///E:/KEY%20FINDINGS%20ON%20THE%202013%20NATIONAL%20LABOUR%20FORCE%20SURVEY.pdf
8. International year of rice (2004). http://www.fao.org/rice2004/en/rice-us.htm
9. Jetter, J., et al.: Pollutant emissions and energy efficiency under controlled conditions for household biomass cook stoves and implications for metrics useful in setting international test standards. Environ. Sci. Technol. **46**, 10827–10834 (2012)
10. https://energypedia.info/wiki/Firewood_Cookstoves
11. Arora, P., Das, P., Jain, S., Kishore, V.V.: A laboratory based comparative study of Indian biomass cookstove testing protocol and Water Boiling Test. Energy Sustain. Dev. **21**, 81–88 (2014)
12. http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-husk/using-rice-husk-for-energy-production. Accessed Feb 2019
13. Anderson, P.S.: TLUD Handbook. Mc-Graw Hill, New York (2010)
14. Grover, P.D.: Cost Estimates for a 'Dream Stove' for Asia (2003). http://www.ikweb.com/enuff/public_html/Dream/Paper-grover.htm
15. Singh, R.M., Shakya, G.R.: Study of the biomass briquetting system and cooking devices, a regional research and dissemination program phase II. Asian Institute of Technology (AIT), Bangkok, Thailand (2001)
16. Le, D.D., Do, D.T., Zwebe, D., Nguyen, M.H.: Rice husk gasifier stove performance testing report, August 2013
17. Singh, A., Tuladhar, B., Bajracharya, K., Pillarisetti, A.: Assessment of effectiveness of improved cook stoves in reducing indoor air pollution and improving health in Nepal. Energy. Sustain. Dev. **16**, 406–414 (2012). https://doi.org/10.1016/j.esd.2012.09.004
18. Hankey, S., et al.: Using objective measures of stove use and indoor air quality to evaluate a cookstove intervention in rural Uganda. Energy Sustain. Dev. **25**, 67–74 (2015). (particulate matter)