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Research article

Performance and emission reduction potential of micro-gasifier improved through better design

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Abstract: Biomass gasification is getting popular for household cooking application in most developing countries including Ethiopia. The preference for biomass gasification is due to the generation of less CO (Carbon Monoxide) and PM (Particulate Matter) in comparison with other biomass cookstoves. Our study showed the improvement in thermal efficiency and emission reduction potential of micro-gasifier. A prototype micro-gasifier was built and tested using the water boiling test protocol. The test results gave a thermal efficiency of 39.6% and a specific fuel consumption of 57 g of fuel/ liter of water. With regard to indoor air pollution, the maximum CO & PM registered were 12.5 ppm and 1.85 mg/m^3, respectively. Using clean development mechanism (CDM) methodology, the estimated emission reduction potential of the micro-gasifier is 1.30 tCO_2 per micro-gasifier per year. Generally, the micro-gasifier has better performance compared to the previous designs proposed by other researchers. Thus, disseminating our micro-gasifier at a larger scale in developing countries such as Ethiopia will be beneficial in reducing deforestation and emission that will be brought about by using open-fire stoves and thus, helps to obtain carbon credit.

Keywords: micro-gasifier; gasifier stove; biomass; performance evaluation; indoor air pollution; greenhouse gas

Abbreviations and Acronyms

AAiT	Addis Ababa Institute of Technology
AIT	Asian Institute of Technology
ASTM	American Society of Testing and Materials
CDM	Clean Development Mechanism
CO	Carbon Monoxide

ER	Emission Reduction
FCR	Fuel Consumption Rate
GHG	Greenhouse Gas
GTP	Growth and Transformation Plan
PM	Particulate Matter
SFC	Specific Fuel Consumption
SGR	Specific Gasification Rate
UNFCCC	United Nation Framework for Climate Change Convention
WBT	Water Boiling Test
WHO	World Health Organization
$B_{old,capita}$	Average baseline fuel wood consumption in tones per capita per year
$HC_{fuelwood,usage,y}$	Host country national fuel wood consumption in tones per year y
$B_{y,device}$	Average annual consumption of woody biomass per appliance in tones per year
$FW_{proportion}$	Proportion of household fuel wood consumed by micro-gasifier
$ER_{y,micro-gasifier}$	Emission reductions by project device during year y in tCO_{2e} (tones of CO_2 equivalent)
$f_{NRB,y}$	Fraction of woody biomass saved by the project activity in year y that can be established as non-renewable biomass using default country specific fraction of non-renewable woody biomass
$NCV_{biomass}$	Net calorific value of the non-renewable woody biomass that is substituted
$EF_{projected\_fossilfuel}$	Emission factor for the substitution of non-renewable woody biomass by similar consumers
$N_{y,micro-gasifier}$	Number of project devices of type i=1 operating in year y

1. Introduction

In developing countries, 50% of the population depends on traditional use of biomass. More specifically, in Sub-Saharan Africa, around 753 million people (i.e. 80 percent of the population) use biomass as energy source. And 95 percent of the population living in Ethiopia uses biomass energy for household activities as well [1]. This will likely to continue in the future [2]. In developing countries, traditional biomass stoves are inefficient and are causing indoor air pollution. In order to curb this problem, gasifier stoves are becoming popular. The only improved biomass cookstove selected for dissemination in Ethiopia is *Tikikil* which has a thermal efficiency of 28% [3]. This cookstove saved on average 1.07 tons of CO_2 per stove where it is used in *kaficho* zone, Ethiopia [4].

Biomass gasification is considered as the future concept for cookstoves which are mostly forced type [5]. Currently, the number of patents obtained by companies for small-scale gasifiers are relatively low [6]. Reed and Larson [7] initiated the concept of gasification of wood gas stoves for cooking applications and the test result showed better performance in indoor air pollution and efficiency. Later on, a natural draft cross-flow gasifier tested at AIT (Asian Institute of Technology) also showed a thermal efficiency of 27% [8]. Other authors also reported a thermal efficiency of 26.5% and 35% with CO (3–6 ppm) and CO_2 (17–25 ppm) for gasifier stoves [9,10]. Dixit, et al. [11] has also reported a thermal efficiency of 37%.Mukunda, et al. [12] stated that forced draft gasifier stoves reached thermal efficiency of up to 50%. A number of efforts are underway to compare empirical result with computational models for gasifier stoves and generally, the results showed reasonable approximation between the two [13]. However, to increase the thermal efficiency and reduce the indoor air pollution remains to be researched. As a result, bringing a more efficient and less polluting gasifier stoves remain to be a challenge for researchers. In light of this, the objective of this study was to evaluate the performance of a micro-gasifier using woody biomass and compare its advantage in terms of indoor air pollution and generation of carbon credit.

2. Materials and Method

2.1. Type of stove and materials for manufacturing

A gasifier stove as is shown in Figure 1 has been developed at AAiT (Addis Ababa Institute of Technology- Ethiopia). its primary air inlet consists of four holes with a diameter of 30 mm at 90^0 apart on the outer casing and 12 holes with a diameter of 4 mm at the bottom of the inner cylinder. The secondary air is used for combusting the gases produced from pyrolysis of the biomass. For doing this, there are 6 holes with a diameter of 4 mm at the top of the central pipe.

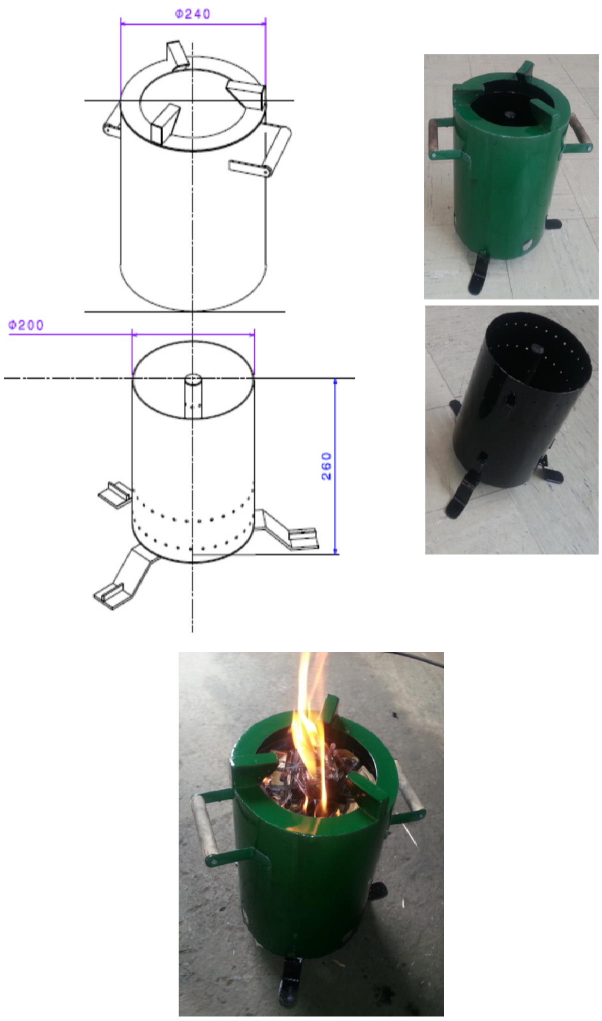

Figure 1. Micro-gasifier.

Most parts of the micro-gasifier such as: reactor*, outer casing, bottom cover and central pipe* were made of mild steel with a thickness of 1.5 mm. The handle is the only part which is made of wood.

2.2. Fuel used for testing

The type of fuel used for conducting the laboratory test was Eucalyptus tree which is commonly used in most part of Ethiopia. Proximate analysis was conducted to analyze the feed stock characteristics. The feed stock characteristics were, moisture content (ASTM D3173-73), volatile matter (ASTM D3175-73) and ash content (ASTM D3174-73). Fixed carbon (FC) was also determined using material balance. Physical and thermal properties of the biomass are shown in Table 1.

Table 1. Physical and thermal properties of eucalyptus tree as feed stock.

Characteristics	Biomass (Eucalyptus Tree)
Size (mm)	15–20
Length (mm)	30–50
Dry density (kg m^{-3})	480
Moisture content(% wb)	5.64
Volatile matter (% db)	80.81
Ash content (%db)	54
Fixed carbon (%db)	13.02
Calorific value (MJ kg^{-1})	18.64

2.3. Design of Micro-gasifier

To manufacture the micro-gasifier, it requires mild steel sheet metal with a thickness of 1.5 mm. The micro-gasifier was manufactured to be aesthetically appealing to the users. User satisfaction is one of the parameters used to evaluate stove acceptability at community level.

The design procedure outlined in [14] was used to come up with the major parameters required for drafting and manufacturing the gasifier stove. This includes *Energy Input, Reactor Diameter, and Height of reactor.*

Energy required for cooking (Energy demand): This refers to the amount of energy need for cooking of a kg of rice[1]. It can be computed by knowing the type of food to be cooked, the specific energy ($E_s = 331.8\ kJ/kg$) and the time required ($T = 15$ min) for cooking.

$$Q_n = \frac{M_f x\ E_s}{T} = 0.369 \text{ kW} \qquad (1)$$

Energy input for cooking (Energy input): This is the amount of energy required for cooking and to be supplied for the heating application. The calorific value of the fuel is 18.64 MJ/kg. Assuming a stove efficiency of 17%, the fuel consumption rate of the fuel can be computed as follows:

[1] *Assuming most cooking foods in Ethiopia resemble rice.*

$$FCR = \frac{Q_n}{(HV_f)(\xi_g)} = 0.419 \text{ kg/hr} \quad (2)$$

Reactor Diameter: It is a major parameter of the micro-gasifier. It is the diameter of the reactor which is obtained by the ratio of FCR to SGR. Assuming FCR to be 2 kg/hr and SGR to be 120 kg/m^{2}hr, the reactor diameter is calculated by the following formula.

$$D = \sqrt{\frac{1.27\, FCR}{SGR}} = 145 \text{ mm} \quad (3)$$

Hence, the diameter of the reactor is assumed to be 200 mm for this particular case in order to accommodate the variation of cooking habits throughout the country.

Reactor Height: This is the overall height of the reaction chamber. This dimension indicates the loading capacity of the reactor. It is calculated based on $\rho_a = 100kg/m^3$.

$$H = \frac{SGRxT}{\rho_a} = 300 \text{ mm} \quad (4)$$

For this particular test, the height is reduced to 260 mm to compensate the increase in diameter.

2.4. Performance evaluation methods

The laboratory test performed to evaluate the stove performance was based on a revised version of the Water Boiling Test Protocol [15].

Thermal Efficiency: The amount of heat gained by the water inside the pot and evaporated compared to the energy of the fuel used for heating. The value for the efficiency can be computed based on the following equation:

$$\eta_{th} = \frac{m_w * C_p * (T_f - T_i) + m_{ev} * h_{fg.w}}{m_f * LHV_f} \quad (5)$$

Burning rate: The rate of fuel consumption during which the water gets boiled. It is calculated by dividing the equivalent dry fuel consumed by the time of the test.

$$r_{cb} = \frac{f_{cd}}{\Delta t_c} \quad (6)$$

Specific fuel consumption: The amount of fuel consumed per unit mass of boiled water. It is calculated based on the following formula

$$SFC = \frac{f_{cd}}{m_w} \quad (7)$$

Fire power: This is the fuel energy consumed to boil the water divided by the time to boil. It tells the average power output of the stove (in Watts) during the high-power test.

2.5. Instrumentation for measurement

Figure 2 shows the test set-up for conducting the water boiling test and the corresponding equipment required for conducting the test. The instruments used for measuring the temperature were

K-Type thermocouple and an infrared thermometer for measuring flame temperature. In addition, sensitive balance was used for measuring the weight of water and fuel. A standard pot commonly used in Ethiopia was used to evaluate the performance of the micro-gasifier which is 7 liter capacity stainless steel pot with 5 liter of water.

Figure 2. Test set-up of micro-gasifier and open-fire stove.

Figure 3 below shows the feedstock, sensitive balance and thermometer which were used to evaluate the performance of the micro-gasifier. The standard water boiling test protocol was used to obtain the thermal efficiency of the micro-gasifier.

Figure 3. Wood and sensitive balance used for the test.

Carbon monoxide and particulate matter concentrations as well as room temperataure were logged every minute during sampling period of the laboratory test. The test room is selected in such a way that it simulates a typical rural household kitchen (2 m × 2 m area and 2.5 m-height). The instruments used for measurement were CO data logger with USB interface (EL-USB-CO with accuracy of ±6 ppm) for carbon monoxide; UCB Particulate Monitor (University of California,Berkeley) for particulate matter ($PM_{2.5}$); and thermocouple data logger with USB interface (EL-USB-TC-LCD with accuracy of ±1 °C) for temperature. The procedure used to set the above cited instruments were based on the procedure outlined by the University of California-Berkeley. The standard procedure for installing the indoor air pollution (IAP) instruments is approximately 100 cm from the edge of the combustion zone and a height of 145 cm from the floor. Here, it is also recommended to place the instruments at least 150 cm away (horizontally) from openable doors and windows where possible [16].

3. Results and Discussion

3.1. Thermal efficiency and specific fuel consumption

The final output of the micro-gasifier designed and manufactured at Addis Ababa Institute of Technology (AAiT) is shown in Fig.4 with the final paints to make it appealing to the end users.

Figure 4. Designed and manufactured micro-gasifier.

Thermal efficiency is calculated based on output over input heat energy. The output is related to the amount of heat supplied to the water in the pot and the input is the energy supplied to the water from the wood burned in the micro-gasifier. The average thermal efficiency obtained is 39.6 ± percent. The other performance indicator is the specific fuel consumption, which shows 70 percent improvement compared to the open fire stove (Table 2).

Table 2. Performance Parameters for Micro-gasifier.

No.	Test parameters	High Power Test (Cold Start)					
		Micro-gasifier					Three-stone
		Test-1	Test-2	Test-3	Avg.	Standard Error	Test-1
1.	Time to boil Pot #1 (min)	30	32	33	31.7	0.87	24
2.	Temp-corrected time to boil Pot #1 (min)	34	34	34	34.0	0.23	27
3.	Burning rate (g/min)	9	9	7	8.0	0.81	35
4.	Thermal efficiency (%)	37	35	47	39.6	3.76	14
5.	Specific fuel consumption (g/liter)	58	65	49	57.0	4.62	187
6.	Temp-corrected specific fuel consumption (g/liter)	66	68	50	61.0	5.83	213
7.	Temp-corrected specific energy cons. (kJ/liter)	1247	1285	940	1158.0	109.4	4013
8.	Firepower (watts)	2822	2954	2158	2644.7	246.2	10913

Bhattacharya and Leon [8] and Belonio [14] obtained a thermal efficiency of a gasifier stove as 27% and 25.9%, respectively. Dixit, et al. [11] also reported thermal efficiency of a gasifier stove as 37%. Panwar and Rathore [9] and Panwar [10] obtained 26.5% and 35%, respectively. The thermal efficiency and specific fuel consumption of our micro-gasifier showed improvement compared to the existing gasifier stoves in the market (Table 2).

As it is usually expected, the time required for boiling 5 liter of water in Addis Ababa using micro-gasifier is 70 percent higher than using the open-fire stove. The Firepower of the micro-gasifier is around 2.60 kW. In this study, the feedstock was limited to woody biomass in which case the inclusion of other feedstock may bring a different value in terms of thermal efficiency and indoor air pollution.

3.2. Boiling point of water in Addis Ababa-Ethiopia – AAiT Workshop

In order to ensure the precision of computing the performance of the micro-gasifier, the boiling point of water was experimentally determined rather than calculating using the altitude. The mean boiling point of water in Addis Ababa was 91 °C where the altitude is 2355 m (Figure 5). As shown in Figure 5, three tests were conducted to determine the average boiling temperature of water in a specific location.

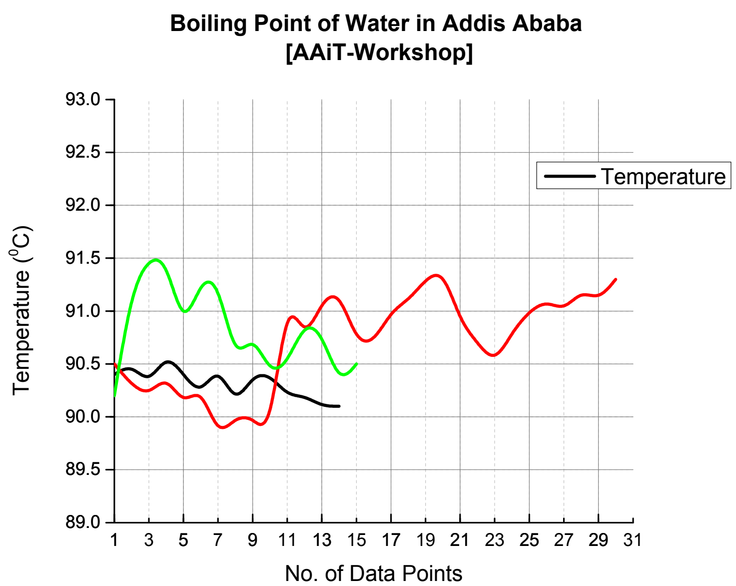

Figure 5. Boiling point of water in Addis Ababa.

3.3. Indoor air pollution

The major two emissions considered for this test in relation to indoor pollution were CO and PM. Figure 5 shows the variation of CO during the test period. The maximum CO exhibited during this test was 12.5 ppm which is below the WHO standard set as 30.6 ppm for 1 hour exposure [17]. As shown in Figure 5, the CO measurements exhibited the maximum value during the 40–50 minutes cooking time.

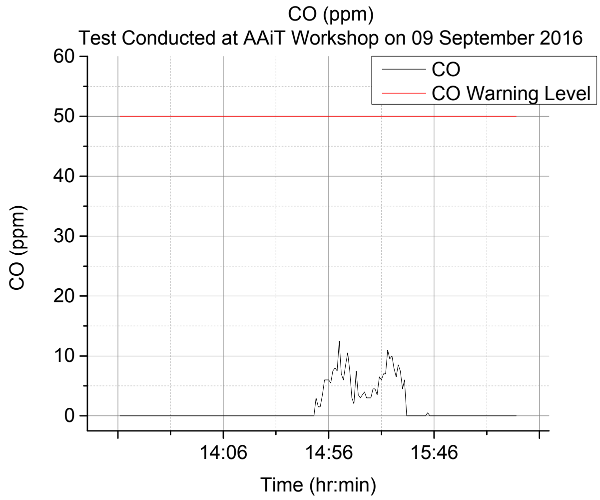

Figure 6. CO concentrations during testing.

Similarly, the amount of PM generated during the test period is plotted to see whether it is in the acceptable range or not. The maximum amount of PM recorded was 1.85 mg/m^3 during the testing period (Figure 7). WHO guideline indicates that the annual mean & 24-hour mean for $PM_{2.5}$ is 10 mg/m^3 and 25 mg/m^3, respectively [18]. Thus, the experimental result for $PM_{2.5}$ is well below the recommended value. The reduction in PM of micro-gasifier showed 10–12 folds which is a huge advantage in terms of indoor air pollution, making the stove highly acceptable by the users.

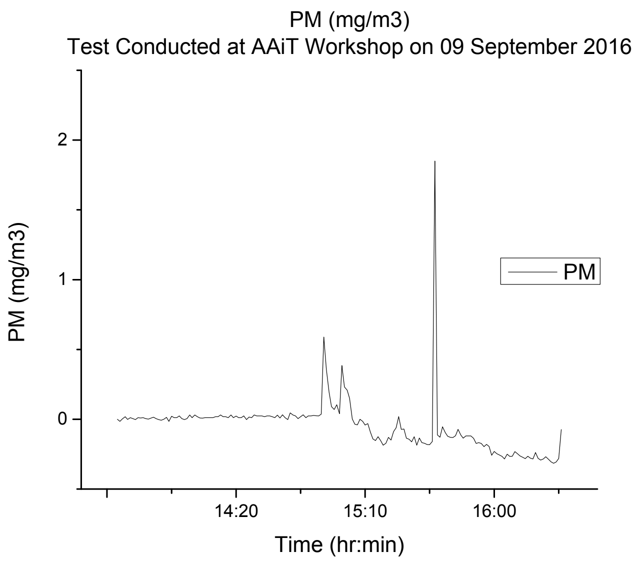

Figure 7. PM concentrations during testing.

Indoor air pollution is responsible for the death of many people in developing countries during cooking. This can be substantially reduced by improving and introducing micro-gasifier. By using a better design of micro gasifier as shown in our case, it was possible to reduce the two emissions that are good indicator of indoor air pollution, CO and PM-where they were significantly reduced below WHO standard [16].

The room used for conducting the test was a simulated typical Ethiopian rural household in which case the door was completely open to the outside. There were also some openings in the upper part of the room. Figure 8 shows the variation of the room temperature with time during the operation of the stove.

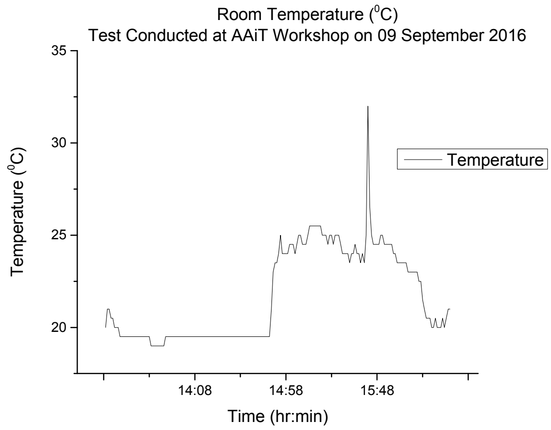

Figure 8. Room temperature vs time.

3.4. Time vs temperature variation for various tests

The variation of temperature as heating was continued until the water reached its boiling point was shown in Figure 9. In the four testes conducted, the temperature exhibited a similar trend

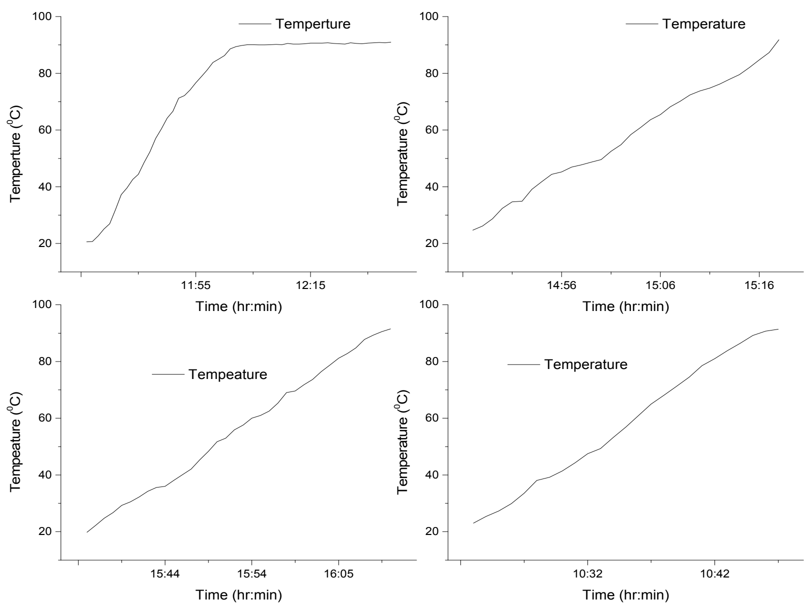

Figure 9. Temperature of water during heating process.

showing the consistency of the boiling of the water at the given altitude and pressure. Similarly, the result indicates the precision level of our test result.

3.5. Conservative estimate for GHG reduction potential

As we have mentioned above, the majority of the population in Ethiopia uses biomass energy for cooking. In order to estimate the GHG saving from introducing micro-gasifiers, the reference dissemination potential of households could be considered based on GTP 2 of Ethiopian Government Plan. In this plan, 11.25 million improved cookstoves are expected to be distributed in the coming five years. The discussion under section 3.5. focuses on estimation of the amount of CO_2 reduced per unit of micro-gasifier, where the total amount of CO_2 reduction can be computed based on baseline survey for a specific location.

The approach followed to calculate the amount of emission reduced per unit of micro-gasifier was based on the clean development mechanism (CDM) methodology outlined by UNFCCC[19].

$$B_{old,capita} = \frac{HC_{fuelwood,usage,y}}{HC_{population,y}} \quad (8)$$

$$HC_{fuelwood,usage,y} = Fuel\ wood\ consumption\ in\ cubic\ meters\ \ x\ \ Wood\ density \quad (10)$$

$Fuel\ wood\ consumption\ in\ cubic\ meters\ = 80{,}185{,}000\ m^3$ [20]

$Wood\ density$ = 0.725 t/m^3 [21]

$HC_{fuelwood,usage,y}$= 80,185,000 m^3 x 0.725 t/m^3 = 58,134,125 t/year

$HC_{population,y}$= 84,320,987 [22]

$B_{old,capita} = 0.689$ t/year

$N_{residents,household} = 6$

$$B_{y,device} = B_{old,capita}\ x\ N_{residents,household}\ x\ FW_{proportion} \quad (11)$$

$FW_{proportion}$= 41.50% for cooking application

$B_{y,device} =$ 1.72 t/device/year

$\eta_{old} = 10\%$ [The default value of 10% was applied as the systems to be replaced are three stone fires].

$\eta_{new,micro-gasifier} = 39.6\%$

$$B_{old,micro-gasifier} = B_{y,deivce,micro-gasifier}\ x\ L_y \quad (12)$$

The default net to gross adjustment factor of 0.95 has been applied to account for leakages:

$B_{old,micro-gasifier} = 1.63$ t/device$/year$

$$B_{y,savings,micro-gasifier} = B_{old,micro-gasifier}\ x\ \left(1 - \frac{\eta_{old}}{\eta_{new,micro-gasifier}}\right) \quad (13)$$

$$B_{y,savings,micro-gasifier} = 1.21 \frac{t}{device} /year$$

The emission reductions created by the micro-gasifier are calculated as follows:

$$ER_{y,micro-gasifier} = \quad B_{y,savings,micro-gafier}\, x\, f_{NRB,y}\, x\, NCV_{biomass}\, x\, EF_{projected_{fossilfuel}}\, x\, N_{y,micro-gasifier} \quad (14)$$

$f_{NRB,y} = 88\%$ [23]

$NCV_{biomass} =$ 0.015 TJ/tone (IPCC default for wood fuel on wet basis)

$EF_{projected\_fossilfuel} =$ 81.6 tCO2/TJ

$$\boldsymbol{ER_{y,micro-gasifier}} = \textbf{1.30 tCO}_2\textbf{/device/year}$$

The emission reduction potential of the micro-gasifier, in terms of carbon credit saving which was calculated as 1.30 tCO_2/device/year is better than other biomass cookstove promoted in the country by various institutions. For instance, World Vision Ethiopia claimed 1.14 tCO_2/device/year [24].

Our result showed better emission reduction which implies that the micro-gasifier tested in our study has a bigger contribution towards CO_2 emission to the environment, thereby reducing global warming and climate change.

3.6. Manufacturing cost of micro-gasifier

The micro-gasifier was made of mild steel sheet metal with 1.5mm thickness and assumed that it will be used at least for five years without maintenance. The unit production cost of the micro-gasifier is 10.85 USD (Table 3). This cost could be partially covered from the carbon saving of the micro-gasifier which is 1.3 tCO_2/device/year. For wider dissemination of the micro-gasifier, awareness creation about the benefit and its implication for alleviating the health problems need to be carried out through joint efforts of governmental and non-governmental and organizations.

Table 3. Manufacturing cost of micro-gasifier.

No.	Description	Total cost (USD)
1	Mild steel sheet metal 1.85m x 0.50m x 1.5mm	4.50
2	Pipe 3/4" and 260mm	0.35
3	Mild steel sheet metal 0.131m x 0.045m x 4.0mm	0.35
4	Rectangular Hollow Section(RHS) 20mm x 30mm x 1.5mm and length 180mm	0.35
5	Wood(for handle) Dia. 20mm and 110mm	0.05
6	Machining cost (cutting, grinding, drilling, etc…)	3.75
7	Labour cost	1.50
	Total	**10.85**

4. Conclusion

Based on our study, a gasifier stove is worth promoting rather than biomass cookstoves and open-fire stoves. This is due to its thermal efficiency and less indoor air pollution and emission reduction. Disseminating this micro-gasifier will result in a reduced fuel wood use in the rural parts of Ethiopia where local people widely use open-fire stove for household cooking. It also reduces indoor air pollution which is the cause of death incidents; and reduction of CO_2 emission which has tremendous implications for the environment in terms of global warming and climate change. The cost of micro-gasifier is relatively small and even that could be subsidized by having a partial carbon credit by selling the emission reduced. Such experience is already available within the country with some non-governmental organization like World Vision Ethiopia. Hence, this micro-gasifier is a better choice for the users.

Acknowledgments

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Conflict of Interest

All authors declare no conflict of interest in this paper.

References

1. IEA (2015) World Energy Outlook. Population relying on traditonal use of biomass for cooking in 2013.
2. Beyene AD, Koch SF (2013) Clean fuel-saving technology adoption in urban Ethiopia. *Energy Economics* 36: 605-613.
3. GIZ-ECO, D.G.f.I.Z.-E.C.O. (2009) Water Boiling Test Results of Various Types of Household Wood Stoves for Non-Injera Cooking.
4. Dresen E, DeVries B, Herold M, et al. (2014) Fuelwood Savings and Carbon Emission Reductions by the Use of Improved Cooking Stoves in an Afromontane Forest, Ethiopia. *Land* 3: 1137.
5. Sutar KB, Kohli S, Ravi MR, et al. (2015) Biomass cookstoves: A review of technical aspects. *Renew Sust Energ Rev* 41: 1128-1166.
6. Kirkels AF, Verbong GPJ (2011) Biomass gasification: Still promising? A 30-year global overview. *Renew Sust Energ Rev* 15: 471-481.
7. Reed TB, Larson R (1996) A wood-gas stove for developing countries. *Energ Sust Develop* 3: 34-37.
8. Bhattacharya SC, Leon MA (2003) A Biomass-Fired Gasifier Stove (IGS-2) For Institutional Cooking. Available from: http://www.faculty.ait.asia/kumar/rets/Publications/Glow_ Indonesia.pdf. [accessed 29.09.2016]

9. Panwar NL, Rathore NS (2008) Design and performance evaluation of a 5 kW producer gas stove. *Biomass Bioenerg* 32: 1349-1352.
10. Panwar NL (2009) Design and performance evaluation of energy efficient biomass gasifier based cookstove on multi fuels. *Mitigation and Adaptation Strategies for Global Change* 14: 627-633.
11. Dixit CSB, Paul PJ, Mukunda HS (2006) Part I: Experimental studies on a pulverised fuel stove. *Biomass Bioenerg* 30: 673-683.
12. Mukunda H, Dasappa S, Paul PJ, et al. (2010) Gasifier stoves - science, technology and field outreach. *Curr Sci* 98: 627-638.
13. Varunkumar S, Rajan NKS, Mukunda HS (2012) Experimental and computational studies on a gasifier based stove. *Energ Convers Manage* 53: 135-141.
14. Belonio AT (2005) *Rice Husk Gas Stove Handbook*.
15. WBT, v., *Water boiling test v.4.2.3*. Cookstove Emissions and Efficiency in a Controlled Laboratory Setting, 2013.
16. University of California, B. *Installing Indoor Air Pollution Instruments in a Home, Version 5.1*. 2005 Available from: http://berkeleyair.com/wp-content/publications/guidelines-for-instrument-placement.pdf. [accessed 10.08.2016]
17. WHO, R.O.f.E. (2010) WHO guidelines for indoor air quality: selected pollutants. Available from: http://www.euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf. [accessed 03.09.2016]
18. WHO (2014) WHO indoor air quality guidelines: household fuel combustion. Available from: www.who.int/indoorair/guidelines/hhfc/HHFC_guidelines.pdf. [accessed 03 September 2016]
19. UNFCCC (2012) CDM, Small-Scale Methodology: Energy Efficiency Measures in Thermal Applications (AMS-II.G). Available from: https://cdm.unfccc.int/methodologies/DB/DCO8WRRQVTGLH1GHQBCL035F5M13R8. [accessed 19.09.2016]
20. UN, U.N.S.D. (2013) *Energy Statistics Database*. Available from: http://data.un.org/Data.aspx?d=EDATA&f=cmID%3aFW%3btrID%3a06. [accessed 28.09.2016]
21. FAO (2004) *Unified Bioenergy Terminology*. Available from: http://www.fao.org/docrep/009/j8227e/j8227e11.htm#P1131_70563. [accessed 19.09.2016]
22. Ethiopia, C.S.A.-. (2012) *Population Statistics Abstract*. Available from: http://www.csa.gov.et/images/documents/pdf_files/nationalstatisticsabstract/2011/2011%20population.pdf. [accessed 28.09.2016]
23. UNFCCC. (2012) *Default values of fraction of non-renewable biomass*. Available from: http://cdm.unfccc.int/DNA/fNRB/index.html. [accessed 28.09.2016]
24. World Vison Ethiopia, W. (2013) *Energy Efficient Stoves Program, CDM Program of Activities Design Document*. Available from: https://cdm.unfccc.int/ProgrammeOfActivities/poa_db/5TE6HLP1Z4KOABSDI873YQCFGXW2RM/view. [accessed 24.09.2016]