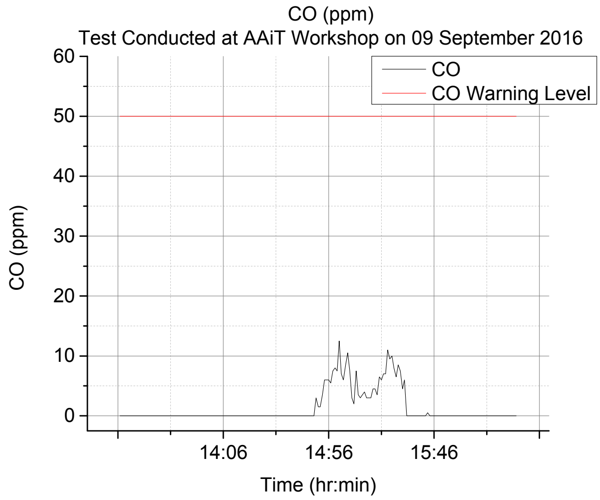

Figure 6. CO concentrations during testing.

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.

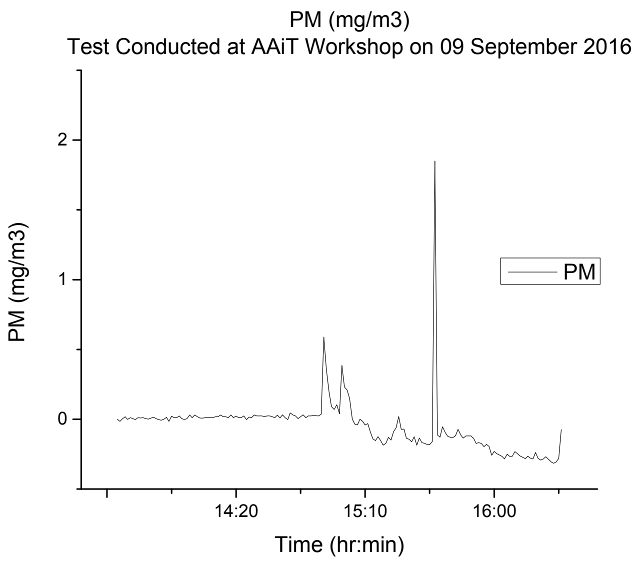

Figure 7. PM concentrations during testing.

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.

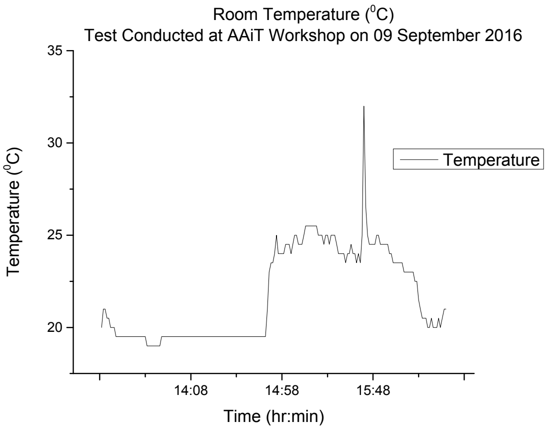

Figure 8. Room temperature vs time.

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

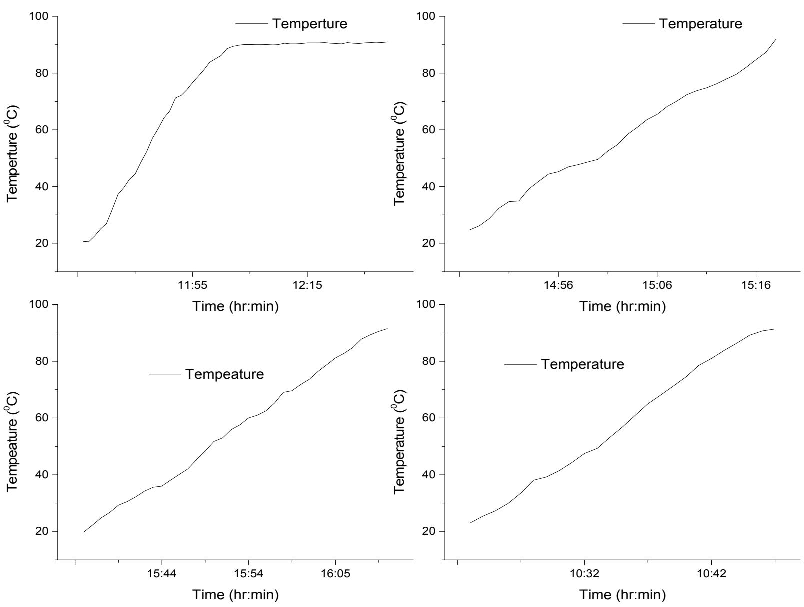

Figure 9. Temperature of water during heating process.

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:

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

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

This research was funded by Addis Ababa University (AAU) and Ethiopian Climate Innovation Center (ECIC). We would like to thank the Ministry of Water, Irrigation and Electricity and Ethio Resource Group (ERG) PLC for lending us the instruments which we used for various measurements during the test period.

Conflict of Interest

All authors declare no conflict of interest in this paper.

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