



Comparison of Thermal and Emissions Performance on Three Stoves for Distilling Areke, A Traditional Ethiopian Beverage

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Abstract. *Areke* is a traditionally fermented and distilled beverage. And it is one of the frequently consumed drinks in semi-urban and rural areas of Ethiopia. Also, it is a drink for most people in the country. Regarding its preparation, it is brewed using a three-stone fire which consumes a large amount of firewood and generates significant indoor air pollution. The evaluation and comparison of thermal and emissions performance of existing cook stoves employed for *Areke* distillation may help the rural poor and semi-urban population to reduce the economic and health costs associated with its preparation. In doing so, Control Cooking Test (CCT) protocol was employed for all the three types of stoves: a three-stone fire, traditional *Areke* stove, and *Mirt Areke* stove. The test results showed that *Mirt Areke* stove reduced fuel use by 51% compared to the three-stone fire while the improvement made by the traditional *Areke* stove is 36%. Indoor air pollution indicators of CO, PM_{2.5} and PM₁₀ also showed a reduction by 29%, 53%, and 52%, respectively, while comparing *Mirt Areke* stove with three-stone fire. In the case of a traditional *Areke* stove, the percentage increase in CO is 14.3% while percentage reduction in PM_{2.5}, and PM₁₀, is 17.9% and 18.3%, respectively. These results indicate that the improved *Mirt Areke* stove has a better performance than the traditional *Areke* stove.

Keywords: *Areke* · Improved cook stove · Distillation · Indoor air pollution

1 Introduction

Ethiopia is one of the countries where a wide variety of traditionally fermented beverages are produced on a fairly small scale, usually for local consumptions. The various traditional fermented beverages are produced on a fairly small scale and usually used for local consumption. To mention just a few of varieties of *Tella*, *Tej*, *Borde*, *Areke*, *Karibo*, and *Korefe* are consumed in Ethiopia (Tafere 2015). The preparation of many indigenous or traditionally fermented beverages is still a household art (Tafere 2015). *Areke* is usually brewed in rural and semi-urban areas and is used more commonly by farmers and semi-urban dwellers than by people who live in the cities (WHO 2004).

In order to prepare *Areke*, spherical round ceramic pot is filled with *difdif* (a mixture of malt, hops and water left to ferment for 5 days in warm zone and for twelve days in cold zone). *Difdif* is the main mash to *tinsis* (which is usually a mixture of malt, *gesho*

(hops), and water kept for 4–5 days in a closed container). In the start, firewood is ignited to begin the combustion until the *difdif* becomes warmer. At a later stage, the quantity of firewood is slowly reduced until it reaches one piece. In the meantime, the vapour from the boiled *difdif* flows through the *Mekane* (condenser tube) and is collected in the canteen which then is immersed into water at ambient temperature. Due to the transfer of heat, the water gets warmer and warmer. Then, the distillation of the *Areke* continues until it becomes complete. There are signs which show that the completion of the activities, i.e., excessive alcoholic odor and knocking sound.

In most of the rural areas of Ethiopia, *Areke* is still distilled using the three-stone fire. A study conducted in one of the regional towns of Ethiopia, *Arisi Negle*, showed that the indoor air pollution of *Areke* distillation is higher than the WHO standard. The CO and PM concentrations were 68.81 ppm and 3.11 mg/m³, respectively during distillation (Mohammed 2008). The Controlled Cooking Test (CCT), where seven pots with separate fuel supply were placed in a single room, resulting in reductions of specific fuel consumption by 4.4% and the time required for brewing the beverage by 22% upon using the improved stove made out of bricks. The improved *Areke* stove has showed a reduction by 52% and 57% in CO and PM, respectively during the whole distillation process (Woldeselassie 2008). *Areke* distillation using biogas stove was also studied in the same location and between 0.6 m³ to 1 m³ of biogas is consumed to distill a liter of *Areke*. The finding also suggested that a significant amount of fire wood consumption could be replaced with biogas for distilling *Areke* in the town (Mengiste 2010).

Similar with other biomass cooking technologies in the country which are used for cooking, baking and brewing, *Areke* distillation using three stone fire causes two of the top leading deaths, which are neonatal disorders and lower respiratory infections, i.e., responsible for the majority of deaths relating to indoor air pollution (GBD 2018).

A number of initiatives were taken to improve the three-stone fire cook stoves for cooking (GIZ-ECO 2011b) and baking (Adem et al. 2019; GIZ-ECO 2011a). However, the *Areke* distillation stove has been a neglected area of research. The indoor air problem associated with distilling *Areke* using a three-stone fire poses a serious health problem. Little effort has been made to evaluate the indoor air quality impacts arising from biomass combustion on *Areke* processing stoves. As a launching pad for research and development on improvement of *Areke* stoves, a standard performance evaluation is crucial. The number of spherical round ceramic pots and stoves varies from household to household ranging from 1 up to 10. So, using a single spherical round ceramic pot and stove as a baseline will help researchers and developers to base their improved design and make comparison.

So, the aim of this research is to experimentally evaluate the *Areke* stoves both the three-stone fire and the improved stoves using the CCT protocol. The result will help developers to disseminate a better performing *Areke* stove throughout the country for reducing firewood consumption, indoor air pollution and health impacts. The dissemination of improved *Areke* stove does not necessarily imply increasing intake of *Areke* rather any gain from the reduction of fuel consumption and indoor air pollution will benefit the household. The major beneficiaries are women and children (ERG 2014).

2 Materials and Methods

2.1 Description of the *Areke* Stove

Areke distillation process is a time consuming activity compared to other household cooking practices. On average, it takes from 2 to 2.5 h per batch excluding the time required to prepare the *difdif* (the processed grains). In the case of a single *Areke* processing unit, a single spherical round ceramic pot with single bamboo pipe and metal canteen is used for distilling *Areke*. As shown in Fig. 1((a) & (b)) the *difdif* is added into a *Ensera* (ceramic pot) where it is supported by three stones called three-stone fire stove. The ceramic pot has the same chemical composition and treatment as a ceramic pan for baking *injera* – Ethiopian flat bread. This stove is used for processing in a single pot where a number of pots could be arranged to produce *Areke* in a single room as shown in Fig. 1(c).

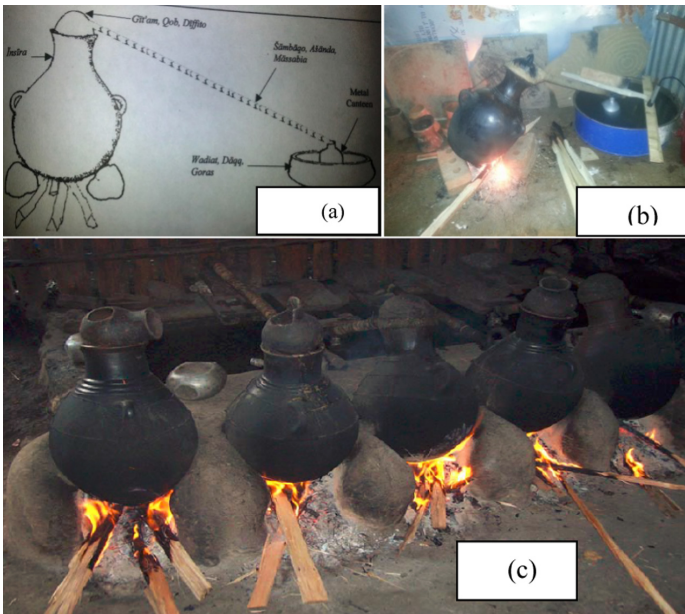


Fig. 1. *Areke* stoves: (a) Schematic representation of single pot, (b) Single pot *Areke* processing and (c) Multiple of number of pot for *Areke* processing

2.2 Mold Developed for *Mirt Areke* Stove

Since *Mirt injera* stoves (*injera* is Ethiopian flat bread) have been under dissemination for quite a number of years, producers have become comfortable to make *Mirt Areke* stove using similar approach. Due to its weight, performance and other conveniences, making the stove into two parts became mandatory. Thus, the final mold was taken to stove producers for a test and feedback was collected and further improvement made. Figure 2 shows the final modified mold was used for producing *Mirt Areke* stove. The CATIA software was also used to draw the detail workshop drawing of the stove.



Fig. 2. Final mold for *Mirt Areke* Stove

Three types of biomass cook stoves (three-stone fire, traditional, and *Mirt Areke* stove) were used to conduct the test. As the name is self-explanatory, the three-stone fire uses three-stones to support the spherical round ceramic pot where fuel is combusted to boil the content of the pot (Fig. 3a). This stove is used for various cooking applications. The second is the traditional *Areke* stove. It is locally made out of mud and finally painted with *wet dung* (Fig. 3b). The third type of stove is constructed with mortar and cement using mold of two halves to make the handling better for women as they are the major users of the stove (Fig. 3c).



Fig. 3. *Areke* stoves: (a) three-stone fire, (b) traditional and (c) *Mirt Areke*

2.3 Firewood Characterization

The firewood which is eucalyptus tree cut into pieces and sun dried for at least three to four weeks, was used for conducting the *Areke* stoves tests. Representative samples were collected and prepared for the characterization of the wood. Table 1 indicates the characterization of the wood determined at the Geological Survey of Ethiopia according to ASTM standard (ASTM 1983).

Table 1. Basic characteristics of wood (Eucalyptus)

<i>General characteristics</i>	
Size (mm × mm × mm)	20 × 20 × 1000
Bulk density (kg m ⁻³)	480
Moisture content (%)	5.64
Higher heating value (HHV) (MJ kg ⁻¹)	18.64
<i>Proximate analysis</i>	
Volatile matter (% db)	80.81
Fixed carbon (% db)	13.02
Ash content (% db)	0.54

2.4 Experimental Setup for *Areke* Stove

The experiment was conducted using three biomass stoves: three-stone fire, traditional stove and *Mirt Areke* stove. In order to make the presentation concise, a general experimental set-up is presented in Fig. 3. The spherical round ceramic pot is filled with *difdif* which is the main mash for *tinsis*, i.e., usually a mixture of malt, *gesho* (hops), and water (Fig. 4). From the start, firewood is ignited to begin the combustion of the fuel wood until the *difdif* becomes warmer. At a later stage, the quantity of firewood is slowly reduced until it reaches one piece. In the meantime, the evaporated *Areke* through *Mekane* (condenser tube) and is collected in the *canteen*. The *canteen* is immersed into water at ambient temperature. Due to the transfer of heat, the water gets warm. Then, the distillation of the *Areke* continues until it becomes complete. There are signs which show the completion of the activities, excessive alcoholic odor and knocking sound. In this experiment, the Control Cooking Test (CCT) protocol is used to be conducted by a professional cook at a laboratory setting was used to evaluate the performance of the *Areke* stoves (Bailis 2004). Following the protocol, the temperature of the water was recorded in 1 min interval until the distillation becomes complete.

The test for each type of stove (three-stone fire, traditional, and *Mirt Areke* stove) were conducted in a typical Ethiopian kitchen, i.e., 2.5 m (length) × 3.5 m (width) × 2.5 m (height). According to the recommendation of the University of California (CEIHD 2005), the instruments used for measuring carbon monoxide, particulate matter, room temperature, and relative humidity were placed at 100 cm from the edge of the combustion zone, at a height of 145 cm from the floor and at 150 cm away from openable doors. CO was measured using indoor air quality meter, KM 410 with accuracy ± 30 ppm, ± 5% of reading (Wohler 2019). PM_{2.5} and PM₁₀ were measured using WP 6301 Air Quality Monitor with a detection range of 0 to 500 mg/m³

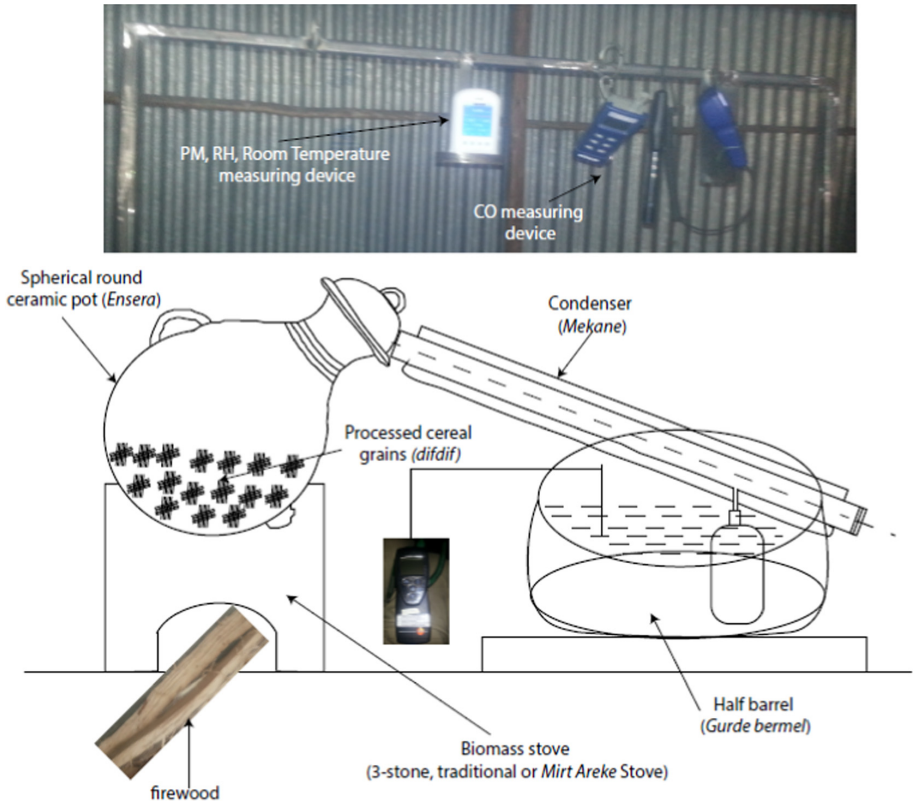


Fig. 4. Experimental Setup for Areke distillation stoves

(Vson 2019). For the conversion of CO unit from ppm to mg/min, we have taken into consideration the volume of the kitchen and time taken to brew Areke (CHSR 2019).

2.5 Performance Cacluations

The amount of fuel used to brew a gram of Areke was calculated for all the three stoves. A total of 9 tests were conducted for evaluating the performance of the three types of stoves under considerations where fuel use was used as one of the performance indicators. Equation (1), (2) and (3) were used in order to evaluate the equivalent firewood (f_d), net weight of food (W_f) and SFC.

$$f_d = (f_i - f_f) * [1 - (1.12 * m)] - 1.5 * m_{char} \tag{1}$$

$$W_f = p_f - p \tag{2}$$

$$SFC = \frac{f_d}{W_f} * 1000 \tag{3}$$

Where,

- SFC Specific Fuel Consumption (g/g)
- f_d equivalent firewood (g)
- f_i initial weight of firewood (g)
- f_f final weight of firewood (g)
- m moisture content of firewood (%)
- m_{char} amount of char produced (kg)
- W_f net weight of *Areke* (g)
- p_f mass of *Areke* with canteen (g)
- p mass of canteen (g)

3 Results and Discussion

3.1 Specific Fuel Consumption

Figure 5 (left side y-axis) shows the specific fuel consumption measurements for all stoves. The right side of the y-axis shows the percentage fuel use reduction by traditional and *Mirt Areke* stoves, with 95% confidence interval for each stove, relative to the three-stone stove. Both *Areke* stoves showed substantial and statistically significant fuel savings relative to the three-stone stove. While the traditional *Areke* stove showed 36% reduction of fuel use. *Mirt Areke* stove registered 51% reduction compared with the three-stone stove as a baseline.

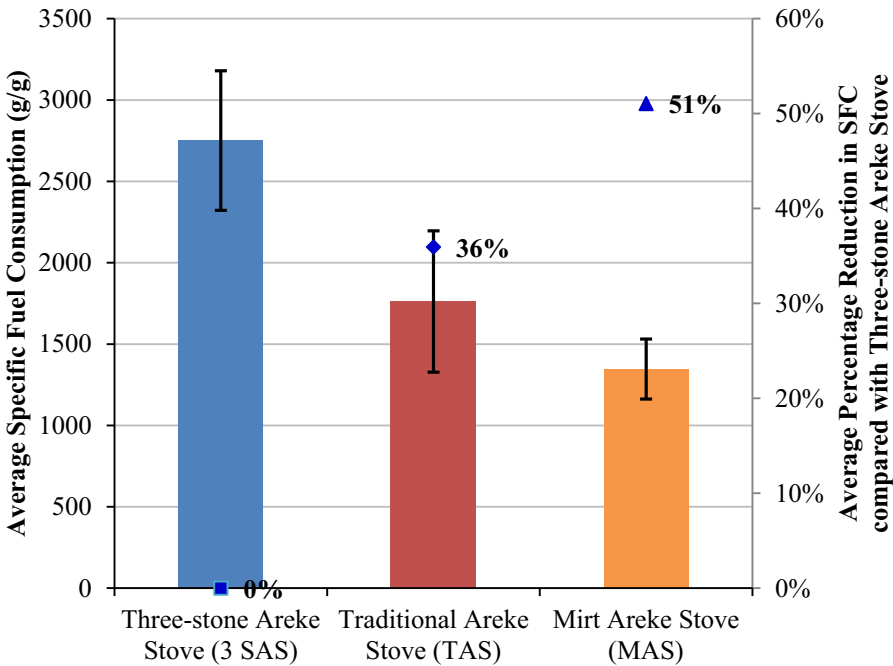


Fig. 5. Average specific fuel consumption (three-stone, traditional and *Mirt Areke* stoves)

In a similar study, a 4.4% reduction in specific fuel consumption was recorded in using a rectangular block stove which holds seven spherical round ceramic pots (Woldeselassie 2008). However, according to the experiment made on a single stove by this author, both the traditional and *Mirt Areke* stove exhibited a better performance in terms of specific fuel consumption. Since *Areke* distillery ceramic pot stove and *injera* baking pan stove have similar materials of construction, they can be compared in terms of their performance. In this regard, *Mirt and Gonzie*, improved enclosed *injera* baking stoves, showed a reduction in specific fuel consumption ranging between 24%–49% (Dresen et al. 2014; Feleke 2007; Gulilat 2011, Gulilat 2014; Jeldeti 2005; Teka 2013; Tufa 2012). Similarly, our performance test which was carried out on a single stove has showed reduction in specific fuel consumption of the same range.

3.2 Average Brewing/Cooking Time

The time to brew *Areke* is also an important indicator of stove performance. Depending on local conditions and individual preferences, stove users may value this indicator equivalent to fuel consumption. Time to brew is calculated from the difference between starting and finishing time of *Areke* processing activity. Figure 6 (left y-axis) shows the average brewing time for traditional and *Mirt Areke* stoves. Figure 5 (right – y-axis) on the other hand, indicates the percentage reduction of traditional and *Mirt Areke* stoves as compared to the three-stone fire stove with 95% confidence intervals.

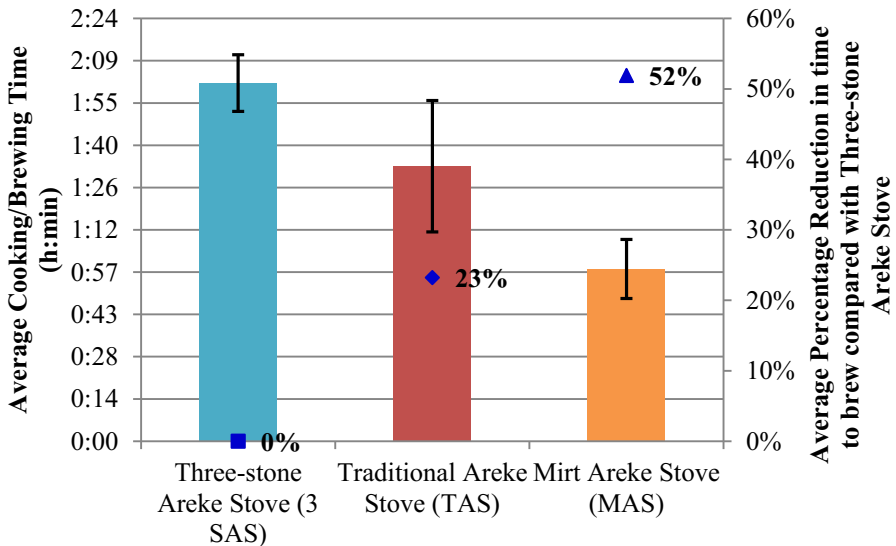


Fig. 6. Average brewing time (three-stone, traditional and *Mirt Areke* stoves)

Traditional *Areke* stove showed a reduction of 23% (29 min) brewing time as compared to the three-stone stove. However, *Mirt Areke* stove reduced the time by more than half of the time taken by three stone (52%; 1:04 h:min). Our finding shows a

better reduction in time to brew using *Mirt Areke* stove which may show a good improvement for *Areke* brewing stoves. Woldeselassie (2008) achieved a 22% reduction in time to brew by using improved *Areke* stove where the computation was based on seven stoves or through spherical round ceramic pots which were used during the testing. However, in our test, a single stove was used during the whole period. One of the performance indicators, i.e., the time for brewing/cooking shows reduction on ceramic *injera* baking stove ranging between 5% to 17% (Feleke 2007; Gulilat 2011; Teka 2013; Tufa 2012). The cause for this variation of *injera* baking time could be further verified by other researchers in the area.

3.3 Indoor Air Pollution

The test result indicated that the average CO generated while the three-stone *Areke* stove is in use is around 14 ppm. Similarly, the average PM_{2.5}, and PM₁₀ were 347 ppm and 387 ppm, respectively. In the case of *injera* baking on the three-stone fire, the recorded CO was 80 ppm which is higher than that of the *Areke* stove. This could be due to the less amount of firewood consumed (Yosef 2007). Table 2 indicates the average CO, PM_{2.5}, and PM₁₀ room air temperature and relative humidity observed during the distillation of *Areke*.

The average concentration of CO, PM_{2.5} and PM₁₀ observed in the test room while using the traditional *Areke* stove were 16 ppm, 285 ppm, and 316 ppm, respectively. And, the average room air temperature and relative humidity were 25 °C and 43%. However, there were no recorded test results for making comparisons with other traditional stoves used for *Areke* brewing.

Table 2. Average CO, PM_{2.5}, PM₁₀, air temperature and relative humidity for a three-stone *Areke* stove

	CO (ppm)			PM _{2.5}			PM ₁₀			Air Temperature (°C)			Relative Humidity (%)		
	3SAS	TAS	MAS	3SAS	TAS	MAS	3SAS	TAS	MAS	3SAS	TAS	MAS	3SAS	TAS	MAS
Test 1	14	20	15	256	332	182	283	369	215	26	25	27	34	40	35
Test 2	11	13	10	350	248	183	373	272	200	27	25	22	29	43	49
Test 3	16	14	4	434	276	124	504	308	140	27	24	23	28	46	48
Mean	14	16	10	347	285	163	387	316	185	27	25	24	30	43	44
STDev	3	4	6	89	43	34	111	49	40	1	1	3	3	3	8

In addition, the result showed that the average concentrations of CO, PM_{2.5} and PM₁₀ in the test room in using *Mirt Areke* stove, were 10 ppm, 163 ppm, and 185 ppm, respectively. In the case of *Mirt injera* baking stove, the registered CO concentration was 7.2 ppm which is less than the *Mirt Areke* stove, due to the difference in application of the stoves for baking rather than brewing (Yosef 2007). In the test room, the average temperature and relative humidity were 24 °C and 44%, respectively. And, the average amount of CO was 10 ppm whereas the average time taken to brew on *Mirt Areke* stove was 57 min. This observed CO value was lower than the WHO recommendation which is less than 30 ppm during one hour exposure (WHO 2010).

Similarly, this is less than the strong recommendation of WHO (2014) which is 0.59 g/min while taking into account the volume of the kitchen and time to brew stands at 0.0044 g/min.

Considering the three-stone *Areke* stove as a reference, the percentage reductions in CO and PM_{2.5} in using *Mirt Areke* stove was better. If the whole tests were conducted under the hood, the results could have a different figure with better accuracy suggested for similar studies in the future. Now, there is a baseline data available for *Areke* stove which will help other researchers and developers to improve the existing *Areke* stove.

In addition to the improvement in the performance of *Mirt Areke* stove, the use of mold to produce the stove in a uniform structure will help users to attain similar results in using the stoves. A stove with a uniform structure was not possible in the case of traditional *Areke* stoves. But, this could be even made better if *Mirt Areke* stove is to be manufactured at industrial scale.

4 Conclusion

The three types of *Areke* distillation biomass cookstoves, a three-stone fire, traditional stove, and *Mirt Areke* stove, were tested for their performance in terms of fuel use and indoor air pollution. The test results showed that *Mirt Areke* stove reduces fuel use by 51 percent compared with the three-stone fire *Areke* stove. CO, PM_{2.5}, and PM₁₀ were reduced by 29%, 53%, and 52%, respectively. Similarly, the traditional *Areke* stove reduce fuel use by 36 percent compared with the three-stone fire *Areke* stove. CO increased by 14% while PM_{2.5}, and PM₁₀ were reduced by 18% for both PM_{2.5}, and PM₁₀ in the case of traditional *Areke* stove.

Following the test results, the mold for *Mirt Areke* stove was prepared and tested for practical application. In order to replicate the *Mirt Areke* stove production, a detailed manufacturing drawing should be prepared and made ready for dissemination.

The tests conducted on biomass *Areke* stoves could be used as a baseline performance data for future improvements. Currently, disseminating the *Mirt Areke* stove with its mold for producers in the country will save a large amount of fuel and decreases indoor air pollution for those who are currently engaged in the distillation of *Areke* around the country.

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