# Development and Testing of Improved Double Skirt Rocket Stove for Reducing the Emission Level of Carbon Monoxide

Fetene Teshome(✉), Eyob Messele, and Kishor Purushottam Kolhe

Department of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, P.O.Box: 26, Bahir Dar, Ethiopia
fetenet2017@gmail.com

**Abstract.** Carbon monoxide is very poisonous and spreading rapidly in air, while using three stone open fire food cooking utmost in all parts of rural area. However, the carbon monoxide is very harmful to human being that resulted the severe diseases, like chronic obstructive pulmonary disease (COPD), lung cancer etc. By considering this fact a clean burning and fuel-efficient cooking stove, is designed and develop at Bahir Dar Institute of Technology (BiT), Bahir Dar, which uses mainly eucalyptus and other wood as a fuel. The present paper aims to reduce the requirement of firewood consumption and emission of carbon monoxide of the traditional three stone open fire stove (TSOFS) by replacing an improved double skirt rocket stove (IDSRS) at institutional cooking kitchen. Each part of the stove is designed based on Aprovecho research center design criteria. The emission of carbon monoxide and particulate matters are recorded by digital indoor air pollution (IAP) meter and results are presented. However; insulation material like Pumice; Loam soil; Synthetic asbestos are used for construction of double skirt rocket stove to reduce the value of firewood consumption and also to increase an efficiency of the rocket stove by 41% than the traditional three-stones cooking method and fabricating double skirt IRS to reduce the loss of heat makes the stove differ from previous single skirt stoves.

**Keywords:** Improved double skirt rocket stove · Insulation material · Carbon monoxide · Particulate matter

## Nomenclature

| | |
|---|---|
| IDSRS | Improved double skirt rocket stove |
| TSOFS | Three stone open fire stove |
| IAP | Indoor air pollution |
| CO | Carbon monoxide |
| PM | Particulate matters |
| WHO | World Health Organization |
| IRS | Institutional rocket stove |


N. G. Habtu et al. (Eds.): ICAST 2019, LNICST 308, pp. 537–547, 2020.
https://doi.org/10.1007/978-3-030-43690-2_39

## 1 Introduction

Globally, more than one billion city dwellers suffer from poor quality air, mostly caused by particulates in the air. Air pollution is the fifth leading cause of death worldwide, responsible for more than 4 million premature deaths every year. There is a close, quantitative relationship between exposure to high concentrations of small particulates (PM10 and PM2.5) and increased mortality or morbidity, both daily and over time. Conversely, when concentrations of small and fine particulates are reduced, related mortality will also go down presuming other factors remain the same. In low- and middle-income countries, exposure to pollutants in and around homes from the household combustion of polluting fuels on open fires or traditional stoves for cooking, heating and lighting further increases the risk for air pollution related diseases, including acute lower respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease and lung cancer. Carbon monoxide, unlike carbon dioxide, does not occur naturally in the atmosphere. The "incomplete" combustion of firewood char coal, natural gas, and oil is a known environmental source of carbon monoxide. Low levels of oxygen and low temperatures result in the formation of higher percentages of CO in the combustion chamber.

**Fig. 1.** Three stone open fire cooking method at BiT student's cafeteria

Around 2.5 billion peoples in the world, particularly belongs to rural areas, utilize biomass energy for a cooking fuel [1]. However; in Ethiopia, all households utilize a solid fuel like wood, open fire cooking methods for cooking their foods. Specially; in commercial and social, hotels, NGO's such as bakeries, restaurants, schools, detention centers, universities, and hospitals; used commonly wood as a cooking material for fuel. Also; as a result of the total amount of wood consumed for cooking, estimated about 62 million tons annually that makes up more than 80% of the total energy consumed in this country on biogas. This puts huge pressure on natural resource sustainability of the country [2]. Nevertheless; Bahir Dar Institute of Technology has a student cafeteria area that uses firewood to prepare food for more than 4000 students every day; uses an open fire or three stone traditional cooking stoves to prepare foods. Commonly, watt is cooked in three or more cooking pot which can hold 200 L every day. The purchasing price of one-meter cube wood is about 667.00 Birr. It means the annual expenditure of the

institute for fuel wood will become about 8,731.64 USD, without considering transport and other related costs. The monthly consumption of wood fuel in the institute for this purpose is about 30-m cube. Mostly, the cooking custom in cooking kitchen includes more three stone open fire stove to finish their work in time, hence many women who engaged for cooking are highly exposed to particulate matters and carbon monoxide emission. The average 11.76% of moisture content is observed in a burning as a fuel for eucalyptus wood. The three stone Open fire cooking method at BiT student's cafeteria is as shown in Fig. 1. Samet *et al*. (2012) divided the major air pollutants by origin, they identified three major groups: (1) combustion sources, (2) biologic sources, and (3) other sources (e.g., radon and radon daughters, volatile and semi volatile organic compounds, and formaldehyde). Moreover; this review has central focus on indoor air pollution that emanates from combustion sources [4]. Smoke that emanates from wood stoves and fireplaces is a potential source of several indoor air pollutants. This is a much larger problem in lesser developed nations [5]. Approximately half of the world's population still relies on biomass fuels (wood, crop residues, and animal dung) for cooking and heating [6]. Wood burning, in addition to producing polycyclic aromatic hydrocarbons and increased respirable particles, is a significant source of indoor CO. The emphasis in this research is to develop Improved Double Skirt Rocket Stove as an alternative to save wood fuel and to reduce the effect of carbon emission. Furthermore; to minimize the dissipated energy, utilization of rocket stove is the best alternative solution. Rocket Stove (RS) is an efficient and hot burning portable stove using small diameter wood fuel. Moreover; the typical application areas of Improved Double Skirt rocket stoves are schools, hospitals, prisons and NGO's. The working condition of this stove is very simple, as fuel is burning in a simple combustion chamber and there is no heat dissipates to the surrounding atmosphere, because the combustion chamber is insulated by different types of heat-resistant materials, like pumice. In this stove, the complete combustion flames' directly reaching to the bottom surface of cooking pot to utilize maximum heat without any loss. Also, it minimizes the consumption of firewood by 41% of the traditional open fire stove. The main difference between a normal fireplace or woodstove and a rocket stove is that rocket combustion is close to complete. When wood is burned it releases volatile compounds that recognize as smoke or soot or creosote. As the fire starts, and the burn tunnel heats up, the rising hot air races up the heat riser, drawing lots of air behind it. This incoming air flows into the feed tube and across the burning wood creating the same effect as pointing a big air-blower at your fire. It gets really hot, the wood burns beautifully, and you hear the air roaring as it charges through the system.

### 1.1 Design Considerations for Improved Double Skirt Rocket Stove (IDSRS)

The design of Rocket stove is shown in Fig. 2; designed and develops by following engineering product development cycle [7–12]. Many influential characteristics affect the design of the part or, perhaps, the entire system of the stove. Usually, quite a number of such characteristics must be considered and prioritized in a given design situation. Therefore, the important design considerations to design the rocket stove are; High heat resistant, lightweight and portable insulation materials, Grate under fire, insulated heat flow paths, Proper gap. The casserole volume is calculated by using Volume = Area × total height, however the area and volume calculated are as 5,099.64 $cm^2$, and

224384 $cm^3$ or 224.38 L respectively Moreover; the design and manufacture of Double skirt rocket stove for a cylindrical diameter of 80.532 cm and height of 44 cm casserole. The space gap for A (height of pot seat from bottom), B (Gap between the insulation and the base of pot at inclined surface), C (Gap between corner of pot and base insulation), and D (Gap between the skirt wall and cooking pot) for air circulation is calculated as 5.5 cm, 4.32 cm, 1.91 cm and 1.93 cm respectively the details are shown in Fig. 2(a). The design of improved double skirt rocket stove is presented in Fig. 2 and it consists of mainly four parts as (1) Skirt (2) Combustion chamber and (3) wood fuel magazine and (4) Leg or Base part as shown in Fig. 2(a–c).


**(a)** **(b)** **(c)**

**Fig. 2.** (a–c) Design of Improved Double Skirt Rocket Stove

## 2 Materials and Method

The design of improved double skirt rocket stove is performed depending upon the parameter; like; water to be vaporized, heat loss, and environmental impact. This improved rocket stove is designed based on Aprovecho research center design parameters and the few refinement in the existing design for the better improvement. Also the local increadent in insulation composition is added for the less heat transfer of the combustion chamber of the rocket stove. The performance evaluation of the stove is determined by controlled cooking test (CCT) method. Based on this method of testing, the measurement for each cooking is recorded for three times by using Eucalyptus wood as a fuel. Moreover; The instruments used for the present study are, Analog Balance, Moisture meter, Infrared thermometer, Digital thermometer, IAP (indoor air pollution) meter, and Steel rule, 50 cm length respectively for the testing of both open fire stove and improved rocket stove as shown in Fig. 3(a–e).

However, the Indoor air pollution meter is used for recording the carbon monoxide, the recording of carbon monoxide for both methods, i.e. three stone and improved rocket stoves are carried out as per standard guidelines of Aprovecho research center [12, 13] (Figs. 4, 5).

The IAP meter is attached at a distance of 1.5 m × 1.5 m distance away and above from the cooking stove as shown in Fig. 6(a, b). The experiments are carried out under Controlled Cooking Test by following steps; (1) initially the local atmospheric conditions are recorded by using available scientific instruments using Digital thermometer. And

(a) Analog Balance

(b) Moisture meter

(c) Infrared thermometer

(d) Digital thermometer

(e ) Indoor air pollution

**Fig. 3.** (a–e) Digital testing devices used for the measurement of weight, moisture, surface temperature, cooking temperature and carbon monoxide. Figure 6(a, b) presents the experimental set up of cooking methods for three stone method and improved rocket stove

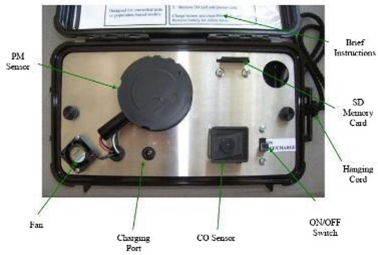
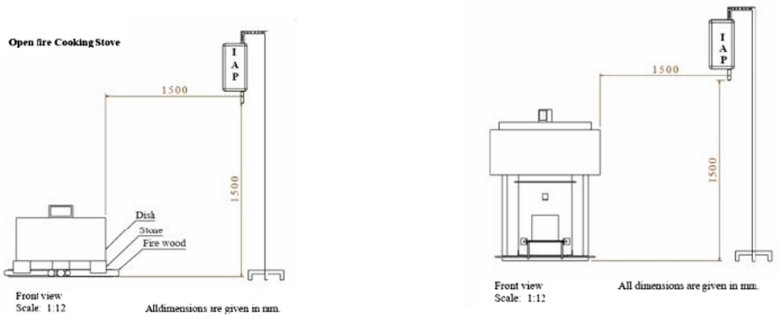



**Fig. 4.** Control panel of indoor air pollution.

**Fig. 5.** (a, b) The cooking of food by using traditional TSV and IDSKRS.

the moisture content of fuel wood is measured by digital moisture meter. (2) The weight of dry wood bundle of fuel is measured on digital Analog Balance for both the open fire stove and improved double skirt rocket stove precisely to avoid mistakes in weight. (3) The digital timer is started for time record during the cooking of food on open fire furnace and improved double skirt rocket stove. (4) While the cook performs the cooking task, the carbon monoxide emission is recorded by the Control panel of Indoor air pollution meter, and relevant observations are recorded during the cooking tenure by both methods. (5) After the completion of cooking, the stop watch is off, and the finished time is recorded. (6) Remove the pot(s) of food from the stove and weigh each pot with food on the digital weigh balance. The observations of the same are recorded. (7) Remove the unburned wood from the fire and extinguish it. Knock the charcoal from the ends of the unburned wood. Weigh the unburned wood from the stove with the remaining wood from the original bundle. Place all of the charcoal in the designated tray and weigh this too. Record both measurements on the Data sheet and Calculation form.




(a) Traditional three stone method **(b)** Improved Double skirt Rocket Stove.

**Fig. 6.** (a, b) Experimental set up of IAP meter for recording carbon monoxide

## 3 Results and Discussion

### 3.1 Results

Based on the testing methodology, the measured results for the open fire stove and Modified double skirt rocket stove are presented in Figs. 7, 8, 9, 10, 11, 12.

Figure 7; depicts the results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for improved double skirt Rocket stove. However; it is observed from above figure that maximum intensity of carbon monoxide emission is 3.6 ppm recorded after 13 min; when cooking started in open shade; moreover, during these 13 min the fluctuations of Particulate matters from 0–152 ug/m$^3$ are observed. Furthermore the maximum flow of particulate materials in the atmosphere recorded is 191 ug/m$^3$ at 3.16 PM after a 19 min from the start of cooking food. Nevertheless; non-significant flow in fluctuations of Particulate matters and carbon monoxide are recorded upto the mid of cooking preparation; after that some significant changes in PM and CO are recorded for test 1 of Improved double skirt Rocket stove. Also; it is observed that the minimum and maximum intensity of carbon monoxide emission observed is as 0 and 3.6 ppm and the minimum and maximum intensity of particulate matters recorded is 0 and

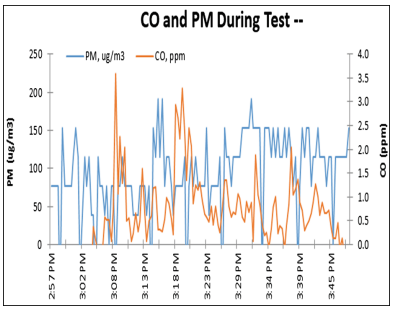



**Fig. 7.** CO and PM levels during IRS test-1

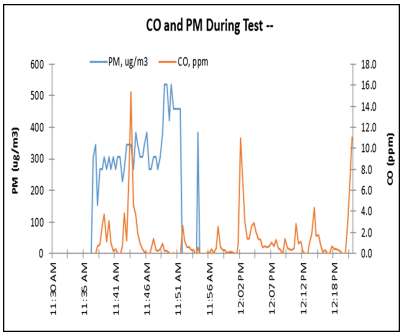



**Fig. 8.** CO and PM levels during IRS test 2

191 ug/m$^3$ respectively. Figure 8; depicts the second test results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for improved double skirt Rocket stove. However; it is observed from the above figure that maximum intensity of carbon monoxide emission is 15.4 ppm recorded after 13 min; when cooking started in open shade; moreover, during these 13 min the fluctuations of Particulate matters from 0–344 ug/m$^3$ are observed. Furthermore, the maximum flow of particulate materials in the atmosphere recorded is 536 ug/m$^3$ at 11.46 AM after 21 min from the start of cooking food. Nevertheless; non-significant flow in fluctuations of Particulate matters are recorded upto the mid of cooking preparation; after that zero value of PM recorded, however for carbon monoxide non-significant fluctuations are recorded from stat to end of testing. Also; it is observed that the minimum and maximum intensity of carbon monoxide emission observed is as 0 and 15.4 ppm and the minimum and maximum intensity of particulate.

Figure 9; depicts the third test results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for improved double skirt Rocket stove. However; it is observed from the above figure that maximum intensity of carbon monoxide emission is 13.2 ppm recorded after 18 min; when cooking started in open shade; moreover, during these 18 min the fluctuations of Particulate matters from 0–7903 ug/m$^3$ are observed. Furthermore, the maximum flow of particulate materials in the atmosphere recorded is 7,903 ug/m$^3$ at 04.07 PM after 4 min from the start of cooking food. Nevertheless; non-significant flow in fluctuations of Particulate matters and carbon monoxide are recorded for the complete test, also; it is observed that the minimum and maximum intensity of carbon monoxide emission observed is as 0 and 13.2 ppm and the minimum and maximum intensity of particulate matters recorded is 0 and 7,903 ug/m respectively. Figure 10; depicts the first test results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for Three stone open fire stove. However; it is observed from the above figure that maximum intensity of carbon monoxide emission is 22.9 ppm recorded after 12 min; when cooking started in open shade; moreover, during these 12 min the fluctuations of Particulate matters from 0–96 ug/m$^3$ are observed. Furthermore, the maximum flow of particulate materials in the atmosphere recorded is 96 ug/m$^3$ from 2.56 PM to 3.17 PM. Nevertheless; significant flow in fluctuations of Particulate matters are recorded and non-significant fluctuations of carbon monoxide are recorded for the complete test, Also; it is observed that the minimum and maximum

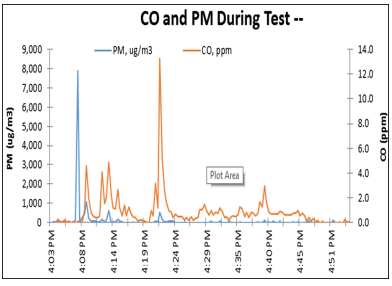



**Fig. 9.** CO and PM levels during IRS test 3.

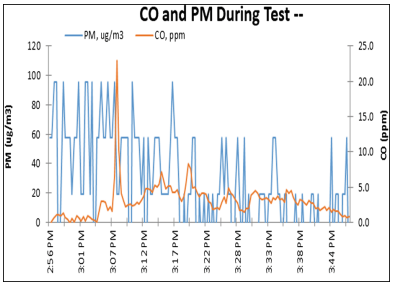



**Fig. 10.** CO and PM levels during three stone open fire test 1

intensity of carbon monoxide emission observed is as 0 and 22.9 ppm and the minimum and maximum intensity of particulate matters recorded is 0 and 96 ug/m$^3$ respectively. Figure 11; depicts the second test results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for Three stone open fire stove. However; it is observed from the above figure that maximum intensity of carbon monoxide emission is 8.6 ppm recorded after 30 min; when cooking started in open shade; moreover, during these 30 min the fluctuations of Particulate matters from 0–1,616 ug/m$^3$ are observed. Furthermore, the maximum flow of particulate materials in the atmosphere recorded is 1616 ug/m$^3$ after 8 min during cooking start. Nevertheless; non-significant flow in fluctuations of Particulate matters and carbon monoxide emission are recorded complete test, also; it is observed that the minimum and maximum intensity of carbon monoxide emission observed is as 0 and 8.6 ppm and the minimum and maximum intensity of particulate matters recorded is 0 and 1,646 ug/m$^3$ respectively.

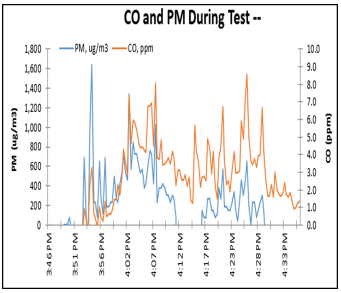



**Fig. 11.** CO and PM levels during three stone open fire test 2.

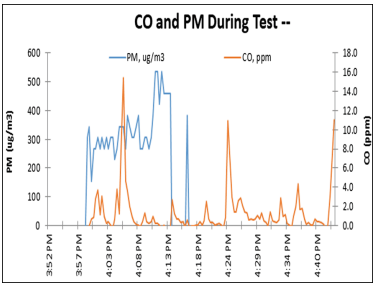



**Fig. 12.** CO and PM levels during three stone open fire test 3.

The comparative average test results of Indoor air pollution meter for recording Carbon Monoxide and particulate matters for Three stone open fire stove Double skirt rocket stove are presented in Table 1. Also Table 2 presents the Test results of Control cooling test for Three stone open fire stove and Double skirt IRS.

**Table 1.** Comparative results of average CO and PM levels for three stone open fire stove and double skirt IRS

| Particular | Double Skirt IRS | | | Avg | WHO std | Three stone OFS | | | Ave |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | | | 1 | 2 | 3 | |
| Avg CO, PPM | 0.306 | 0.962 | 0.542 | 0.603 | 4 | 3.19 | 3.13 | 0.962 | 2.43 |
| Avg PM kg/m | 84.51 | −93.59 | 38.68 | 9.870 | 25 | 7.1 | −962.27 | −93.591 | −349.5 |

**Table 2.** Test results of CCT for three stone open fire stove and double skirt IRS

| SN | Details of cooking | Unit | Test | | | Mean | Standard deviation | |
|---|---|---|---|---|---|---|---|---|
| 1 | Three stone stove | | 1 | 2 | 3 | | | |
| | TWfc | g | 57100 | 57100 | 57100 | 57100 | – | – |
| | Wcr | g | 2400 | 1750 | 1700 | 1950 | 391 | 391 |
| | Edwc | g | 28779 | 20985 | 40318 | 30027 | 9727 | 9727 |
| | Sfc | g/kg | 504 | 368 | 706 | 526 | 170 | 170 |
| | Tct | min | 57 | 59 | 58 | 58 | 1 | 1 |
| 2 | Improved Double Skirt Rocket stove | | | | | | | |
| | Twfc | g | 57100 | 57100 | 57100 | 57100 | – | – |
| | Wcr | g | 500 | 1250 | 1000 | 917 | | 382 |
| | Edwc | g | 16,487 | 18136 | 18286 | 17636 | 998 | 998 |
| | Sfc | g/kg | 289 | 318 | 320 | 309 | 17 | 17 |
| | Tct | min | 87 | 102 | 97 | 95 | 8 | 8 |
| 3 | Comparison TSOFS and IDSRS | | | | | | | |
| | | | % difference | | T-Test | Sig @ 95%? | | |
| | Sfc | g/kg | | 41% | −2.19 | | | No |
| | Tct | min | | −64% | −3.19 | | | Yes |

**Twfc:-** Total weight of food cooked, **Wcr:-** Weight of char remaining, **Edwc:-** Equivalent dry wood consum, **Sfc:-** Specific fuel consumption, **Tct:-** Total cooking time

### 3.2 Discussion

From Table 1; it is observed that the average of three experiments of 0.603 ppm value of carbon emission level is recorded for double skirt rocket stove. And for three stone open fire rocket stove average of three experiment carbon monoxide level recorded is 2.427 ppm. It means the that double skirt rocket stove is having 1.824 ppm carbon monoxide less as compared to three stone rocket stoves. However, the WHO recommends the safe value of carbon monoxide acceptable for human being is below 4.00 ppm in 24 h mean. However; the carbon emission level is safe in both cooking methods for using single stove. But for the commercial purpose there is a need to use a greater number of cooking stoves for cooking. Hence; if more than three stone open fire stoves used in a same cooking shade, the carbon emission level may exceed the value 4 ppm recommended by WHO guide line. While for double skirt IRS the value may not crossed the maximum value 4 ppm recommended by WHO in the same condition. Also, the average PM level for double skirt IRS observed in Table 1 is 9.87 ug/$m^3$ for three experiments. And for three stone the average of PM level for three experiments noted is −349.587 ug/$m^3$ means negligible. By following both methods, the value recorded is less than 25 ug/$m^3$ recommended by WHO. Hence; the double skirt rocket stove is safer and more suitable for cooking the food. CO and PM levels were significantly reduced with

the improved double skirt stoves. CO levels over the 24 h period is much lower than the maximum allowable exposure level recommended by WHO. With the improved stoves, CO level is reduced by 24.85% compared to the three stone open fire stove conditions. From Table 2; it is observed that, while using three stone open fire stove, it needs to add much fuel wood once in three direction. After burning is started, much amount of heat is dissipated to the atmosphere. In addition, cookers are exposed to heat, Particulate matters and carbon monoxide during cooking. This stove can cook 57.1 kg W about in 1 h. The mean specific fuel consumption of the stove in three tests is about 526 g/Kg. However, for Double skirt IRS is 309 g/Kg. During testing institutional rocket stove (IRS), Limited burning fuel is adding in the specified burning chamber. After burning is started, less amount of heat is dissipated to the atmosphere. In addition, cookers are not exposed to heat, particulate matters and carbon monoxide during cooking. This stove can take about 1:30 h to cook 57.1 kg W. However, the cooking time is somehow longer in improved double skirt rocket stove, the fuel consumption is better than three stone open fire stove by 41%.

## 4 Conclusion

From this study the following conclusions are made;

(1) During the test, the average specific fuel consumption of improved double skirt rocket stove observed is lesser than by 41% over the three stone open fire stove.
(2) The improved double skirt rocket stove helps to reduce the emission of CO concentration levels in the kitchen by 24.85%. However, the average of three experimental results the emission of carbon monoxide is 0.603 ppm, and PM is 9.870 for the double skirt rocket stove.
(3) The improved double skirt rocket stoves help to keep the kitchen and nearer surrounding area clean and hygienic and free from carbon monoxide, and kept the atmosphere free from smoke and soot which can severely spoil the food and make running nose and watery eyes. The improved stove can store only 200-l sizes cooking pot in the assigned skirt.
(4) The double skirt rocket stove is constructed from structural steels, sheets, clay and insulation materials (pumice) that help it to reduce the heat loss during cooking.

The improved double skirt IRS stove is ergonomically safe less hazardous and preferred to work on cool, smokeless kitchen, and helped cookers to maintain their strength throughout the day.

## References

1. Gaia Consulting Oy: Improved Cook Stoves Final Report GHG Mitigation and Sustainable Development Through the Promotion of Energy Efficient Cooking in Social Institutions in Ethiopia, p. 18 (2012)
2. Samet, J.M., Marbury, M.C., Spengler, J.D.: Health effects and sources of indoor air pollution (Part 1). Am. Rev. Respir. Dis. **136**, 1486–1508 (1987)

3. Gold, D.R.: Indoor air pollution. Clin. Chest Med. **13**, 215–229 (1992)
4. Cliff, J.: Indoor air pollution and acute respiratory infections in children. Lancet **339**, 396–398 (1992)
5. Koning, H.W., Smith, K.R., Last, J.M.: Biomass fuel consumption and health. Bull. World Health Organ. **63**, 11–26 (1985)
6. Kolhe, K.P.: Development and testing of tree climbing and harvesting device for mango and coconut trees. Indian Coconut J. **52**(3), 15–19 (2009). Published by Ministry of Agriculture, CDB board Kochi, Kerala
7. Kolhe, K.P.: Mechanized harvesting device a need of coconut growers in India. Indian Coconut J. **73**(2), 15–19 (2010). Published by Ministry of Agriculture, CDB Board Kochi, Kerala
8. Kolhe, K.P., Jadhav, B.B.: Testing and performance evaluation of tractor mounted hydraulic elevator for mango orchard. Am. J. Eng. Appl. Sci. **4**(1), 179–186 (2011)
9. Kolhe, K.P., Powar, A.G., Dhakane, A.D., Mankar, S.H.: Stability and ergonomic design features of tractor mounted hydraulic elevator. Am. J. Eng. Appl. Sci. **4**(3), 380–389 (2011)
10. Oluyamo, S.S., Bello, O.R.: Particle sizes and thermal insulation properties of some selected wood materials for solar device applications. IOSR J. Appl. Phys. **6**(2), 54–58 (2014)
11. Ghader, A.: Int. J. Adv. Appl. Sci. **1**(6), 31–36 (2014)
12. Celik, S., Family, R., Menguc, M.P.: Analysis of perlite and pumice based building insulation materials. J. Build. Eng. **6**, 105–111 (2016)
13. Bryden, M., et al.: Design Principles for Wood Burning Cook Stoves. Aprovecho Research Center, Cottage Grove (2002)