

Performance Evaluation of an Improved Dual Pot Cookstove

¹Zakari Z. I., ²Garba M.M., ¹ Zauro S. A, ³ Bature A.S., and ¹Sani U.

¹ Department of Energy and Applied Chemistry, Faculty of Chemical and Life Science, Usmanu Danfodiyo University Sokoto

²Department of Civil Engineering, Faculty of Engineering, Usmanu Danfodiyo University Sokoto

³Sokoto Energy Research Centre Sokoto, Usmanu Danfodiyo University Sokoto, Nigeria

ABSTRACT

Wood is an important source of energy that has been used for eras in cooking, boiling water, lighting, and heating. This study was carried out to evaluate the performance of a dual-pot improved cook stove. The designed stove's performance was contrasted with a standard charcoal stove that is readily available in the marketplace using standard methods. Water Boiling Test (WBT) and Controlled Cooking Test (CCT) were performed on the stoves. According to the WBT, the dual pot Improved Cook Stove's thermal efficiency, specific fuel consumption, burning rate, time to boil, and firepower were found to be 81%, 0.045, 0.0072 kg/min, 30 min, and 3700W, respectively. On the other hand, with the conventional charcoal stove, the results were 58.7%, 0.10, 0.0062 kg/min, 65 min, and 3200W, respectively. According to the CCT, the dual pot improved cook stove's specific fuel consumption and cooking time were found to be 0.136 and 52 minutes, respectively, and 0.232 and 83 minutes, respectively, for the conventional charcoal stove. The Improved Cook Stove reduces indoor air pollution, minimizes harmful effects on human health and reduces the money spent on fuel than the Conventional Charcoal Stove.

Keywords: Thermal efficiency, specific fuel consumption, cook stove.

INTRODUCTION

As the world's population has grown, energy consumption has risen steadily throughout time. Wood is an important source of energy that has been used for eras for cooking, boiling water, lighting and heating (Rehfuess, 2006). A third of the world's population, 2.5 billion people rely on the traditional use of solid biomass to cook their meals (IEA, 2017). Maria de Fatima *et al.* (2010) found out that traditional stoves are still the most prevalent way of cooking in the developing countries regardless of their inefficiency and risks associated to human health and the environment. According to Eleri *et al.* (2012), 72% of the population of Nigeria uses traditional fuel wood for cooking; they primarily cook on the conventional three-stone cook stove to do these tasks. Such cooking stoves are not efficient in energy use, and they also bring about environmental impacts like decline of forest and associated emission of greenhouse gasses such as carbon dioxide (Lee *et al.*, 2013). One would anticipate that Nigerians would have embraced new heating and cooking technology given the rise in technological development (Eleri *et al.*, 2012). In Africa, traditional stoves are commonly used in rural and semi urban settings, the most serious consequence of burning biomass in the home is the risk to expose

the cooks to respiratory and lung diseases. Women and children spend more time at home than men do, utilizing a less-efficient Residential fuel combustion device for cooking has emerged as one of the major sources of air pollution, which have a substantial impact on human health (Edwards *et al.*, 2004; Jetter *et al.*, 2012). The current inefficient cooking employed in the developing world have negative health impacts. Poor combustion efficiency in cooking stoves converts wood fuel into particulate matter, carbon monoxide and other gases that are responsible for health problems associated with indoor air pollution (Edwards *et al.*, 2003). Although, fine and ultrafine particulate matter emits during biomass combustion and this has been a significant concern to both regulatory authorities and environmental scientists due to their effects on human health and the environment. Thus, emphasis is then channeled on optimizing the performance of a biomass fuel stove in order to reduce emissions and improve energy efficiency, to address all the problems associated with the continuous use of biomass fuels in traditional cook stoves (Tafadzwa *et al.*, 2018).

The inefficient fuel combustion in traditional stoves release gaseous products with a higher global warming

*Corresponding author. E-mail: xeexah92@gmail.com

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potential than carbon dioxide, such as carbon monoxide (Ramanathan and Carmichael, 2008). So, burning wood fuel the traditional way has been criticized for its negative impacts on the environment and indoor health which has resulted in policies and campaigns to discourage its use (Bailis *et al.*, 2007). In order to reduce the usage of firewood in cooking, improved biomass cook stove is a viable alternative. Nigeria experiences one of the highest numbers of smoke related deaths in the world. Improved cook stoves are designed to be more efficient and environmentally friendly than traditional cook stoves; they can be used in a variety of settings, from rural households to commercial kitchens (Bailis *et al.*, 2009).

MATERIALS AND METHODS

Stove Performance Analysis

Two standard tests -Water Boiling Test (WBT) and Controlled Cooking Test (CCT), were carried out to evaluate the performance of the stoves.

Water Boiling Test (WBT)

Water Boiling Test (WBT) is a standard method for evaluating cook stoves performance based on boiling water. It was used to determine the thermal efficiency, the time to boil, the burning rate, the specific fuel consumption and the fire power of the stoves under same atmospheric conditions. The WBT version 3.0 of the Shell Foundation Household Energy Project reported by Bailis *et al.* (2007) was used to evaluate the stoves performances. It is an internationally known and well-defined protocol that can be used to test and compare any cook stove in the field or in the lab. This allows WBT results from any lab to be compared with those from other labs using other stoves.

The water boiling test (WBT) evaluated the stoves during two phases of operations: the high-power phase with a cold start and high-power phase with a hot start. After the setup, some environmental conditions that includes; wind speed and ambient temperature were recorded.

First phase: High power (Cold start) phase

Procedure: The timer was prepared; the pot was weighed prior to adding water and it was weighed again after addition of water. The thermocouples were placed in each pot to measure and record the initial temperatures. The charcoal was weighed and lit, and the time was recorded. The time water in the pot, boiled was recorded and the temperature was also recorded. The charcoal was removed, extinguished and weighed. The water temperature for pots on each stove was measured and each pot was weighed with its water.

Second phase: High Power (Hot start) phase

Procedure: The timer was restarted; the pots were refilled with fresh cold water and the pots with water were weighed and their initial temperature was measured. The charcoal fuel was kindled and the starting time was recorded. The thermocouples were placed in each pot to measure and record their initial temperatures. The time the water reached boiling point was recorded and the temperature recorded. After reaching the boiling point, the charcoal was extinguished, removed and weighed.

Thermal efficiency (H) is the ratio of the work done by heating and evaporating water to the energy consumed by burning wood (Bailis *et al.*, 2007). Mathematically,

$$H = \frac{4.186Ww(T_f - T_i) + 2260Wv}{F_d \times LHV} \quad (1)$$

Where:

ww = the mass of water in the pot in kg,

4.186J/g⁰C = the specific heat of water,

(T_f - T_i) = the change in water temperature in °C,

Wv = the of the amount of water evaporated from the pot,

2260J/g = the latent heat of evaporation of water.

F_d = the fuel consumed in kg,

LHV = the lower heating value of the fuel

Time-to-boil is the time it takes the amount of water to reach the boiling point. The time-to-boil in this WBT was recorded from the time the charcoal was considered lit until the water started boiling. (Bailis *et al.*, 2007). The charcoal was qualitatively determined to be lit when enough charcoal was burning such that the fire would not die out with the addition of a pot being set on it to heat.

Fire Power (P) is the ratio of the fuel energy consumed by the stove per unit time during the test (Bailis *et al.*, 2007).

Mathematically:

$$P = \frac{f_d \times LHV}{60(t_f - t_i)} \quad (2)$$

Where:

F_d = the fuel consumed (kg)

(t_f - t_i) = the final and initial duration of the test (min)

LHV = the lower heating value of the fuel (MJ/kg)

Specific fuel consumption (SC) is the ratio of the amount of fuel consumed to the amount of water remaining at the end of the trial, It can be defined for any number of cooking tasks, and should be considered "the fuelwood required to produce a unit output" whether the output is boiled water, cooked beans, or loaves of bread. In this case, specific fuel consumption refers to a measure of the amount of

charcoal required to produce 1 L (or 1 kg) of boiling water (Bailis *et al.*, 2007).

Mathematically:

$$SC = \frac{fd}{wwf} \quad (3)$$

Where,

Fd = amount of fuel consumed (g)

Wwf = the mass of water boiled (kg)

Burn rate (F) is the measure of fuel consumption to bring water to boil. It is the ratio of fuel consumed to duration of the test (Bailis *et al.*, 2007).

Mathematically:

$$F = \frac{1}{t} \times \frac{100(Wi - Wf)}{100 + M} \quad (4)$$

Where,

t = the total time taken for burning fuel (min)

Wi = the initial mass of the fuel before burning (kg)

Wf = the mass of fuel after burning in (kg)

M = the moisture content.

Controlled Cooking Test (CCT)

The CCT is an efficiency test that is designed to assess actual impacts on household fuel consumption using locally available fuels, pots, and local cooks (Kshirsagar and Kalamkar, 2014). The CCT is meant primarily to compare the performance of stoves through the specific fuel consumption (SC) and the total cooking time, in a standardized cooking task (Bailis *et al.*, 2004). The ambient temperature and wind speed were taken before the commencement of the experiment.

Procedure:



Plate 1: The improved cook stove

RESULTS AND DISCUSSION

The conventional charcoal stove consumed more charcoal 0.45kg for boiling 6.88kg of water than the Improved Cook Stove which used 0.24 kg of charcoal fuel to boil the same amount of water. Water in pot for the Improved Cook Stove and the conventional charcoal stove boiled at 99.70°C and 99.73°C respectively (Table 1). Table 2 shows the temperature

One kilogram (1kg) of the food (rice) sample was measured, the charcoal fuel was measured and then kindled. The timer was set and the time recorded. The time food cooked was recorded. The pots with food were weighed and recorded after cooking is done. The remaining charcoal was weighed and recorded.

Specific fuel consumption: This is the principal indicator of stove performance for the CCT. The specific fuel consumption as defined by the WBT 3.0 protocol (Bailis *et al.*, 2007) was adopted. Specific Fuel Consumption:

$$SC = \frac{fd}{wwf} \quad (5)$$

Where,

Fd = fuel consumed (g)

wwf = weight of pot with cooked food kg)

Total weight of food cooked (Wf) is the final weight of food cooked. It was simply calculated by subtracting the weight of the empty pot from the pots with the cooked food, after the cooking task is completed

$$Wf = Wwf - P \quad (6)$$

Where,

wwf = weight of pot with cooked food (kg)

P = weight of empty pot (kg)

Total cooking time (Δt): This is also an important indicator of stove performance in the CCT. This is calculated as a simple clock difference:

$$\Delta t = tf - ti \quad (7)$$

Where,

tf = finish time

ti = start time



Plate 2: The conventional charcoal stove

of water in both stoves as it boils with respect to time. The improved cook stove has a hot water pot which undergoes thermosiphon movement as water in the first pot boils. Pot 1 indicates the pot with water to be boiled in the improved cook stove, while pot 2 indicates the hot water pot incorporated to the improved cook stove. Pot 3 as shown in table 2 is the pot containing water to be boiled in the conventional charcoal stove. As seen in the table above, in the cold

start phase, the water in pot 1 boiled after 30 mins at 99.7°C and pot 2 reached 62.50°C while pot 3 boiled after 65 mins at 99.73°C that is an interval of 35min. In Uganda, analogous findings revealed that an average 27 min reduction of cooking time per household per day was achieved by the rocket Lorena cook stove (Habermehl, 2007).

Similarly, in the hot start phase were boiling of water started with an already hot stove, the improved cook stove boiled after 20 min at 99.40 °C while, the conventional charcoal fuel boiled after 45min at 99.70 °C that is an interval of 25min. As water in the improved cook stove boiled the hot water pot in the improved cook stove reached a temperature of 61.75 °C which is an added advantage over the conventional charcoal stove.

Table 1: Water Boiling Test WBT result

Parameters	Improved cook stove	Conventional charcoal stove
Weight of pot (kg)	0.76	0.76
Weight of pot with water (kg)	7.64	7.60
Final weight of water (kg)	5.35	4.50
Weight of water evaporated (kg)	1.53	2.37
Weight of charcoal (kg)	0.50	0.50
Residual weight of charcoal (kg)	0.26	0.05
Weight of charcoal used (kg)	0.24	0.45
Initial temperature of water (°C)	32.50	32.50
Final temperature of water (°C)	99.70	99.73
Ambient temperature (°C)	32.5	32.5
Wind speed (m/s)	1.1	1.1

Results for the overall performance of the Improved Cook Stove and the conventional charcoal stove with respect to thermal efficiency, specific fuel consumption, burn rate and fire power was shown in Table 3.

Table 2: Average values for Water Boiling Test

Time (min)	Cold Start			Hot Start		
	Improved cook stove	Conventional charcoal stove	Pot 3	Improved cook stove	Conventional charcoal stove	Pot 3
	Pot 1 (°C)	Pot 2 (°C)	Pot 3 (°C)	Pot 1 (°C)	Pot 2 (°C)	Pot 3 (°C)
0	32.47	32.47	32.47	33.33	33.33	33.33
5	43.00	35.53	35.53	50.37	36.63	42.17
10	54.77	38.50	39.30	68.10	44.70	52.33
15	72.20	46.00	43.37	87.30	52.77	64.93
20	84.53	50.57	48.37	99.40	61.75	76.97
25	93.50	59.15	53.93			84.53
30	99.70	62.50	59.90			92.50
35			65.53			86.10
40			76.10			92.20
45			83.30			99.70
50			88.63			
55			91.67			
60			96.10			
65			99.73			

Table 3: Results from WBT

	Improved cook stove	Conventional charcoal stove
Thermal efficiency %	81.0	58.7
Specific fuel consumption	0.045	0.10
Time to boil water (min)	30	65
Burn rate (kg/min)	0.0072	0.0062
Fire power (W)	3700	3200

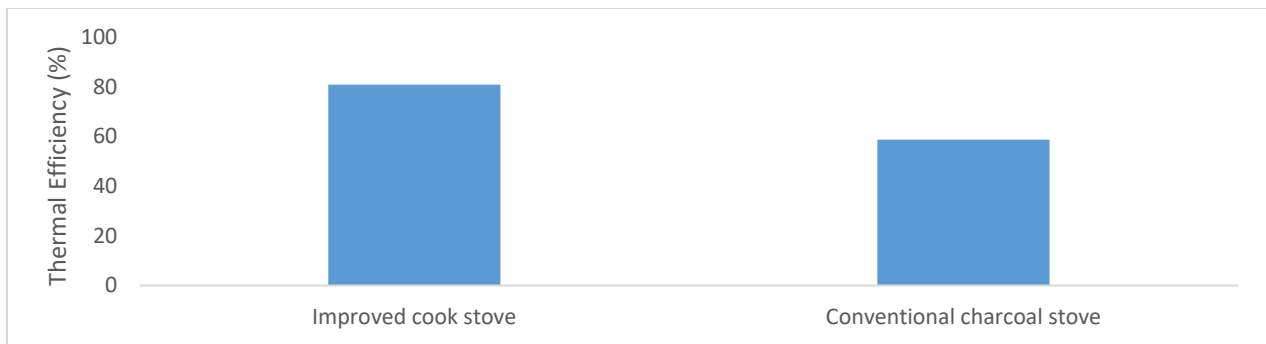


Figure 1: Thermal efficiency of improved cook stove and conventional charcoal stove from WBT

The thermal efficiencies of the Improved Charcoal Stove and the conventional charcoal stove were 81% and 58.7% respectively as shown in figure 1, which shows that the improved cook stove is 31.9% more efficient than the conventional charcoal stove. The

improved cook stove in this study has a higher thermal efficiency than some improved stoves in literature. A rocket stove made of galvanized sheet metal with a ceramic lining had a thermal efficiency of 28% (Mekonnen, 2022)

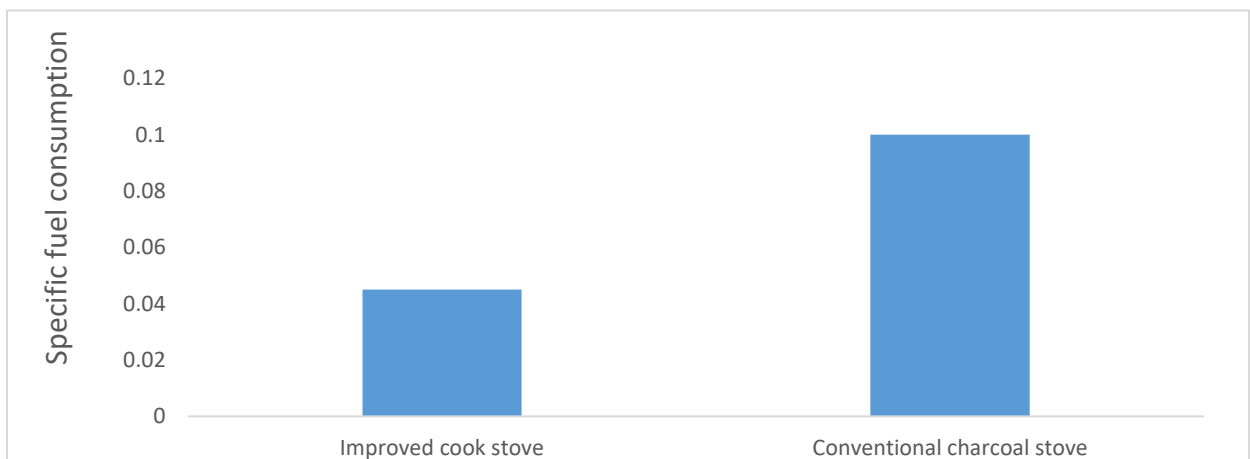


Figure 2: Specific fuel consumption of ICS and conventional charcoal stove from WBT

The conventional charcoal stove consumed more fuel according to the specific fuel consumption result in figure 2 where the conventional charcoal stove and the

improved cook stove consumed 0.10 and 0.045 respectively. Other findings in China, Guatemala, and the Gambia indicated that adoption of ICSs (improved

cookstoves) saved fuel by 40.1%, 39%, and 40%, respectively (DeWan *et al.*, 2013; Bielecki and Wingenbach, 2014; Mamuye *et al.*, 2018).

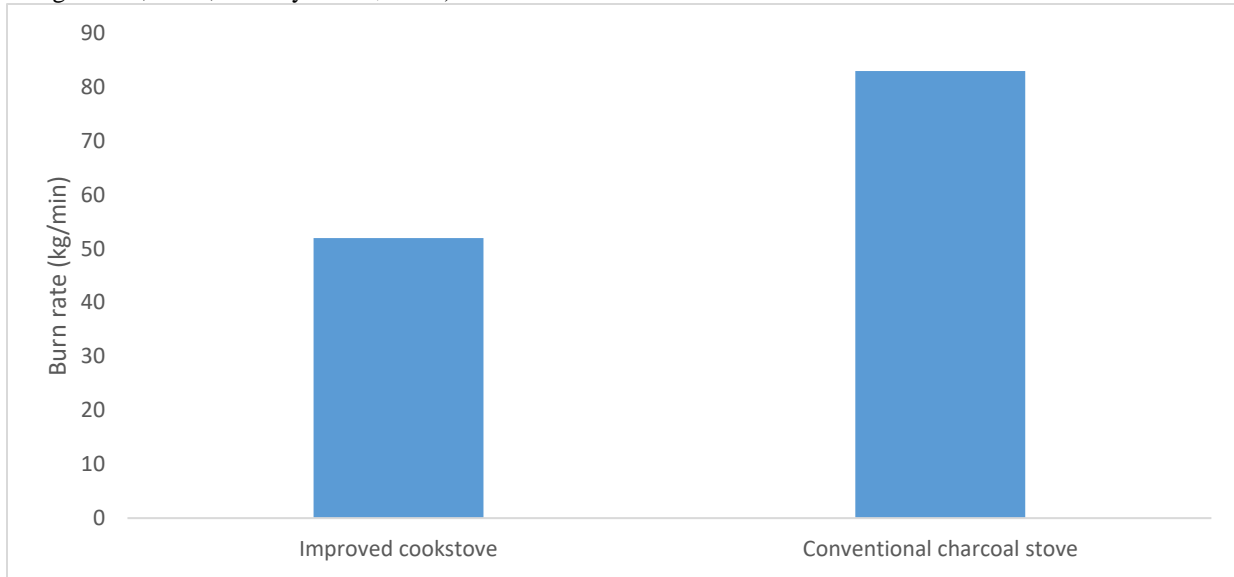


Figure 3: Burn rate of the improved cook stove and the conventional charcoal stove

The burn rate which measures how economically the stove burns the charcoal fuel in its combustion chamber is higher in the improved cook stove than the conventional charcoal stove, with the Improved cook stove having 0.0072 kg/min burn rate and the conventional charcoal stove having 0.0062 kg/min as

shown in Figure 3. Olorunisola (1999) stated that the advantage of a high burn rate during the combustion of a solid fuel is the enhancement of the self-sustenance of the fire. Khan *et al.* (2016) obtained 0.023 kg/min burning rate of a developed rocket stove.

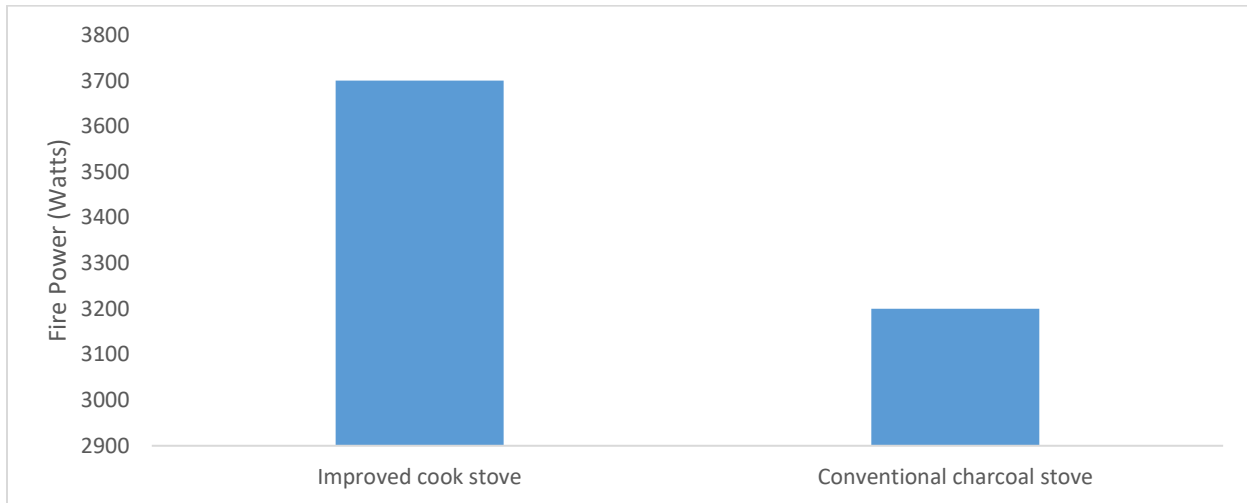


Figure 4: Fire power of improved cook stove and conventional charcoal stove from WBT

The fire power for the conventional charcoal stove is less than that of the improved cook stove which is 3.7 kW and 3.2 kW respectively as shown in figure 4, the fire power measures the ratio of the fuel energy consumed by the stove per unit time. From previous

studies on improved cook stove, a developed rocket stove obtained 6.5 kW fire power, which is the ratio of fuel energy consumed by the stove per unit time (Khan *et al.*, 2016).

Controlled Cooking Test Result**Table 4:** Controlled Cooking Test CCT result

Parameters	Improved cook stove	Conventional charcoal stove
Weight of pot (kg)	0.76	0.76
Weight of food to be cooked (Rice) (kg)	1.0	1.0
Initial temperature of pot with water (°C)	35.2	35.2
Final temperature of pot with water (°C)	99.67	99.87
Initial weight of charcoal (kg)	0.50	0.50
Final weight of charcoal (kg)	0.223	0.013
Time taken for cooking (min)	52	83
Weight of cooked food (kg)	2.03	2.10
Weight of charcoal used for cooking (kg)	0.277	0.487
Ambient temperature (°C)	35.0	35.0
Wind speed (m/s)	1.2	1.2

The weight of pots, initial temperature of water and quantity of charcoal fuel used for the experiment on both stoves was uniform. The environmental conditions with respect to ambient temperature and wind speed were the same. The amount of charcoal used for cooking 1kg of rice using the Improved Cook Stove was 0.277 kg which is less compared to the

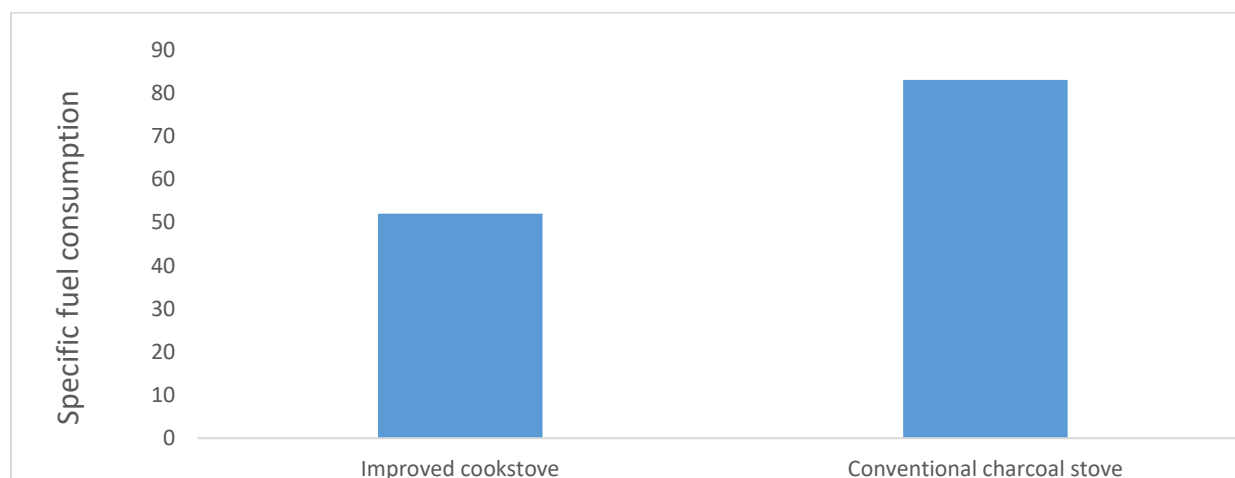
conventional charcoal stove which consumed 0.487 kg of charcoal to cook 1 kg of rice. The conventional charcoal stove took 83 mins, while the improved cooks stove took 52 mins to cook the same amount of food, which was 1kg of rice. The experiment was performed under the same atmospheric conditions for both stoves.

Table 5: Controlled Cooking Test (CCT)

Types of stoves	Specific Fuel Consumption	Time spent (min)
Improved cook stove	0.136	52
Conventional charcoal stove	0.232	83

Table 5 shows the specific fuel consumption and time spent for cooking 1kg of rice. The improved cook stove had a specific fuel consumption of 0.136 which

is less than that of the conventional charcoal stove which is 0.232. The time spent cooking using the improved cook stove

**Figure 5:** Specific fuel consumption of improved cook stove and conventional charcoal stove from CCT

The controlled cooking test is conducted to simulate real cooking more closely than the WBT in terms of

specific fuel consumption and time taken to cook. The controlled cooking test (CCT) provides the estimates

of fuel consumed by a given cook stove while performing a specified cooking task. From the result seen in figure 5, specific fuel consumption of the

conventional charcoal stove is higher than the improved cook stove, which was 0.232 while the improved cook stove consumed 0.136.

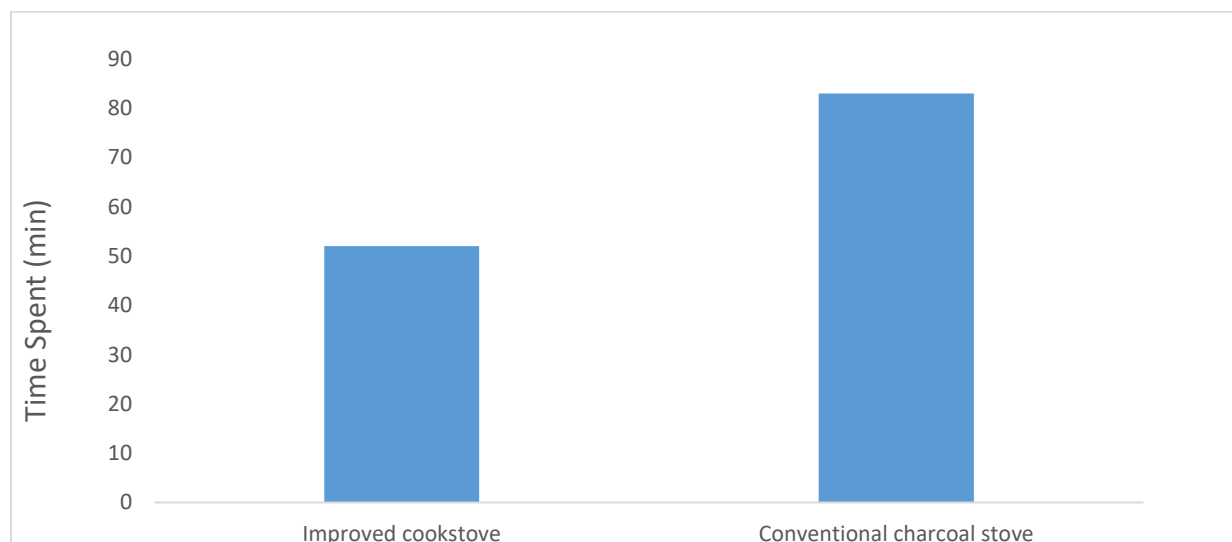


Figure 6: Time spent using improved cook stove and conventional charcoal stove from CCT

Time spent for cooking 1kg of rice using the improved cook stove was 52mins while the conventional charcoal stove took 83 mins as shown in figure 6, an interval of 31mins was recorded between the two stoves with respect to cooking time. Similar findings in Ethiopia were that improved charcoal stoves such as Mirchaye and Lakech save 13–17 min of cooking time per day as compared to the old-style metal stove (Mamuye *et al.*, 2018).

CONCLUSION

The results of the WBT and CCT conducted showed that the improved cook stove has a higher thermal efficiency from the WBT which was 81%, while the conventional charcoal fuel had a thermal efficiency of 58.7%. The improved cook stove had a lower specific fuel consumption of 0.045 and 0.136 for WBT and CCT respectively while the conventional charcoal stove had a specific fuel consumption of 0.1 and 0.232 for both WBT and CCT respectively. It shows the Improved Cook Stove is more efficient than the Conventional Charcoal stove.

The fire power and time to boil in the Improved Cook Stove was higher than that of the Conventional Charcoal Stove which was 3700W and 30 min respectively for the Improved Cook Stove while the Conventional Charcoal Stove had 3200W and 65min respectively. In the case of burning rate the conventional charcoal stove had a lower burning rate of 0.0062 kg/min while the improved cook stove had 0.0072 kg/min burn rate. From the results it shows that the improved cook stove is a better, more efficient and

is a more environmentally friendly cook stove than the conventional charcoal stove.

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