Development of an Improved Coal Stove for Cooking in Developing Countries

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Abstract

In this study, an improved coal stove was designed, fabricated and tested to evaluate the thermal performance of the stove. The performance of the stove was compared with that of traditional coal stove and conventional kerosene stove. The results obtained showed a better performance of the improved coal stove in terms of cooking duration and specific fuel consumption than that of the traditional coal stove and kerosene stove. The results also showed that the improved coal stove with coal burning rate of 0.15 kghr^{-1} can handle fuel more efficiently and economically than traditional coal stove, which has coal burning rate of 0.20 kghr^{-1}. The thermal efficiency of improved coal stove was found to be 42.6%, whilst those of kerosene and traditional coal stoves were 40.5 and 28.2%, respectively.

***Keywords**: Thermal performance, traditional coal stove, conventional kerosene stove, specific fuel consumption.*

Introduction

One third of the world's population of six billion lives in developing countries. Many of these people lack access to modern energy services for economic and social development and some of their present energy system is unsustainable (Smith 1993). And the emergence of perennial fuel crisis in the developing countries has drawn attention to the need for energy experts to further concentrate on producing viable alternatives and/or complements to kerosene and cooking gas for domestic cooking (Olorunsola 1999).

In some homes electricity is used for cooking but the supply is erratic, unreliable and a high percentage of the population in the developing world is not on the electricity grid. Gas burns quite efficiently but it is expensive and out of reach of the common man. Solar energy another possible alternative energy source is rather location-specific in terms of utilization. The associated problems of energy storage for use during the period of little or no sunshine also require technological artifacts that are presently very scarce in the developing countries (Bolaji 2005). Nearly 2 billion people, constituting about a third of humanity, continue to rely on biomass fuels and traditional technologies for cooking and heating (Momoh and Soaga 1999; Akinbami, *et al*. 2001; Johansson and Goldemberg 2002).

Traditional fuels such as biomass are quite difficult to burn completely in simple household-sized stove. The use of these fuels has a negative impact on the health of household members, especially women and children, when burned indoors without either a proper stove to help control the generation of smoke or a chimney to vent the smoke outside (Smith 1993). Traditional cook-stoves cause indoor concentrations of important pollutants, such as carbon monoxide, benzene and formaldehyde. Such exposures are linked to acute respiratory infections, chronic obstructive lung diseases, low birth weights, lung cancer and eyes problems (Kaoma and Kasali 1994). Therefore, accelerated technological effort is required to improve coal-stove and coal's environmental performance.

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Although coal stands out as an affordable, available and safe to store resources that is relatively straightforward to employ for domestic cooking, but the use of coal in inefficient stoves that waste resources and produce substantial amounts of indoor air pollution would be unsustainable. However, continual technology development will tame coal's disadvantages and allowed coal to be used with much greater efficiency and greatly reduced environmental impact.

The aim of this work is to use locally available materials to develop a more efficient, affordable and safe coal-burning stove in which the use of the stove will result in lesser consumption rates of fuel and reduce the indoor air pollution. This paper also reports the comparative performance analysis of an improved coal stove, a traditional coal stoves and the conventional kerosene stove.

Materials and Methods

Design Considerations

The following factors were considered in the design of the improved coal stove:

Costs of Production: The stove was constructed with locally sourced materials to keep the cost as low as possible to enhance affordability by low-income earners.

Ease of Manufacture and Subsequent Maintenance: The design of the stove was such that minimal technical skills as possessed by road-side artisan welders would be required in fabricating and subsequent replacing components parts of the stove.

Thermal Efficiency: The thermal efficiency of a cooking stove depends largely on how well the heat generated is transferred from the fuel to the pot (Olorunsola 1999). To achieve maximum heat transfer, the fuel-bed-to-pot distance was kept as close as possible to minimize heat losses. The procedure and formulae employed in the calculations of parameters were based on the approach use by Ahuja, *et al*. (1987); Danshehu, *et al*. (1992); and Olorunsola (1999).

The burning rate, R, corrected for the moisture content of the fuel was calculated using Eq. (1):

$$R(kghr^{-1}) = \frac{100(W_i - W_f)}{(100 + M)t}, \qquad (1)$$

where:
W_i = initial weight of fuel at start of test, kg;
W_f = final weight of fuel at end of test, kg;
M = moisture content of fuel, %;
t = total time taking for burning fuel, s.

The burning rate and the net calorific value, Q_{net}, of the fuel were used in the calculation of thermal efficiency, η_{th}, according to Eq. (2):

$$\eta_{th} = \frac{W_{wi}C(T_f - T_i) + (W_{wi} - W_{wf})L}{R \times t \times Q_{net}} \times 100\%, \qquad (2)$$

where:
W_{wi} = initial weight of water in the pot, kg;
W_{wf} = final weight of water in the pot, kg;
T_i = final temperature of water, ^{0}C;
T_f = initial temperature of water, ^{0}C;
C = specific heat capacity of water, kJkg^{-1}K^{-1};
L = latent heat of vaporization of water at 100^{o}C, kJkg^{-1}.

Description of an Improved Coal Stove

The commonly used traditional coal stove is a mere coal burning container with stands. It does not contain any features that will help in the effectively burning of the fuel and reduction of indoor pollution. The improved coal stove is shown in Fig. 1. It consists of two combustion units, the flue chamber and chimney.

The Combustion Units: The combustion units are where coal is burnt and heat is generated. They are mounted on the flue chamber. Each of the units consists of the housing, fire-box, air-inlet pipes and grate.

Housing: The housing was fabricated from mild steel sheet of 2 mm in thickness. It is a hollow cylinder of 215 mm in height and 230 mm in diameter. It houses the fire-box, it contains eight holes to accommodate air-inlet pipes and also bears the weight of the pot. Two handgrips are attached to the combustion unit to facilitate the easy carriage of the unit.

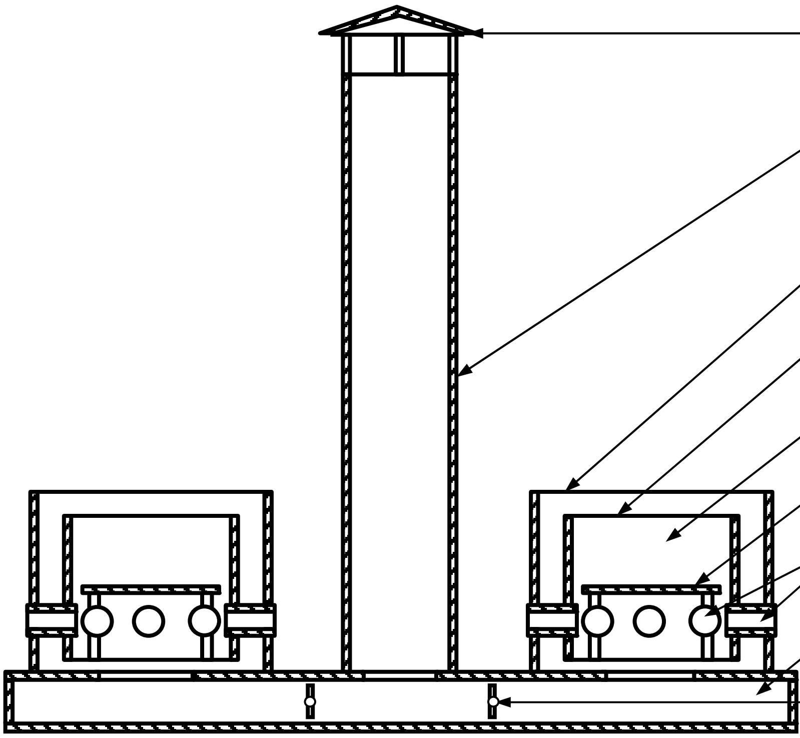

Fig. 1. The sectional front view of improved coal stove.

Fire-box: The fire-box is also made from mild steel sheet of 2 mm thick. It has dimension of 180 mm height and 160 mm diameter. It is where the actual combustion takes place. It contains eight holes to accommodate air-inlet pipes.

Air-inlet Pipes: They are mild steel pipes of 40 mm in length and 25 mm in diameter. They are eight in number and they serve as air passages from outside atmospheric air into the fire-box to aid combustion. They also fixed the fire-box to the housing and ensured firm connection between the two cylinders.

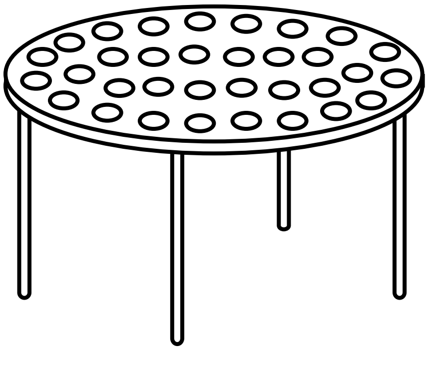

Fig. 2. Grate.

Grate: The grate is a metal frame for holding coal. It is made from mild steel sheet of 3 mm thick. Sufficient holes were drilled on the plate for easy air passage. The grate was supported by four mild steel rods welded to the plate; each of the rods is 6 mm in diameter and 60 mm in length (Fig. 2).

The Flue Chamber: Air circulation is important in order to keep the fire burning in the combustion unit. The draught is obtained in the stove with the help of the connection between the chimney, the flue chamber and combustion unit. The flue chamber is a rectangular flat box fabricated from mild steel sheet of 2 mm in thickness and 320 x 800 x 80 mm in dimension. The combustion units and the chimney pipe are mounted on the chamber as shown in Fig. 1. The flue chamber contains draught regulators or dampers. The function of the regulator is to control the volume of air admitted through the air-inlet pipes into the fire-box.

Chimney Pipe: The chimney pipe was fabricated from mild steel sheet of 2 mm in thickness; it is a hollow pipe of 820 mm in height and 110 mm in diameter. A metal cap was attached to the top of chimney to prevent gust from blowing into chimney pipe.

Performance Evaluation

The improved coal stove was set in the laboratory where a number of tests have been carried out on it. Two other stoves (traditional coal stove and kerosene stove) were also set in the same laboratory and were used in comparison with the improved coal stove. The apparatus used for the tests included three medium-size aluminium pots, a weighing balance, a stopwatch and matches.

Tests on Burning Rate

Tests on burning rate were carried out with the three types of stove. Appropriate fuel was charged into each stove and the initial weight of fuel at the start of test, the final weight of fuel at the end of test and the time taken to burn were recorded. This test was repeated two more times for the three stoves and the average burning rate value was calculate for each of the stoves.

Water Boiling Tests

According to Danshehu *et al*. (1992), Water Boiling Tests (WBTs) are short, simple simulations of standard cooking procedures. They measure the fuel consumed and time required for simulated cooking. WBTs are usually employed to investigate the performance of stove under different operating conditions to an expected stove performance. It is used by stove designers, researchers and field workers for quick comparison of the performance of stoves. The data obtained were used to compute the thermal efficiency for each stove using Eq. (2).

Controlled Cooking Test

The Controlled Cooking Test (CCT) is to compare the fuel consumed and the time spent in cooking of meal on different stoves. The tests were carried out with two food items (rice and beans). The controlled cooking tests enable the determination of the specific fuel consumption, which expresses the amount of fuel required to obtain 1 kg of cooked food. For each of the test that were carried out, the cooking pots were first weighed, after which 0.4 kg of food was placed in each of the pots which already contain 1.5 L of water. The weights of the fuel in each of the stoves before and after the tests were noted. The data collected were used in calculating the specific fuel consumption (SFC) using the following equations:

$$SFC = \frac{Mass\ of\ consumed\ fuel}{Total\ mass\ of\ cooked\ food}, \qquad (3)$$

$$SFC = \frac{W(1-M) - 1.5W_f}{m_{pf} - m_p}, \qquad (4)$$

where:
W = mass of fuel ($W_i - W_f$), kg;
M = moisture content of fuel, %;
m_{pf} = mass of the pot with cooked food, kg;
m_p = mass of the pot, kg.

Equation (3) was applied for kerosene stove and Eq. (4) was applied for both improved and traditional coal stoves. The specific fuel consumptions for the stoves are given in Table 1.

Time Spent in Cooking

The time spent in cooking per kg of cooked food is calculated using Eq. 5 and the results are given in Table 2.

$$Time\ spent = \frac{Total\ time\ spent\ in\ cooking}{Total\ mass\ of\ cooked\ food} = \frac{T_c}{M_f}, \qquad (5)$$

where:
T_c = Total time spent in cooking;
M_f = Mass of cooked food.

Result and Discussion

The burning rate obtained for the three stoves were 0.15 kghr^{-1}, 0.20 kghr^{-1} and 0.14 kghr^{-1} for improved coal stove, traditional coal stove and kerosene stove respectively. This result shows that the traditional coal stove had a higher burning rate than both improved coal stove and kerosene stove. The higher the burning rate the shorter the life span of the fuel, therefore, burning rate determines the life span of the fuel during combustion. It is often disadvantageous to have too high a burning rate. Hence the lower burning rates obtained from the improved coal stove and kerosene stove show that the two stoves handled fuel economically. The burning rate obtained in traditional coal stove was close to the 0.21 $kghr^{-1}$ obtained by Kaoma and Kasali (1994) from the test of coal briquettes in a Zambian clay stove. These results show that developing countries need a more efficient stove for cooking to replace the traditional stoves.

The thermal efficiencies obtained from the improved coal stove, traditional coal stove and kerosene stove were 42.6, 28.2 and 40.5%, respectively. The higher thermal efficiency of improved coal stove and kerosene stove was due to the minimal loss of convective heat current in the two stoves. Also, the higher burning rate of fuel in traditional coal stove lower the thermal efficiency of the stove since both parameters are inversely proportional to each other.

Fig. 3 shows the temperature rise versus time relationship obtained from the water-boiling test carried out with the three stoves. The result showed better performance of improved coal stove and kerosene stove than traditional coal stove. And the performance of the improved coal stove was slightly superior to that of kerosene stove. It took 12 min for 2 litres of water to boil on the improved coal stove, while the same quantity of water took 14 and 20 min to boil on kerosene and traditional coal stoves respectively.

The results of controlled cooking test (CCT) and time spent in cooking are shown in Tables 1 and 2. As shown on Table 2, the time taken to cook 0.4 kg of rice on improved coal stove, kerosene stove and traditional coal stove were 34.65, 39.50 and 52.55 min, respectively, while cooking 0.4 kg beans on these stoves took 45.90, 53.20 and 69.65 min, respectively. These results show that improved coal stove cooks food faster than the two other stoves. The specific fuel consumption of improved coal stove, kerosene stove and traditional coal stove obtained for cooking rice were 0.22, 0.24 and 0.41 kg/kg of cooked food, respectively, while 0.29, 0.32 and 0.54 kg/kg of cooked food respectively were obtained for cooking beans (Table 1). Although there is no much difference between the specific fuel consumption of improved coal stove and kerosene stove, nevertheless, the superiority of improved coal stove is demonstrated as the values obtained using improved coal stove were greater than that of kerosene stove.

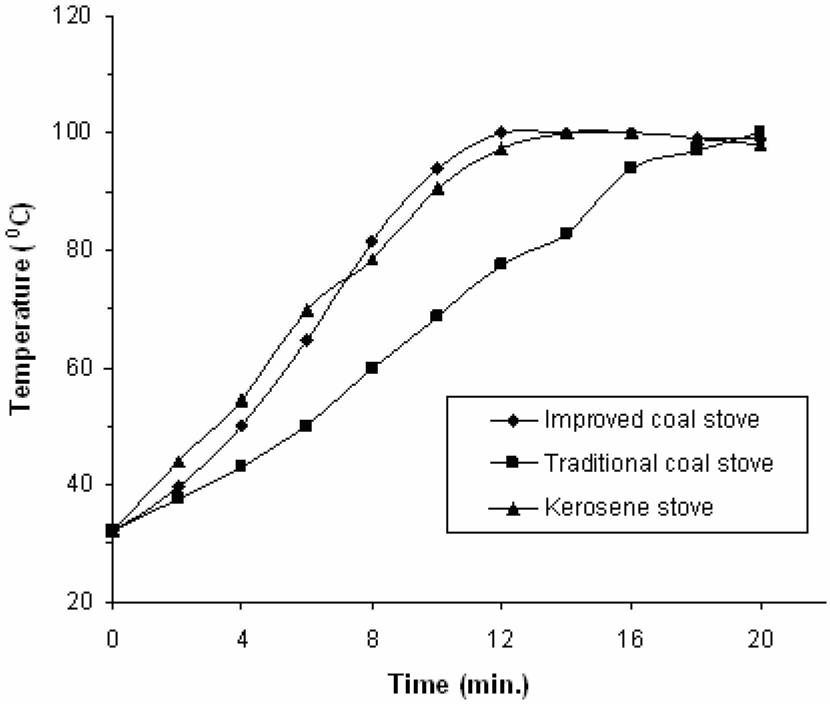

Fig. 3. Rate of temperature rise of water using improved coal stove, traditional coal stove and kerosene stove.

Table 1. Control cooking test (CCT).

Type of stove	Specific fuel consumption (kg/kg of cooked food)	
	Rice	Beans
Improved coal stove	0.22	0.29
Traditional coal stove	0.41	0.54
Kerosene stove	0.24	0.32

Table 2. Time spent in cooking.

Type of stove	Time spent in cooking 0.4 kg food (min)		Time spent in cooking (min/kg of cooked food)	
	Rice	Beans	Rice	Beans
Improved coal stove	34.65	45.90	86.63	114.75
Traditional coal stove	52.55	69.65	131.38	174.13
Kerosene stove	39.50	53.20	98.75	133.00

Conclusion

Larger percentage of the population in developing countries relies on biomass fuels and traditional technologies for cooking and heating. And the burning of biomass fuels in the traditional and inefficient cook-stoves has a negative impact on the health of household members. Therefore, in this study a more efficient coal-burning stove was designed, fabricated and the thermal performance of the stove was compared with that of traditional coal stove and conventional kerosene stove.

The results obtained showed that the improved coal stove with fuel burning rate of 0.15 $kghr^{-1}$ and kerosene stove with fuel burning rate of 0.14 $kghr^{-1}$ can handle fuel more economically than traditional coal stove, which has fuel burning rate of 0.20 $kghr^{-1}$. The results also showed a better performance of the improved coal stove in terms of cooking duration and specific fuel consumption than that of traditional coal stove and kerosene stove. The thermal efficiencies of the improved coal stove, kerosene stove and traditional coal stove were found to be 42.6, 40.5 and 28.2%, respectively.

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