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Flat Bottom Pot Institutional Cookstove: Assessing the Efficiency and Power with and without a Blower

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Abstract

Cooking is a vital part of life, and it is usually done on a cook stove. Cook stoves have seen various modifications and improvements along the lines of various reasons. For instance, there have been modifications based on fire control, usage, and size among others. In recent times, stove modifications are geared towards increased fuel efficiency and reduced emissions.

Improved cook stoves that run on solid biomass have the potential to increase the nutritional value of meals prepared with it. These stoves also have reduced emissions due to complete combustion and this can help curb indoor air pollution and its attendant problems.

The Applied Industrial Ceramics and Rural Enterprise Development Unit (AIC-RED) of Technology Consultancy Centre (TCC), KNUST, Kumasi, has developed and constructed an Institutional Cookstove. The stove was tested to assess its power and fuel efficiency with and without a blower forced draft. The stove had a power of 11.5 kW without a blower and 11.6 kW with a blower. The fuel efficiency was 47.4% without the blower and 54.5% with the use of a blower. The amount of fuel used for the stoves with forced and natural draft was 11.93 kg and 14.2 kg respectively, a difference of 2.27 kg. On the other hand the amount of charcoal produced by the stoves with forced and natural draft was 0.14 kg and 0.47 kg respectively, a difference of 0.33 kg.

Keywords: Institutional cookstoves; Water boiling test; Fuel efficiency; Power and forced air

Introduction

In the recent conference "Circular Bioeconomy Days – Focus on new protein sources for Europe" held in Aarhus University Campus Foulum, Denmark, it was made known that smoke is the third largest killer after AIDS and Malaria. Most of the cookstoves in Ghana use either fuel wood or charcoal as source of fuel. Fuel wood and charcoal form 75% of Ghana's total cookstove fuel according to [1]. This puts a lot of pressure on the forest reserves in the country. The rate at which wood is

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consumed from the forests far exceeds the growth rate of the forests in Ghana [2]. For people in developing countries, biomass fuels are a cheaper source of fuel for cooking and in some cases the only practical source of fuel for cooking. Emission of particulate matter, and for that matter black carbon emission, poses great health problems. It is suggested that the dominant proportion of this emission is from cooking with biomass fuels [3]. Cooking with biomass fuels also poses a threat as a great contributing factor to deforestation [4]. About 30 years ago, 32% of the world's population and 45% in the developing world relied mainly on wood fuel [5], but unfortunately with all the advancement in technology, the trend has not changed much. Most people still rely on wood fuel for cooking and heating.

The story is not different around most parts the developing world. There is global usage of biomass stoves, and this joined with increasing population growth can increase health risks as well as affect the environment negatively [6].

The Word Health Organisation (WHO) reports that about 3 billion people prepare their meals and heat their homes with poorly designed cookstoves that run on biomass globally. The death of close to 2 million people is as a result of inhaling polluted indoor air caused by the use of solid biomass fuels. High particulate matter in the air has adverse health effects on people. In a study in 1600 cities the average PM10 level was found to be 71 $\mu g/m^3$ [7].

Some specific illnesses associated with indoor air pollution include pneumonia in children under age five and Chronic Obstructive Respiratory Disease (CORD) that claims the lives of about 1 million people annually [8].

According to Aprovecho Research Center, some women in an effort to feed their families walk long distances to pick and gather fuel wood into heavy bundles and carry them home on their heads or on their backs. Some of these women are nursing mothers and must carry the heavy bundle of fuel wood and also carry the baby at their back or in front of them. Some of them are also at risk of being raped and humiliated by immoral people [9].

A study in Central America revealed that, exposure to smoke from a biomass stove and smoking three packs of cigarettes a day were no different in children [4]. The implications of rudimentary biomass stoves on global warming, human health and deforestation which leads to other environmental degradation like erosion and destruction of habitats of living organisms, calls for a worldwide development of improved cookstoves [9].

Inefficient cookstoves also contribute to the increasing amounts of greenhouse gases and black carbon (soot). This is because these stoves make use of biomass and/or fossil fuels, but do not burn them completely. Millions of people worldwide use stoves of this kind Inefficient and ineffective stoves and ovens of all kinds are a major source of black carbon aerosols, producing one-fifth of all black carbon emissions globally. The black carbon emitted from these cooking, roasting, and smoking devices, not, only contributes to climate change, but also disrupts weather patterns and accelerates the melting of snow, ice and glaciers, which many people rely on for drinking water and farming. The adoption of innovatively simple creative clean and efficient cookstoves and ovens is an important approach to mitigating climate change, as well as saving lives, environment and creating wealth as less fuel is used for larger quantities of food processing. In her research into the possible positive effect of using and promoting efficient institutional cook stoves[10], observed that there would be income- and employment-generation, the acquisition of new skills and knowledge, prevention of declines in soil fertility due to preserved trees and woodlots, protection of water, flora and fauna and maintaining the biodiversity due to preserved forest cover, reduction of other emissions due to avoided or on the other hand a more efficient combustion of fuel wood, which will create and raise the level of environmental awareness. [10] also remarked that the promotion of efficient institutional stoves would cause savings in wood that will go a long way to have rippling effect of reduction in fuel costs, preservation of forest reserves, and the reduction in greenhouse gas (emission of CO_2 and CH_4) due to avoided combustion, on one hand, and more efficient combustion of fuel wood on the other hand.

Stoves that serve the needs of many people or any stove that uses more than 20 litres of water are known as institutional stoves. These stoves are usually large in size and constructed firmly. They are used to cook, boil, heat, bake, roast or smoke food items and meals for schools, hospitals, prisons, factories, canteens, festivals, commercial eating places, among others[11] Good institutional stoves are stoves that are improved or advanced.

A stove qualifies to be an improved or advanced stove if it uses fuel efficiently, resulting in less fuel consumed, which translates into less money or time spent on buying or gathering fuel respectively. Another quality is that it should burn fuel cleanly, not only efficiently, hence reduce indoor air pollution and have a positive health implication for the users of the stove. The stove should also be appreciated by its users. The design and implementation of more efficient cookstoves which reduces the emission and uses less fuel to cook is therefore encouraged. Better designed cookstoves can reduce carbon monoxide (CO) and particulate matter (PM) emissions by 50-90% and at the same time increase the efficiency of fuel by 30-60% (depending on additional parameters like heat exchange and platform for steam cooking), with reference to an open fire with a three stone cooking configuration system. It has been observed that this is mainly due to an improvement on the combustion of the fuel because of its confinement in a designed combustion chamber [12]. The main contributions of the chamber enclosure are a better airflow control and reduced heat transfer losses by radiation and convection. This also improves combustion which as a result reduces emissions [12].

The idea of forcing air into a fire has been around for a long time. Blast furnaces work based on this principle. According to historians, China started using blast furnaces to make cast iron in the 5th century BC. When air is forced into a fire, it is able to increase the temperature and intensity of the flames. Forced air promotes complete combustion and hence causes a reduction in stove emissions [13]. On adding a fan to an improved stove that produced relatively less emission, [14] observed that there was further decrease in the emissions from the stove. Through the introduction of the fan, high velocity jets of secondary air positioned above the fuel bed increased the mixing of gases, smoke, air, and flame resulting in close to complete combustion [14]. In a Side Feed Forced Draft Stove, in which fuel wood was fed into the side horizontally, researchers did not have much success reducing emissions when jets of secondary air were introduced above the fire. However, when jet of air was introduced from under the fuel, blowing air up into the sticks and fire, the mixing of air-fire-gas-smoke resulted in lowered emissions. The emission was found to be $PM_{2.5}$: 4.5 mg/min, High Power at 3.3 kW and $PM_{2.5}$: 3.8 mg/min, Low Power at 1.4 kW [14].

There are three modes of heat transfer in a cookstove. These are conduction, radiation and convection. Among these, the major contributor is convection.

Heat transfer by convection in a stove occurs when a gas by natural or forced means flows into the fire and there is exchange of heat energy between particles through conduction. The velocity of gases flowing through the stove is one of the factors that influence the extent of heat transfer by convection. Forcing air into the combustion chamber of the stove with a blower can increase the velocity of the gases in the stove, this will result in an increase in heat transfer by convection and this can also increase the overall thermal efficiency of the stove [15].

Most restaurants and traditional eating spots in Ghana use biomass institutional cookstoves. These have no chimneys to direct smoke and heat outside the cooking area. Heat emitted from such stoves make the cooking area too hot for human comfort. The institutional cookstove used in this study, built and improved by TCC of KNUST in collaboration with SNV, has a chimney. During operation, the outer temperature of the cookstove does not go beyond ambient temperature of 30º Celsius.

The main objective of this study is to assess the impact of forced air on the power and fuel efficiency of an institutional Cookstove, the main objective of this study is to assess the impact of forced air on the power and fuel efficiency of an institutional Cookstove, assess the efficiency and power of the institutional cookstove and provide technical advice to stove manufacturers and entrepreneurs.

In his study of the impact of forced convection on the performance of cookstoves, Agenbroad observed that, with increase in the volume flow rate of the introduced air, combustion improved with a resulting increase in the temperature of the stove system [12]. FIG. 1 shows the trend observed by Agenbroad.

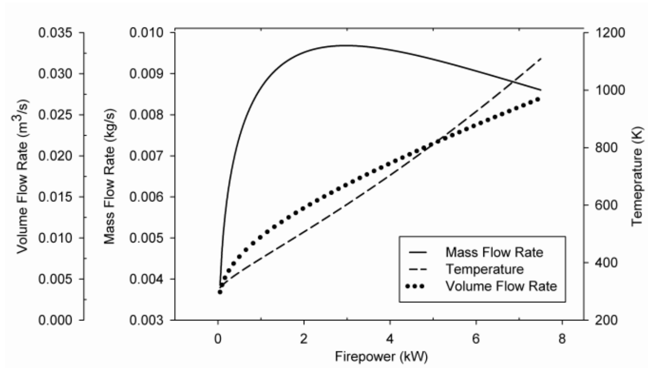

FIG. 1. **Mass flow rate, Temperature and Volume flow rate of air in a Cookstove Source: [12].**

In a study in [16] reported that about 90% of the institutional kitchens in Malawi depended on biomass for cooking and about 20-50% of the food budgets was on expenditure on energy because among the institutions surveyed, about 60% of Institutional cooking used technologies with highly inefficient stoves.

This study investigated the effect of forced convection on the efficiency of the cookstove. Forced draft was introduced using a bellow.

The flat bottom pot and institutional cookstove (IC)

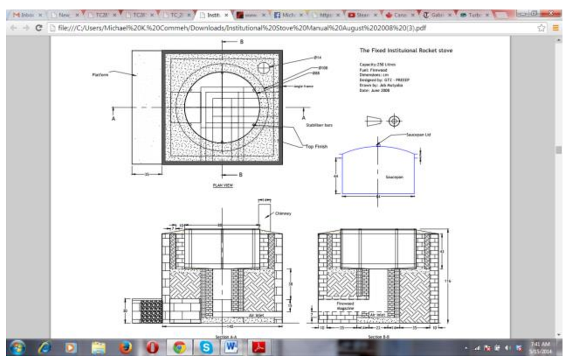

FIG. 2. **Institutional Cookstove (IC)**

The pot is a 3 mm thick stainless-steel metal pot, with a diameter of 84 cm and a height of 44 cm. It sinks into the institutional stove completely. The gap between the side of the pot and the wall of the IC is 2 cm without skirting as shown in FIG. 2. IC is built of dense normal clay brick with insulating bricks used for the combustion chamber and the wall, where the pot sinks into the brick insulation cavity that connects to the combustion chamber as shown in FIG. 3.

FIG. 3. **Flat Bottom Pot Institutional Cookstove**

Methodology

The assessment of the stove was carried out using the water boiling test. The procedure used is as follows: Initial readings and measurements were taken; fire was set in the stove and used to heat water to boiling point, with temperature build-up measured every five (5) minutes. The water was then allowed to boil for a period of time, and then final readings and measurements were taken. The power and efficiency of the stove were then calculated using collected data. The stove was tested first without a blower and later with a blower.

Results and Disscusion

The general definition of the power of a stove is the rate at which it uses or burns fuel. In this study power was defined as the rate at which useful heat is transferred into the pot. Hence, the useful power is the amount of energy in Joules transferred to the water per unit time and is dependent on the stove, fuel supply and the pot used to heat the water.

The efficiency of a stove is therefore the rate of production of energy per fuel wood consumption. Again, in this study, the efficiency of a stove is the ability of the stove to transfer more heat energy for its intended purpose with a minimum expenditure of fuel wood.

An energy input of 210.75 MJ yielded an energy output of 99.88 MJ, a power of 11.5 kW and a fuel efficiency of 47.40% when the stove was tested without a blower. The introduction of a blower increased energy output by 1.43 MJ, power increased by 0.1 kW and fuel efficiency by 7.1% even though the energy input was decreased by 24.8 MJ.

The increase in power and fuel efficiency could be attributed to the fact that the blower introduced enough air for complete combustion. That is, the introduction of blower, increased velocity of hot gases flowing through the combustion chamber or the riser from the forced air which also helped in the heat utility transfer, through the creation of votex. Since the velocity of the gases increased, the rate of gas impinging on the bottom surface of the pot and flowing along its sides increased and resulted in increased heat transfer and consequently, power and fuel efficiency. It was observed that there was more blue flame when the blower was used, than when natural air flow was used; an indication of good combustion resulting in lower emissions and very hot gases.

Parameters and equations for calculating power

Q_w=Useful Heat in Water

Q_e=Heat of Evaporated Water

Q_t=Total Useful Heat Transferred to Water (Energy Output)

C_w=Specific Heat Capacity of Water

C_w=4.186 J/g°C

M_w=Weight of Water

W_w=Weight of Water Evaporated

V=Specific Heat of Vaporation of Water

V=2,260 kJ/kg

ΔT=Change in Temperature of Water

t=Time used for test

t=145 mins=8700s

$$\boldsymbol{Qw = Cw \times Mw \times \Delta T} \text{ (1)}$$

$$\boldsymbol{Qe = Ww \times V} \text{ (2)}$$

$$\boldsymbol{Qt = Qw + Qe} \text{ (3)}$$

$$\boldsymbol{Power = \frac{Qt}{t}} \text{ (4)}$$

Parameters and equations for calculating efficiency

E_{fw}=Energy of Fuelwood
E_c=Energy of Charcoal
Q_{fw}=Total Energy produced by Fuelwood (Energy Input)
S_w=Specific heat combustion of wood
S_w=16 MJ/kg
S_c=Specific heat combustion of charcoal
S_c=35 MJ/kg

$$\boldsymbol{Efw = Sw \times Mfw} \text{ (5)}$$

$$\boldsymbol{Ec = Sc \times Mc} \text{ (6)}$$

$$\boldsymbol{Qfw = Efw - Ec} \text{ (7)}$$

$$\boldsymbol{Efficiency = \frac{Qt}{Qfw}} \text{ (8)}$$

TABLE 1 show the data collected during the testing of the stove without a blower.

TABLE 1: **STOVE WITHOUT BLOWER**

Ambient temperature	27.1°C
Initial temperature of water (T_o)	28.7°C
Maximum temperature of water (T_{max})	99.0°C

Weight of cooking container	38.2 kg
Initial weight of water (M_w)	104.4 kg
Final weight of water	73.8 kg
Weight of evaporated water	30.6 kg
Initial weight of fuelwood (M_{iw})	15.2 kg
Weight of fuelwood left (M_{lw})	1.0 kg
Weight of fuelwood used (M_{fw})	14.2 kg
Weight of charcoal produced (M_c)	0.47 kg

TABLE 2 Shows the data collected during the testing of the stove with a blower.

TABLE 2. **STOVE WITH BLOWER**

Ambient temperature	28.2°C
Initial temperature of water (T_o)	28.0°C
Maximum temperature of water (T_{max})	99.0°C
Weight of cooking container	38.2 kg
Initial weight of water (M_w)	104.4 kg
Final weight of water	72.8 kg
Weight of evaporated water	31.6 kg
Initial weight of fuelwood (M_{iw})	14.13 kg
Weight of fuelwood left (M_{lw})	2.2 kg
Weight of fuelwood used (M_{fw})	11.93 kg
Weight of charcoal produced (M_c)	0.14 kg

TABLE 3 Shows the data collected during the testing of Stove performance.

TABLE 3. **STOVE PERFORMANCE**

Test	**Energy Input (MJ)**	**Energy Output (MJ)**	**Power (kW)**	**Efficiency (%)**
Stove without blower	210.75	99.88	11.50	47.40
Stove with blower	185.95	101.31	11.60	54.50

Conclusion

The TCC Flat Bottom Pot Institutional Stove when tested without forced draft had an efficiency of 47.4%, with input power of 11.5 kW. While forced air gave thermal efficiency of 54.5% with 11.6 kW power. The use of forced draft from a blower made it more fuel efficient with low power and better energy efficiency. This showed in the less charcoal left, which is 0.14 kg, for forced draft test, as against 0.47 kg for natural convection. The use of this stove in institutional and commercial kitchens can help save funds spent on buying fuel wood and reduce indoor air pollution. The provision of chimney will reduce indoor air pollution drastically as emissions would be directed out of the kitchen. The higher input energy of 210.75 MJ but lower thermal efficiency (47.4%) is due to the fact the incomplete combustion created heavier particulate matter that could have hampered easy flow of hot gases to enhance heat utility into the pot. The lower input energy of 185.95 MJ but higher thermal efficiency (54.50%) is due to enhanced combustion due to less particulate matter. Forced draft can give higher thermal efficiency with low input power.

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