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Development and performance evaluation of a pressurized kerosene stove

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ABSTRACT

A pressurized kerosene stove was developed and evaluated for household use. The stove component consists of a kindler, a cut-off relief valve, a pressure pump and the burner assembly. The burner configuration is serpentine to cause initial delay in fluid flow before the nozzles. The test observation revealed a bright blue flame showing appreciable complete combustion with significantly low smoke emission. The performance efficiency of developed stove depends on fuel temperature at the nozzle, pump pressure and vapour to liquid mixing ratio. Comparing with liquefied stove, pressurized stove has enhanced performance than liquefied stoves.

Keywords: Pressurized kerosene stove, atomization, liquefied, nozzles

1. INTRODUCTION

Tackling the challenges of poor fuel economy and harmful emissions and adapting traditional stoves to burn specific fuel have been identified in literatures based on fuels they burn such as solid, liquid and gas fuels. Coal, gas, kerosene and electric stoves are considered as alternatives to biomass cooking for the developing countries. Fuels such as animal dungs, agricultural wastes, charcoal, wood, sawdust, biomass briquettes etc. are classified as solid fuels; kerosene, alcohol, waste crankcase oil, kerosene, diesel oil and other hydrocarbons are termed liquid fuels while biogas, natural gas, liquefied petroleum gas (LPG) are classifying as gaseous fuel. Furthermore, bio-fuels are significantly the commonest and cheapest sources of energy in domestic households and cottage industries. Above 80% of the energy utilization in developing countries were contributed by fossil fuel (Cherubini et al., 2009; Tanaka, 2010). Nearly in all developing countries of the world, cooking using biomass solid fuels, predominantly wood is common. On the national scale, as the Nigerian economy expands and serious deforestation from these activities, alternative fuel sources such as fuel atomization are required within the rural communities for sustainable economic growth. An approach to solving this problem is to improve the burning efficiency of the fuel, for example, by fuel atomization and introducing more fuel-efficient cookstoves.

Nevertheless, further improvements are ongoing to increase fuel efficiency, eliminate smoke and harmful emissions associated with combustion (Yuntenwi, 2008; Schreiner, 2011; Bello et al., 2015). Improvements in stove design seek to increase combustion efficiency, reduce heat loss and provide adequate draft and air-to-fuel ratio for complete combustion. Stove designers utilized the best parameter and conditions suitable for the intended stove development and utilization. Indigenous technologies had inspired solutions to engineering problems associated with stove development and the use of internally clay-lined stoves as one of the efficient innovations in evaluating the performance of low/medium sawdust briquettes (Adegoke and Mohammed, 2002).

These categories of fuel form the basis for further classification into the traditional stove technology (e.g., three stone fires, TSF), improved cookstove (ICS) and clean cookstoves (Johenls & Murray, 2013). The Improved cookstove technology is mainly used for stoves that have improved efficiency over the TSF and with a chimney or closed combustion chamber to remove smoke from the cooking area (The World Bank, 2011). Clean cookstoves are designed for more efficient energy, like electricity and Liquefied Petroleum Gas (LPG) (GACC, 2012). Majority of these devices produce inadequate heat besides being sources of harmful indoor pollution. It is estimated that, about 3000 and above people died every year in Nigeria because of indoor air pollution created and generated by inefficient kerosene or biomass combustion in cooking stoves (Kammen, 1995). Due to unreliable electricity supply and inadequate distribution in some area, the use of electric cooker solar cooker and biogas are still limited in the rural communities.

Kerosene stove (cooker) is a household device developed to satisfy the present day need of cooking. Household energy especially cooking energy mostly account for a big part of the general energy consumption in many civilized countries such as Nigeria. Recently, pressurized kerosene cooker came into existence in cooking activities due to the increasing cost of kerosene and the high rate of consumption of the fuel in cooking. However, the cost of commercial pressurized kerosene cooker is high and not within the reach of local consumes. To minimize these problems, this research was carried out to develop an efficient device for burning kerosene as an alternative to domestic cooking. The device was developed to discourage excessive wood exploitation and reduce the cost of using electricity for cooking. It is user-friendly, easy to operate and also reduce soot on the pot surface.

2. MATERIALS AND METHOD

Materials

Stove description

The stove comprises of a fuel tank, 1.6-1.8 bar hand pressure pump, Burner with suitable preheating pan, 3 fuel injection nozzles arranged at 120 degrees apart, a manual control device and a pin for mass flow rate of fuel (Figure 1). The fuel tank is cylindrical and serves as reservoir with 8 litres capacity. There are three openings on the tank; one for the pressure relieve valve, the other for kerosene supply while the third opening is for fuel supply to the nozzles. Two valve types are installed on the tank; pressure relief value and pressure control valve. The pressure relief valve protruded at 2.5cm above the cylinder and used to relief excess pressure from the tank (cylinder) when the pressure is high in the system/ tank / cylinder and also serves as pressure inlet to the tank (cylinder). The inlet pressure control valve is made of a stopcock valve which regulates the flow of liquid or gas through a pipe from the reservoir.

Figure 1 Experimental device setup

The copper pipe is a 6mm diameter reddish brown nonferrous metallic material, with desirable properties such as good heat conductivity, corrosion resistant, malleable and ductile for fluid flow. Attached to the tips of the copper pipe are three copper nozzles (1mm diameter) arranges at concentric 120° having the same desirable properties as the copper pipe with an orifice for fuel atomization during combustion. The nozzles are used to direct the flow of the atomized fuel (Bernoulli's principle applies in nozzle where flow accelerates and pressure drops as the live diameter is reduced. Nozzle size determines the color of flame. The smaller the nozzle, the bluer flame it gives (Ifeanyichukwu et al., 2012). The pressure pump is a device for moving liquid or gas when pressure is applied. The pump comprised of valves mechanically actuated to control the flow of fluid.

The pot stand was constructed of 2.5mm thick angled iron 40cm high and 40 by 40cm wide to support the cooking utensils such as pots, kettles and also secures the burner below. Three metal cups made of tin foil cups of 75mm diameter were each clamped to the steel pipe and positioned under each of the three nozzles to generate initial heart required to vaporize kerosene flowing through the serpentine copper pipe, for quick kerosene atomization through the nozzle in form of vapour.

Fuel

Kerosene as a fluid is extracted from crude oil and if lit produces heat. It is a source of heat especially in cooking and other heat consuming substance that requires it. Kerosene does not evaporate easily if ignited to produce heat, it is a by-product of crude. Its properties include: Colourless to pale straw liquid with a characteristic odour, Boiling range at 760 mmhg: 151 – 301 degrees Celsius, Vapour density: 0.5mmhg at 20 degree Celsius, Density: 810kg / cubic meter, Specific gravity: 0.81, kinematical viscosity: 0.17651 meter squared per second (Rajput, 2004).

Methodology

Design considerations

Tank design

The cylindrical tank was designed to hold the pressurized kerosene, made of 2mm thick mild steel welded together by welding. Among other considerations in material selection are hardenability, corrosion resistance, cost, tensile strength, weldability and ductility. The normal stresses in the cylinder equilibrates against internal walls requiring good material is used to avoid failure and bursting. By these analyses, the tank volume is evaluated from the expression

$$Volume\ of\ kerosene\ needed\ = \frac{Mass}{Density}\ (ml^3) \quad 1$$

Thickness of the wall of the tank is 0.01m.

The pressure required in the tank to drive the kerosene is obtained from Bernoulli's theory as

$$P_2 = \frac{l_k G^2}{2} + P_1 \quad 2$$

$$G = \frac{M_k}{l_k A_n} \quad 3$$

Where,

P_1 = atmospheric pressure = 101.325 kPa

P_2 = pressure required to pump kerosene from the tank

Area acted upon by the stress A_r is given by:

$$A_r = \ 2\pi r^2 + rxL \quad 4$$

Pump design

The pump is a piston-type air delivering system moving in one direction (single acting). Pressure delivery is limited by the rate of pumping and strength of the pumping house. In pump design, weight and ease of pumping are considered. The pump has a flexible leather washer at the top of the piston. When the piston is extended, air expands and pressure is reduced below atmospheric, allowing air to flow past the leather washer into barrel. The piston then pushes down, compressing the air below it with each stroke of the piston. The maximum pressure developed is limited by the rate of pumping and operator strength. The force, the piston produced depends on air pressure and surface area of piston.

Fuel atomization

The fuel contained in the fuel tank is pressurized through an air-pump (Kammen, 1995) primed by hand to atomize the liquid. Atomization (continuous breaking down of liquid phase fuel into discrete vapour droplets) was achieved by preheating the burner with the help of a wick provided; then the burner transfers the heat to the kerosene as it passes through the pipe while the absorption of heat by the kerosene results in the vaporization. During this process the surface area of the liquid increased, giving it greater affinity with atmospheric oxygen for proper and efficient combustion (Ababio, 2004).

Stove burner system

A pressure type burner that utilizes the principle of pressurization and preheating to vapour (atomization) fuel which passes through the nozzle and is ignited to heat up the utensils was selected for the design.

Burner nozzle

An oil burner nozzle was selected to promote efficient combustion of fuel (Figure 2). The nozzles supplied the required atomized quantity of heated fuel into the combustion chamber to ensure complete combustion as much as possible.

Figure 6 Fuel burner nozzles selected

Preheating coil design

Various studies were conducted on preheating coil designs to find an optimal geometry for sustainable preheating. Spiralled coil was considered optimal geometry for efficient preheating because of the ability of the combustion flames to reach the largest surface area of the copper coil.

Operation

To ignite the stove, the burners are first pre-heated by the metal cup under the nozzles with the help of charcoal and kerosene in it, then light it with a lighter. Once heated the cylinder (tank) is pressurized with the help of a medium hand bump integrated into the cylinder (tank) which increase the flow rate of the kerosene from the tank (cylinder) to the burner chamber up through the rising pipe or tube. After pressurizing the kerosene, the connect the hose to the rising pipe and the burner pipe and hold it with a clip, then open the stop cock and allow the pressurized kerosene to get to the nozzles, allow the kerosene to atomize (heated) for some seconds, then light the burners and place your pot on top of the frame. Additional pumping increases the pressure in the cylinder (tank) which makes the flame larger; a touch on the relief value will release pressure from the cylinder and makes the flame smaller.

Performance evaluation

The effectiveness of the kerosene burner was evaluated based on the fuel supply rate to the burner and the physical size of the burner (design) and materials used according to Ifeanyichukwu et al., (2012).

3. RESULTS AND DISCUSSION

The developed stove under test was shown in Figure 3; (a) the ignition stage the stove burning with yellow flame, Figure 3b control of atomized fuel sprays and Figure 3(c) shows the equilibration in nozzle spray pattern with reasonable level of atomization from the three nozzles. Series of tests carried out on the stove as shown in the figures below showed.

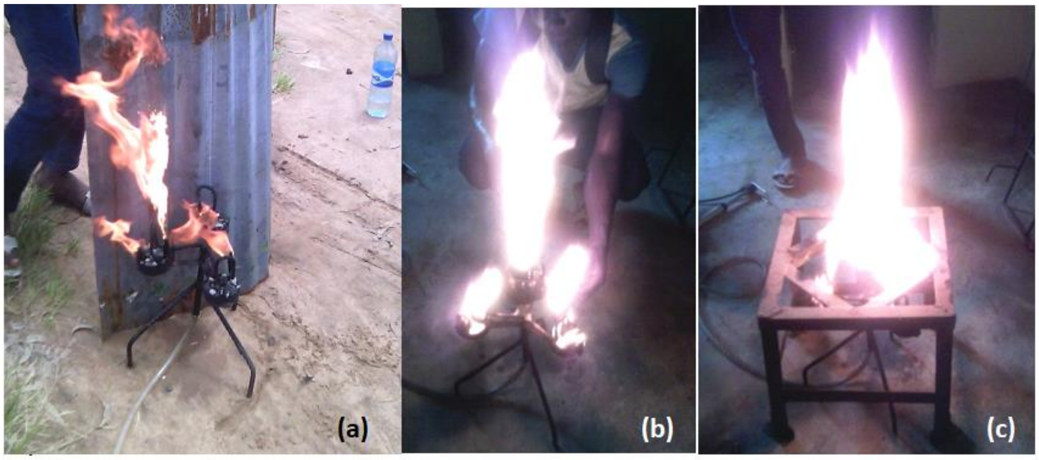

Figure 3 Flame test a) ignition b) atomization c) equilibration

Performance evaluation was done by cooking 1kg of rice and the results are shown in Table 1. The compression noise level was generally low while the flame colour varied from bright blue flame at high pressure of 50kPa to yellowish sooty flame at low pressure of 20kPa. This result showed that atomization increased with pressure and consequently affect the flame colouration. Time taken to cook 1kg of rice varied between 25 minutes and 90 minutes at highest and lowest pressures respectively.

Table 1 Stove performance evaluation

Pressure (kPa)	Compressor noise level	Flame colour	Flame length (mm)	Nozzle dia (mm)	Time of cooking (hr)
50	Low	Bright blue	10	1	0.45
40	Low	Blue	9	1	0.85
30	Low	Pale blue	9	1	1.30
20	Very low	Yellowish sooty flame	7	1	1.50

Table 2 shows the comparative performance evaluation of the developed pressurized stove and generally available liquefied stove. From the table, the fuel consumption rate is lower for pressurized stove than other kerosene stoves (Table 2), thereby reducing greenhouse effects (Kammen, 1995). Pressurized stove has better performance in blue flame production and smokiness. However, the performance efficiency is lower for pressurized stove.

Table 2 Comparison of pressurized stove with liquid stove

S/No	Pressurized stove	Liquefied stove
1.	Low fuel consumption	Consumes more fuel
2.	Bright blue flame produced	Produced yellowish blue flame
3.	1mm diameter nozzles used	Nozzle not available
4.	Atomized kerosene used	Uses liquid kerosene
5.	Completely eliminated smoke	Traces of sooty smoke experienced
6.	Clean energy produced	Energy produced with soot traces
7.	Lower average efficiency	Higher average efficiency

Figure 2 shows the comparative performance efficiency of pressurized stove and liquefied stove during the cooking of 1kg of rice. From the figure, the liquefied stove has a relatively uniform efficiency due to the constant pressure compared with pressurized stove at different pressures. At the highest pressure of 5kPa, the stove has an efficiency value of 43, 46% and burn with characteristic bright blue flame, compared to higher efficiency value of 64.12% with yellowish sooty flame which is not suitable for domestic applications.

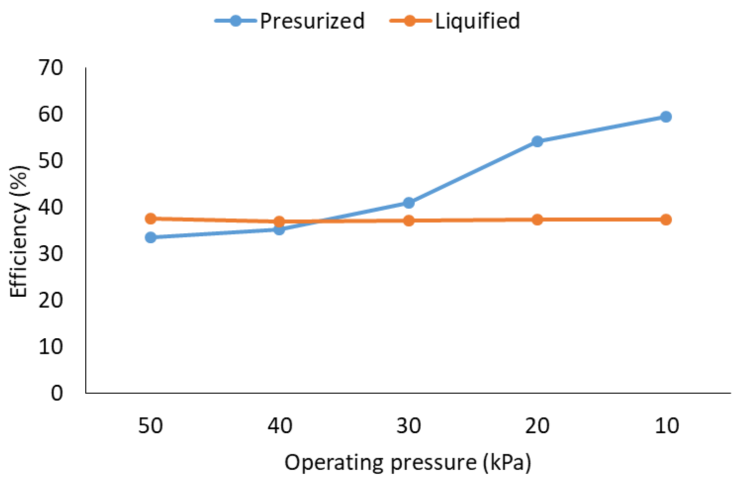

Figure 2 Comparative analysis of stoves performance efficiencies

4. CONCLUSIONS

From the results of the combustion tests, the following conclusions are made.

A pressurized kerosene stove was developed which was able to completely atomize fuel and burn without smoke (indicating complete combustion).

Significant improvement in fuel atomization was observed with the inclusion of preheating cups.

The performance efficiency depends on fuel temperature at the nozzle, pump pressure, and vapour to liquid mixing ratio.

Pressurized stove performance was better than liquefied stoves.

Ethical issues

Not applicable.

Informed consent

Not applicable.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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