Improvement Design of an Existing Atomized Kerosene Stove for Better Performance

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Abstract

The existing atomized kerosene stove being used in some households in Nigeria does not give room for primary air fuel mixture but secondary one before combustion. This in turn leads to higher specific fuel consumption and ultimately lower thermal efficiency (resulting from low combustion efficiency) of the stove. In order to arrest this situation, there is a need to redesign the existing atomized kerosene stove. To this end, this work improved the existing atomized kerosene stove by making improvement design on its inlet unit through the introduction of primary air inlet in addition to the existing secondary air inlet and pre-mixing chamber at the throat with the limitation that the improvement does not take in to consideration the degree of mixing of air fuel mixture. The work tested the improved and the existing designs, the result of the test show that the improved design has a better thermal efficiency in a way of 70% compare to the existing design with thermal efficiency of 50%. Also the fuel consumption rate (SFC) of the existing design is 0.34 kg of fuel/kg of water evaporated while that of improved design is 0.30 kg of fuel/kg of water evaporated. It was concluded that the improved atomized kerosene stove is more thermally efficient and has an improved fuel consumption rate over the existing stove.

Keywords: Improvement design, atomized kerosene stove, combustion efficiency, specific fuel consumption

Introduction

Many cooking devices have been manufactured to facilitate the process of cooking. These devices use different kinds of fuels such as gas, wood, kerosene, charcoal and others (Dansheu, 1992; Raiyani, 1993; Kammen, 1995 and Kersten, 1998). Prominent among the cooking devices is the kerosene stove. Kerosene is more readily available both in the town and cities, hence the popularity of conventional wick-kerosene stove in many homes (Moh, 2010). An improvement on the conventional wick-kerosene stove is the atomized kerosene stove in which the kerosene is pressurized with the aid of a pump (Ifeanyichukwu et al., 2012). The fluid flow is due to pressure difference between the fuel tank and the stove orifice. There is also pre-heating of the kerosene before the orifice which leads to atomization of the fuels at the exit from the orifice. Moh, 2010 and Ejilah et al., 2013 stated that there is a need for atomization because actual combustion processes are hardly ever complete even in the presence of excess air.

In an effort to develop economical means of cooking, different people and institutions have come up with different designs and innovations of cooking gadgets. Nevertheless, each design comes up with its peculiar limitation especially with reference to the environment in which it is being used. For instance, the burner in the existing design of the atomized kerosene stove is designed in such a way that it allows pre heating by allowing the fuel/kerosene to travel through the pipe above the provided pre-heating cup. In essence, a pre-measured highly flammable fluid is poured into the pre-heating cup and is ignited with or without the wick provided. After, the kerosene is allowed to flow, as the kerosene flows, its temperature increased due to heat transfer mechanisms. Subsequently, this leads to its (kerosene) atomization when trying to escapes from the orifice (Moh, 2010). The atomized kerosene at the point of escape mixes with the air in the surrounding and the premixed fuel is combusted. It is important to note that at the beginning, atomization is first enabled by the reason of preheating taken place at the preheating cup and combustion first begins by the application of fire first introduced through matches (Ifeanyichukwu, 2012). Subsequently, further and continuous atomization, air-fuel mixing and combustion is enabled by continuous flow of the pressurized kerosene through the orifice (Ejilah et al, 2013). In view of low thermal efficiency (resulting from low combustion efficiency) and higher specific fuel consumption of the existing atomized kerosene stove, this work improved the existing atomized kerosene stove by making improvement design on its inlet unit through introduction of primary air inlet in addition to the existing secondary air inlet and pre-mixing chamber at the throat.

Methodology

Theoretical analysis

Chemistry of kerosene combustion

Although liquid hydrocarbon fuels are mixtures of many different hydrocarbons, they are usually considered to be a single hydrocarbon for convenience. For example, gasoline is treated as octaneC_8H_{18}, and the diesel fuel is dodecane$C_{12}H_{26}$. Since kerosene is of the alkene family (C_nH_{2n+2}) and is found within the range of carbon chain of$C_8 - H_{12}$, for the purpose of this analysis an average value of C_{10} is used; that is, when n=10 the kerosene becomes$C_{10}H_{22}$. The general equation of combustion of fuel (hydrocarbon) in air (oxygen) is:

$$C_xH_y + a(O_2 + 3.76N_2) \rightarrow bCO_2 + dH_2O + eN_2 \quad (1)$$

Further analysis gives:

$$C_{10}H_{22} + 15.5(O_2 + 3.76N_2) \rightarrow 10CO_2 + 11H_2O + 58.28N_2 \quad (2)$$

This implies that I mole of kerosene requires 15.5 moles of oxygen (73.78 moles of air) to burn it properly.

Analysis of flow through pipe

In dealing with energy loss, Bernoulli's equation (eq. 3) is applied.

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 \quad (3)$$

Where: P_1 = Pressure in the cylinder; P_2 = Atmospheric pressure; D_1 = Diameter of pipe; D_2 = Diameter of orifice; A_1 = Area of pipe; A_2 = area of orifice; ρ = Density of kerosene; V_1 = velocity of kerosene in pipe; V_2= velocity at the orifice; L = approximate length of pipe and g = Acceleration due to gravity. Bernoulli's theorem essentially states that for an ideal flow, the potential energy due to the pressure, plus the kinetic energy due to the velocity of the flow is constant. In practice, with flowing through a pipe, Bernoulli's theorem must be modified, thus an extra term must be considered to allow for energy loss due to friction in the pipe. Thus:

$$\frac{P}{\rho} + \frac{V^2}{2g} - f = constant \quad (4)$$

Where *f* is the frictional loss

Using compressible flow theory, mass flow rate through a nozzle of area A is:

$$\dot{m} = C_d \rho_o A \sqrt{2\left(\frac{\left[\frac{\gamma}{\gamma-1}\right]\frac{P_o}{\rho_o} r^2}{\gamma\left(1-r^{\frac{(\gamma-1)}{\gamma}}\right)}\right)} \quad (5)$$

Where: P_o= Pressure of gas upstream of nozzle; ρ_o= Density of gas upstream nozzle; r = $\frac{P_1}{\rho_o}$ and P_1= Pressure downstream of the nozzle. The flow rate (Q) of liquid (kerosene in this case) through orifice is equal to the product of velocity (V) of the flow and area (A) of the orifice in the pipe as shown in equation 6

$$Q = VA \quad (6)$$

Similarly, to determine the flow rate (Q) of gas through orifice, an empirical version of Bernoulli's equation is employed as shown in equation 7

$$Q = 0.0467 C_d A_o \sqrt{\frac{P}{S}} \quad (7)$$

Where: A_o= area of orifice (m^2); P = kerosene pressure before orifice (*mbar*); S = specific gravity of kerosene and C_d =coefficient of discharge for the orifice

Components design

Orifice

To maximize C_d, (a) the angle of approach before the orifice was fixed as 30°; and (b) the length of the orifice channel was put as 2 times of the orifice diameter.

Entrainment

The velocity (v_0) of the gas in the injector orifice is given by:

$$v_0 = \frac{Q}{3.6 * 10^{-3} A_0} \tag{8}$$

While the velocity in the throat is reduced to:

$$V_t = V_0 \frac{A_o}{A_t} \tag{9}$$

Ignoring the vena contractor and friction loss, the gas pressure immediately after the nozzle/orifice becomes:

$$P_t = P_0 - \rho \frac{V_o}{2g} (1 - (\frac{A_o}{A_t})^4) \tag{10}$$

The value of P_0 is around atmospheric pressure, as the throat is open to the air, so this drop in pressure is sufficient to draw primary air in through the air inlet ports to mix with the gas in the mixing tube. The primary aeration depends on the "entrainment ratio" (*r*), which is determined by the area of the throat and the injector:

$$r = \sqrt{s}\left(\sqrt{\frac{A_t}{A_0}} - 1\right) \tag{11}$$

Where A_t and d_t are the area and diameter of the throat and A_0 and d_0 are the area and diameter of the injector. Prigg's formula holds if the total flame port area (A_p) is between 1.5 and 2.2 times the area of the throat. This ratio is approximately independent of the pressure and the flow rate. The primary air supply is rarely enough to give a stoichiometric mixture.

Throat size

The flow rate of the mixture in the throat (Q_m) is given by:

$$Q_m = \frac{Q(1+r)}{3600} \tag{12}$$

With Q_m in m^3/s and Q in m^3/h

The pressure drop due to the flow of the mixture down the mixing tube (throat) should be checked, by first calculating the Reynolds's number:

$$\text{Re} = \frac{\rho d_t v_t}{\mu} \tag{13}$$

Where ρ and μ are the density and viscosity for the mixture. The pressure drop (ΔP) is given by:

$$\Delta P = \frac{f}{2}\rho v_t^2 \frac{L_m}{d_t}$$

$$\text{Where } f = \frac{64}{R_e} \text{when } R_e < 2000 \qquad (14)$$

$$\textit{And } f = \frac{0.314}{R_e^{1/4}} \text{ when } R_e > 2000$$

Re = Reynolds number

Figure 1 below shows the burner of the existing stove and figure 2 shows the exploded view of the burner. Figure 3 however shows the burner of the improved stove and figure 4 shows the exploded view of the burner.

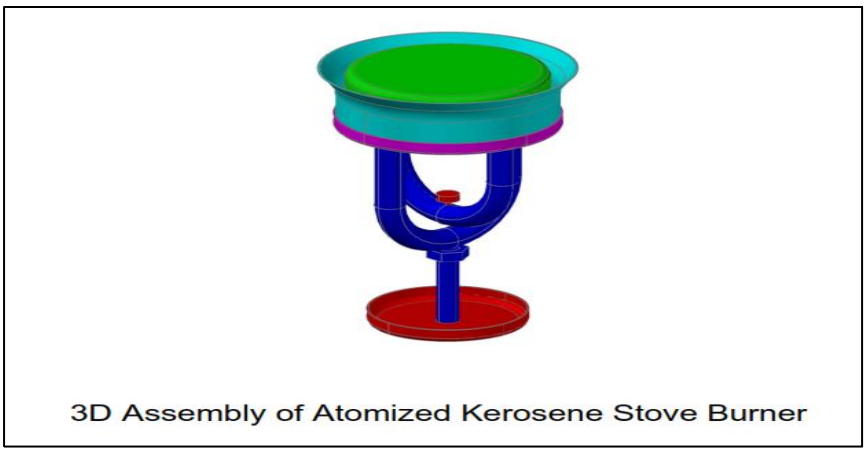

Figure 1: Existing atomized kerosene stove burner

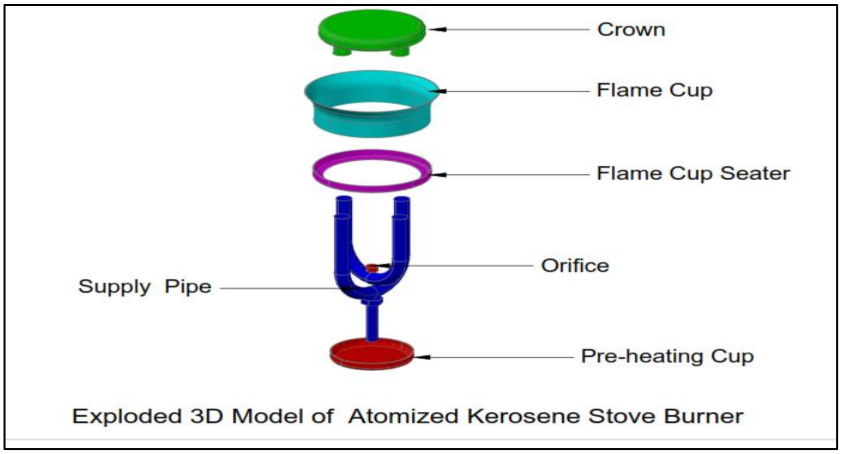

Figure 2: Exploded view of the existing atomized kerosene stove burner

Figure 3: Improved atomized kerosene stove burner

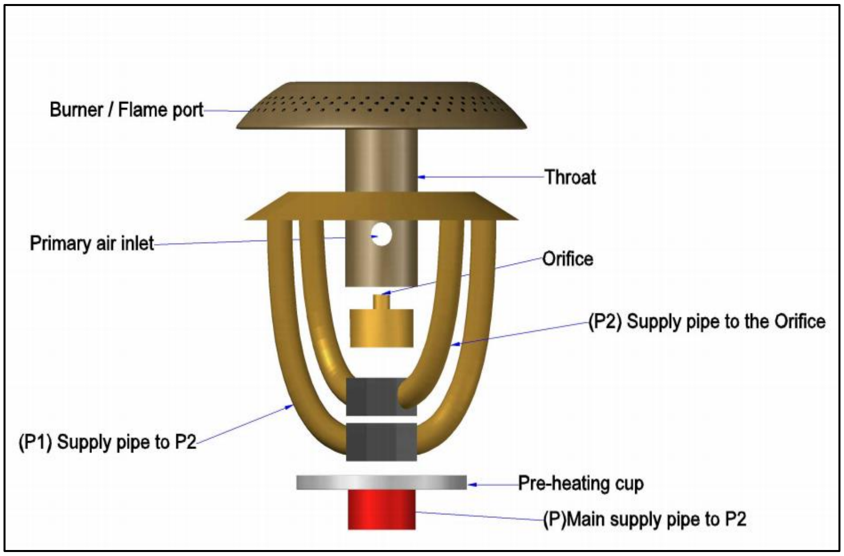

Figure 4: Exploded view of the improved design

Fabrication and construction

The fabrication of parts and construction of this modified design was carried out at Mark Jones fabrication and construction limited, Eleyele, Ibadan, Oyo state, Nigeria. Preheating pipe along with the orifice were adapted from the burner of the existing atomized kerosene stove while throat, primary air inlet, burner port, and mixing tube were adapted from the burner of the gas cooker. Figure 5 and 6 below shows the existing design alongside the new design.


Figure 5: Improved design Figure 6: Existing design

Experimentation

The new design was tested alongside with the existing design. Basically, two experiments were carried out. Namely: water boiling and controlled cooking test (SFC).

Water boiling test

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, the performance of each stove was measured by carrying out water boiling test on each. The test involves heating the standard quantity of water from the ambient temperature to boiling as rapidly as possible. In the test carried out, time to boil a fixed mass of water (1.5kg) from cold start was determined, and temperature of the water was checked at intervals while the stove was allowed to supply heat for 2 hours, 40 minutes. The test was carried out 5 times and the average was compiled.

The data obtained were used to compute the thermal efficiency of each stove using Eq. 15.

$$\eta th = \frac{W_{wi}C(T_f - T_i) + (W_{wi} - W_{wf})}{RxtxQ_{net}} x\ 100\% \quad (15)$$

Where: *Wwi*= initial weight of water in the pot, kg; *wf*= final weight of water in the pot, kg; *i*= initial temperature of water,°C; T_f= final temperature of water, °C; *C* = specific heat capacity of water, kJkg–1K–1; *L* = latent heat of vaporization of water at 100°C, kJkg–1.

Controlled cooking test (SFC)

The Controlled Cooking Test (CCT) is to compare the fuel consumed and the time spent in cooking a meal on different stoves. The tests were carried out with two food items [Oryza Sativa (Rice) and Dioscorea Spp (yam)]. This test was carried out so as to know the specific fuel consumptions of each stove, which expresses the amount of kerosene required to obtain 1 kg of cooked food. For each of the tests that were carried out, the cooking pots were first weighed, after which 1 kg of food item was placed in each of the pots which already contained 1.5 L of water and cooking was done. In a controlled cooking test carried out, the volume of kerosene consumed was checked and the weight of the cooked food in the pot also weighted, then their ratio was found. The data collected were used in calculating the specific fuel consumption (SFC) using the following equations:

$$SFC = \frac{volumeofkeroseneconsumed}{Totalmassofcookedfood} = \frac{V_i - V_f}{m_{pf} - m_p} \quad (16)$$

Where: *V*= volume of fuel (V_i– V_f); m_{pf}= mass of the pot with cooked food; m_p= mass of the pot.

Results and discussion

The testing of the modified atomized kerosene stove and the existing atomized stove was carried out to determine the efficiency of both stoves so as to know which gives greater advantage to use. The test in this work was carried out using 0.0003m orifice diameter. Also, the pressure in the tank was kept at 1MPa for both stoves.

Water boiling test

As illustrated in figure 5, as the cooking/boiling time increases, the temperature of the boiling water increases for the two models of the stoves under test. However, the boiling temperature was reached faster for the improved atomized kerosene stove when compared with the existing atomized design.

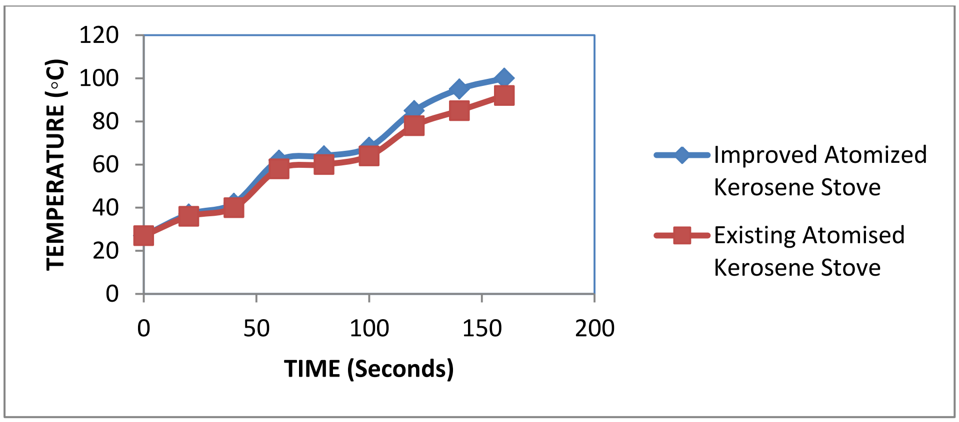

Figure 5: Graph of temperature rise (°C) versus time (seconds

Specific fuel consumption

The results show that, the existing atomized kerosene stove has relatively higher specific fuel consumption of 0.34kg consumed fuel/kg evaporated water while on the other hand, the improved/modified atomized stove has a lower 0.30kg consumed fuel/kg evaporated water as shown in figure 6. This shows a lower trend in fuel consumption pattern of the improved atomized stove over the existing one.

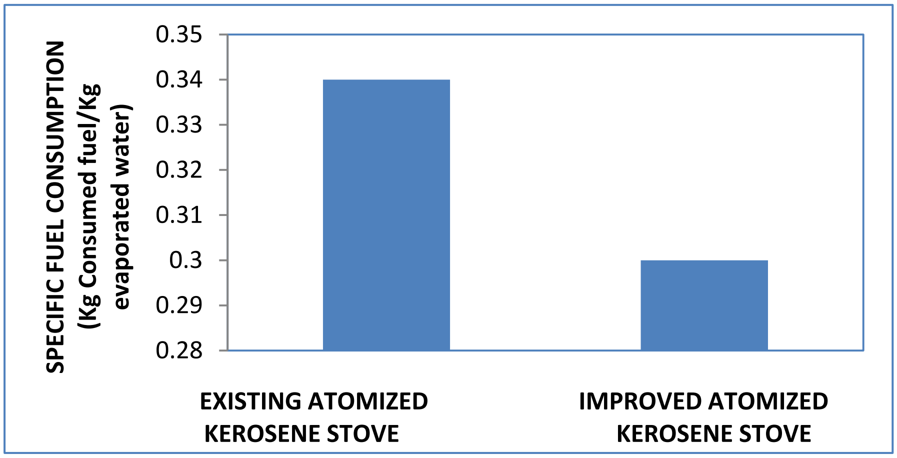

Figure 6: Specific fuel consumption ***rate for the two different stoves under*** **comparison**

Conclusion

From our results in this work, the newly improved or modified design stove is more thermally efficient and consumes less fuel per unit time when compared with the existing design.

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