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The Design and Construction of a Portable Kerosene Pressure-Cooker

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Moh, Kenechukwu David- Postgraduate Student, Department of Mechanical/Production Engineering, Enugu State University of Science and Technology, Enugu, Nigeria.
E-mail: Kenemoh@yahoo.com
Phone: +2348039533013

Abstract

This paper dealt with the design and construction of a portable kerosene pressure-cooker. The existing cookers and the problems associated with them were analyzed. The need and importance of this work were also high highlighted. The design consists of three parts: the cylinder, the piping, and the frame. The R-12 refrigerant cylinder was redesigned to suit the kerosene cylinder, since it has the desirable features for that purpose. Using the principles of fluid dynamics, this work was able to establish that the power of the cooker is 179.922KW, and that under a constant pressure of IMPa the cooker will discharge and burn 1 litre of kerosene in 3.5 minutes giving out an enormous heat energy of 38.2MJ

Key Words: Volumetric flow rate, mass flow rate, power, energy, pressure.

Introduction

Household energy especially cooking energy, often accounts for a big part of the overall energy consumption in many developing countries such as Nigeria. In Nepal for example about 70% of the total energy consumed was used for cooking purposes only.

In general, wood is still the main energy source in the rural areas of tropical countries. Steadily rising firewood consumption for cooking purposes results in deforestation of large areas, creating severe ecological problems. Smoke (Carbon monoxide) that comes out as a result of incomplete combustion of carbon poses health risk to humans and the environment, i.e. it irritates the eyes and lungs, and contributes to air pollution.

The use of electric-cooker is limited mainly due to the inadequate distribution and supply of electricity, especially to the rural areas, similarly the use of solar-cooker and biogas are still limited due to technical and handling problems.

In Nigeria today, kerosene is relatively cheap with respect to cooking gas, and considering the fact that deforestation is not good for the environment, it becomes expedient to design and construct a kerosene pressure-cooker.

Design Objectives and Requirements

1. To present an economical means of cooking
2. To present a cooker that does not pose health risk to the user and is environment friendly, i.e. applies complete combustion of kerosene.
3. The cooker should be simple and easy to operate
4. The cooker should be safe and easy to maintain
5. The cooker should be able to produce enough useful heat with minimum energy loss.

Importance of This Work

1. It would discourage the use of wood as fuel for a domestic cooking since it is affordable and economical
2. It can be used for commercial purposes (restaurants and Hotels) since the kerosene cylinder is designed to contain large quantity of kerosene which can burn for a longer period of time.
3. It does not form soot on the utensil used on it since the atomization and vaporization of the kerosene helps it to burn properly in the presence of oxygen.
4. Kerosene, as fuel, is more available and affordable than cooking gas.

Background

In an effort to develop an 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. A look at the different types of cookers available would help us to understand the importance of this particular work.

Types of Cookers

Gas Cooker

This is a simplification of kerosene pressure cooker. It gives a fair amount of heat with little fuse, and is quite simple to use. However, it is expensive when compared to the kerosene alternatives, and at high altitude, the fuel simply fails to work.

Alcohol Stove

Generally, alcohol stoves are more popular in Europe especially in Scandinavia. This types of stove is often used for making food where simmering is more important than actual boiling. It has a light design and alights easily, but it is liable to soot the utensils.

Kerosene Stove

It is of two categories: wick-burners and pressure-burners.

Wick-burners utilize the capillary effects of fluids. The wicks draw-up kerosene from the reservoir and are eventually alight to produce flame as the source of heat. (See fig 1)

Pressure-burner is based on the principle of pressurized kerosene being pre-heated to vapor (atomization), which passes through a spreading device (orifice) and is ignited to heat up the utensils. The pressure is usually supplied through an air-pump.

Properties of Kerosene

Appearance and Odour: colourless to pale straw liquid with a characteristic odour.

Boiling range at 760mmHg: 151-301^{0}C,

Vapour density: 4.5 (Air=1)

Vapour pressure: 0.5 mm Hg at 20^{o}C

Density: 810 kg/m^3

Specific gravity: 0.81

Freezing point: -18^0c

kinematic viscosity: 0.17651 m^2/s

Solubility in water: insoluble

Atomization of Kerosene

In actual combustion process, it is common practice to use more air than the stoichiometric amount to increase the chances of complete combustion. Things are not so simple, however, when one is dealing with actual combustion processes. For one thing, actual combustion processes are hardly ever complete, even in the presence of excess air, thus, the need for atomization. This is the process of breaking up a continuous liquid phase of the fuel into discrete droplets (vapor).

The atomization of kerosene at the burner requires preheating of the burner with the help of a wick provided for it. The burner transfers the heat to the kerosene as it passes through the burner. The absorption of the heat by the kerosene results in its vaporization.

During this process, the surface area of the liquid is increased through vaporization making it to have a greater affinity with atmospheric oxygen for proper and efficient combustion.

Atomizers may be classified into two broad groups:

1. Pressure atomizer in which fuel oil is injected at high pressure.

2. Twin fluid atomizers in which fuel oil is injected at moderate pressure and compressible fluid (steam or air) assists in the atomization process.

For the purpose of this work, we chose pressure atomizer see fig 2

Combustion of Kerosene

The kerosene is typically burned as a suspension of droplets generated by atomization process. The vapor mix with surrounding air and ignite.

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 octane, C_8H_{18}, and the diesel fuel is dodecane, $C_{12}H_{26}$.

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Since kerosene is of the alkane family (C_nH_{2n+2}) and is found within the range of carbon chain of C_8-C_{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 is

$$C_xH_y \ a(O_2 + 3.76N_2) \longrightarrow bCO_2 + dH_2O + eN_2$$

From the equation above:

Carbon: x= b

Oxygen: 2a=2b+d

Hydrogen: y =2d

Nitrogen: 3.76a =e

Thus, for $C_{10}H_{22}$ (kerosene)

Carbon: x = b= 10

Hydrogen: y = 2d = 22 ; d =22/2 = 11

Oxygen: $2a = 2b + d$; $a= \dfrac{2b +d}{2} = \dfrac{(2x10) + 11}{2} = 15.5$

Nitrogen: 58.28=e

∴ the combustion equation becomes

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

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

Design Procedure and Analysis

The design consists of three parts:

i. The cylinder in which kerosene is kept under a high pressure.

ii. The piping, which carries the kerosene to the burners, and the burners where the kerosene is atomized, ignited and burnt.

iii. The frame, which supports the burners, and carry the utensils.

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The Kerosene Cylinder

The R-12 refrigerant cylinder is observed to have all the desirable features required for the design of the kerosene cylinder. The original specified pressure on the R-12 cylinder is 1.4 MPa (Maximum pressure). In selecting the cylinder, the following properties were considered.

1. Tensile strength
2. Weldability
3. Ductility
4. Corrosion resistance

All we need do is to cut open the original control valve of the R-12 cylinder and attach a small copper pipe of about 1cm diameter that will pass from the valve to about 0.5 cm from the bottom of the cylinder. The valve, with the pipe, is brazed back to the original position. See fig 3.

Two new openings are made on the top of the cylinder slightly below the control valve. A car tyre valve is brazed on one of the openings while on the second opening a small externally threaded short steel (3cm long) which can be covered (airtight) by a nut is brazed on it.

The tyre valve is the means through which pressure from the air pump is supplied to the cylinder, while the second opening is the means through which kerosene is filled into the cylinder.

The control valve is used to regulate the amount of kerosene that flow from the cylinder, through the hose, to the burners. A base is brazed to the cylinder to give it stability. The pressure is supplied through a manual air-pump

Flow through Pipe and Burner

The principles of fluid dynamics require that a pressure drop across the piping must be created so that the fluid can flow through the pressure gradient.

When liquid flows in a pipe it experiences some resistance to its motion, due to which its velocity and ultimately the head of the liquid available is reduced. This loss of energy (head) is classified as follows:

a. Major energy losses: i.e. lose due to friction

b. Minor energy loses: i.e. loss due to sudden enlargement of pipe, sudden contraction of pipe, bend of pipe, an obstruction in pipe, pipe, fitting, etc.

Considering the fact that we are dealing with a short pipe (hose=1m), loss due to friction is neglected.

In minor energy losses we will consider only loss due to sudden contraction of pipe in order to take care of flow situation at the orifice of the burner. To show this, let's consider an orifice plate placed in a horizontal pipe as shown in fig 4

Applying Bernoulli's equation between sections 1 and 2

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_f + h_c \qquad \text{------ (1)}$$

Where $h_y = \frac{4fLV_1^2}{2g\,D_1}$ = head lose due friction (neglected)

$h_c = \frac{0.5\,V_2^2}{2_g}$ = head lose due sudden contraction of pipe (orifice)

$Z_1 = Z_2$

P_1	=	Pressure in the cylinder = IMPa
P_2	=	Atmospheric pressure = 101300Pa
D_1	=	Diameter of pipe (hose) = 0.012m
D_2	=	Diameter of orifice = 0.0003m
A_1	=	Area of pipe (hose) =1.13 x$10^{-4}$$m^2$
A2	=	Area of orifice=7.07x$10^{-8}$$m^2$
ρ	=	density of kerosene = 810 kg/m^3
V_1	=	Velocity of kerosene in the pipe (hose)
V_2	=	Velocity of kerosene at the orifice
L	=	Length of pipe (hose) = 1.0m

g = Acceleration due to gravity = $9.81 m/s^2$

$\therefore$ equation (1) becomes

$$\frac{P_1 - P_2}{\rho} = \frac{V_2^2 - V_1^2}{2} + \frac{0.5\, V_2^2}{2} \qquad \text{------ (2)}$$

$A_1 V_1 = A_2 V_2$

$$V_1 = \frac{A_2 V_2}{A_1} = \left(\frac{D_2}{D_1}\right)^2 V_2$$

$\therefore\ V_1 = 0.000625 V_2$

substituting the value of V_1 in equation (2)

$V_2 = 66.619 m/s$

$Q = A_2 V_2 = 4.71 x 10^{-6} m^3/s$

This is the volumetric flow rate of kerosene through the orifice of the burner when the pressure in the cylinder is 1MPa.

The mass flow rate of kerosene becomes

$m = \rho Q$

$= 3.815\ x 10^{-3}$ kg/s

The Frame

The frame if made of steel. It has a simple function of carrying the utensils and as a support to the burners. Fig 5.

Discussion of Results

The volumetric flow rate, Q, obtained showed that the maximum quantity of kerosene that will be discharged and burnt every second, if the pressure in the cylinder is maintained at IMPa, is $4.71x10^{-6}m^3$. The amount of kerosene discharged at the orifice of the burner can be regulated by altering the pressure head across the pipe (hose) with the help of a control valve, (knob) fitted before the orifice of the burner.

It is known that whenever 1 litre ($0.001m^3$) of kerosene is burnt completely, it gives out 38.2MJ of heat energy, consequently, from calculations:

$4.71x10^{-6}m^3$ will give out 179.922 KJ of heat energy per second thus, the power of the cooker becomes.

$$\text{Power} = \frac{\text{energy}}{\text{Time}} = 179.922 \text{ KJ/S} = 179.922\text{KW}$$

It is also established that under constant pressure of IMPa, the cooker at maximum output, will discharged and burn I lire ($0.001m^3$) of kerosene in about 3.5 minutes.

Conclusion

This design was carried out in recognition of the present problems experienced by many Nigerians due to irregular supply of electricity and the persistent scarcity of petroleum products. Also, the environmental and health hazards associated with firewood cooking were also taken into cognizance.

The various problems associated with the conventional kerosene stove were also highlighted, and this design is meant to overcome these problems especially the problem of sooty flame. The design and construction of this kerosene pressure-cooker was carried out successfully see fig 5. In fact, one of the major successes of this work was the ability to use a discarded R-12 cylinder, which was regarded as a waste, to design the kerosene pressure cylinder.

Recommendation

This study recommends that the production of this pressure-cooker in commercial quantity should be encouraged with a view to reduce the cost of production, and consequently make it more affordable to Nigerians. Furthermore, the large scale production of this pressure-cooker will not only create employment opportunity to the local people but will also reduce the wide dependence on wood as a source of fuel for domestic cooking and create a healthier environment.

Considering the enormous amount of heat the cooker can produce, an oven for baking bread can be fashioned out of it.

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Table1. Bill of Engineering measurement and Evaluation (BEME)

S/N	Hem Description	Quantity	Unit Price (N)	Cost (N)
1.	Kerosene cylinder	1	100	100
2.	Burner stand and frame	1	1700	1700
3.	Hose	1	200	200
4.	Burner	1	400	400
5.	Bott and Nut	2	10	20
6.	Hose clips	4	40	160
7.	Control valves	2	150	300
8.	Tube	1	150	150
9.	Oil paint	1	350	350
10.	Nut and thread on the cylinder	1	200	200
11.	Car-tyre Valve	1	50	50
12.	Welding			600
13.	Kerosene fitter	1	200	200
14.	Hand pump	1	400	400
	Total			**4830**

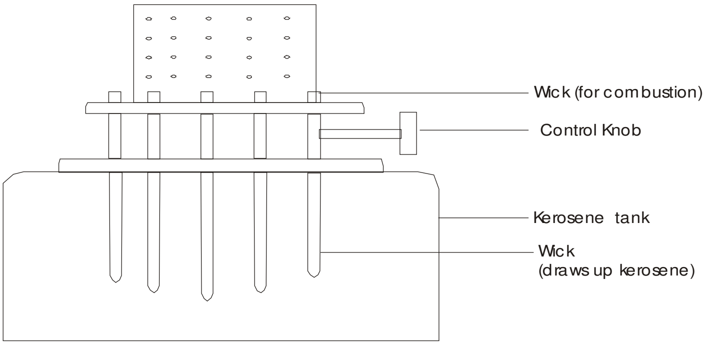


Fig. 1. Wick burner

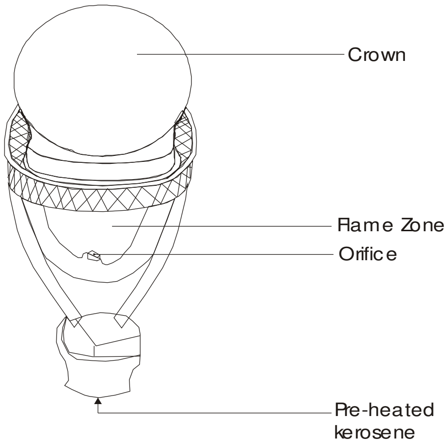
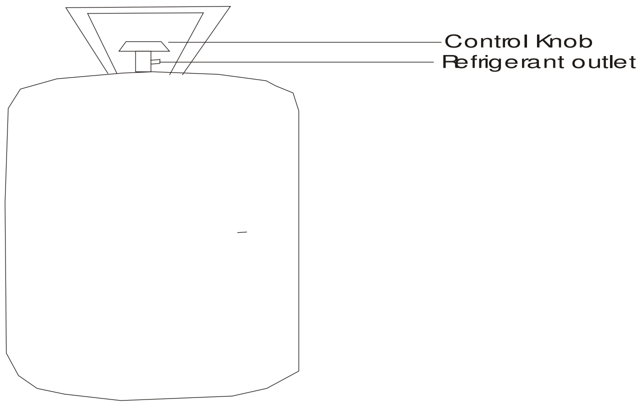
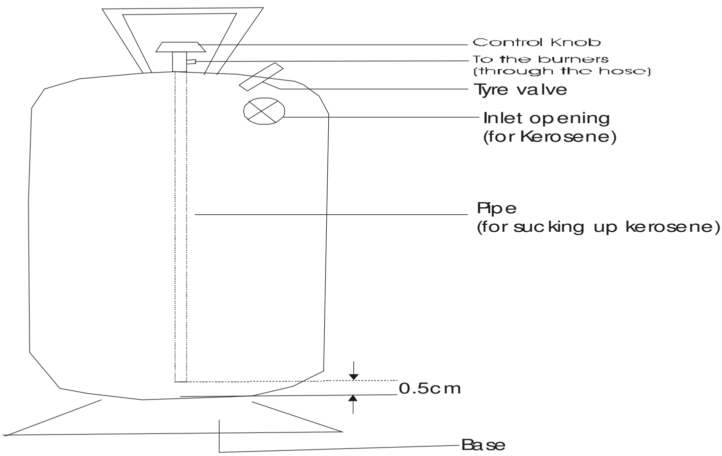


Fig. 2 Pressure burner
(Atomizer)

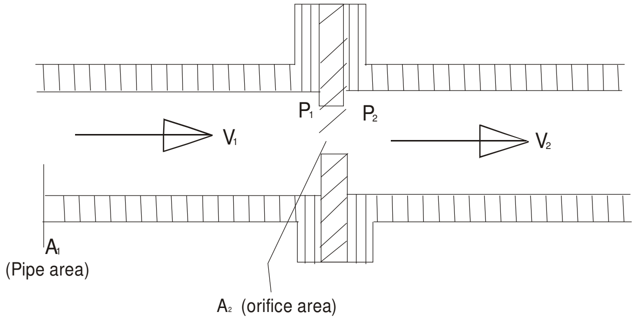


(a) Original R-12 Cylinder

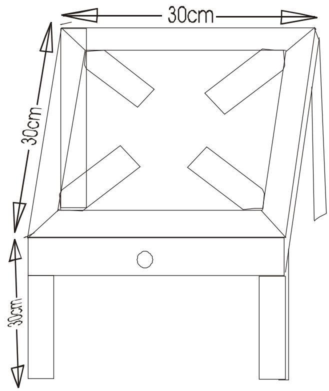


(b) Re-desgined R-12 cylinder

Fig. 3 Kerosene cylinder.



Fg. 4. Flow through an orifice



Fg. 5. The Frame

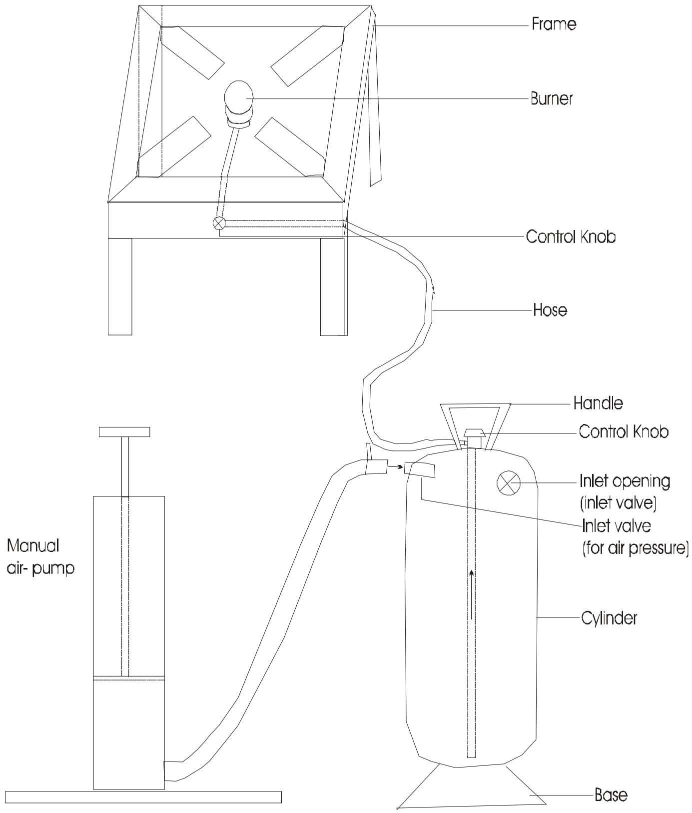


Fig. 6 Assembly of Kerosene pressure - cooker