Development of A System for Atomizing and Combusting of A Mixture of Used-Engine Oil and Kerosine

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Abstract: *The importance of burning fuel in our everyday life cannot be over-emphasized. Severe environmental pollution appears to be threatening the development prospects of our country. This paper reports on experimentally developed system for the atomization and evaluation of the combustibility of a mixture of used-engine oil and kerosene. The two petroleum products, used-engine oil and kerosene, are mixed in a mixing chamber and then atomized with aid of a smooth nozzle into vapor droplets. The atomized fuel was tested by igniting and the result was a smooth burning flame which signifies a good combustible fuel. The result showed that 1kg of kerosene required 15kg or 11.6m3 of air for total combustion, while 1kg of oil required for complete combustion 14.91kg or 11.532m^3 of air. The calorimetric temperature of the mixture was found to be 2.76 x 10^{3}K. Thus, once a sound technology is established the mixture can be used in areas such as in domestic cooking, combustion in small furnace, steam raising, bakery ovens and metallurgical heating.*

Key Words: *Used-engine oil, mixing chamber, atomization, flashpoint, higher calorific value, lower calorific value.*

I. Introduction

The main function of engine oil is to reduce friction and resulting wear between bearing surfaces. This is achieved by interposing a film of the oil between the sliding surfaces. Lubricating oil for internal combustion engine, also function to cool surfaces by picking up heat and dissipating it through the crankcase. It also reduces compression losses by acting as a seal between the cylinder walls and the piston rings [10].

Engine oil must possess certain properties in order to accomplish its functions satisfactorily. It must possess sufficient viscosity and oiliness to protect the mechanical devices at the necessary speeds, pressure and temperature. It must be of such nature that it can be satisfactorily handled by the lubricating system and must also be able to withstand service conditions. It is, however, pertinent that such properties will degrade gradually until such a time when it becomes unfit for further use.

ENGINE OIL: engine oil is used to lubricate piston type internal combustion engine. It is a lubricant containing a base oil and a synthetic additives which improve the properties of the base oil or impart to it the required properties. The composition and viscosity of the base oil, and the types and concentrations of the additives generally determine the service properties of the engine oil.

The basic components of engine oil have a viscosity of between 3.5 to 22 cst at 100°C. The concentration of the engine oil additives is varied within a wide range.

According to [10], engine oils are classified by the Society of Automobile Engineer (SAE) by their viscosity grades. The viscosity is measured at both 0°F (-18°C) and 210°F (98.9°C). SAE 5W, 10W and 20W viscosity numbers are related to 0°F (-18°C) measurements, and SAE 20, 40 and 50 to 210°F (98.9°C).

1.1 PROPERTIES OF USED-ENGINE OIL:

Diesel engines burn AGO in order to produce mechanical power and the by-products of such combustion are harmful to the engine by causing acidic attack and by depositing particles of "ash" and soot which are abrasive. The engine oil must afford a high level of rust and corrosion protection in order to overcome the acidic by-products of combustion. A higher acidity is detrimental to alloyed bearing metals. Also since engine operates at high temperatures, oxidation prevention is of paramount importance in the formulation of engine oils.

According to [4], when engine oil deteriorates, engine gums would form due to influence of oxygen and so its chemical composition would change. It has been shown that the maximum sediments rendering the oil unsuitable for further use is 1-1.5% and a maximum of 3% if additives are taken into account. Failure to renew the oil at this state invites wear. The flashpoint decrease is an indication of oil quality. A minimum allowable flash point of a lubricant after period of service is 170 — 180^{0}C as against 190— 2l0^{0}C for fresh diesel

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lubricating oils. The used oil has a water content of over 0.5%. Other properties of used-engine oil according to are:

(a)   **Contamination**: this is probably the most common reason for changing oil. The contaminants may be gaseous, such as air and ammonia; liquid such as water and oil of another types; or solid such as fuel dirt, grit road dust and wear products. Oils in an IC engine, does not wear out or breakdown but becomes unfit for further use through contamination and through loss of additives.
Solid contaminants may, however, be controlled by filtering or centrifuging or both.

(b) Contaminants in the Used Engine Oil:
-**Sulphur**- very small traces of Sulphur may be present in the used-engine oil.
Its presence is undesirable. The corrosiveness of the oil is directly related to the organic Sulphur content. However, during combustion, the Sulphur is oxidized to SO_2.
-**Water**- the presence of water in the oil is also undesirable because the presence of globules of water at the outlet of the oil burner may lead to flame failure. Also the globules of water may freeze in supply lines during cold weather.

(c) **Viscosity**: This property determines the behavior of oil in practical appliances such as in a atomization, flow and pumping. It is the main factor determining the atomization of the oil. The used-engine oil has an insufficient viscosity to support an oil film between bearing and its journal. The oxidizing influence of oxygen on oil result in increasing the viscosity, however, it may be reduced by heating to a higher temperature and by blending with less viscous kerosene to enhance atomization.

(d) **Oxidation**: this is influence by the degree of agitation of the oil with air, presence of Catalyst such as iron and copper in finely divided form, and temperature rise. The Oxidation rate, for example, double for every 8 — 10°C temperature rise.

(e) **Calorific Value**: the increase in water content and the presence of contaminants. Together lower the calorific value of engine oil. A typical calorific value of used- engine Is 27.9 Mi/Kg

TABLE 1.1: Properties of engine oil

Properties	New engine oil	Used-engine oil
Viscosity at 37.8°C	45 cst	99.0 cst
Gross calorific value	43.5 Mi/Kg	27.9 cst
Net calorific value	41.1 Mi/Kg	-
Compositions C	85.6%	-
H	11.7%	-
S	2.5%	0.43%
Ash	-	2.0%
Water contents	-	0.5%
Relative density	0.93	-
Heating value	-	38.23 Ki/Kg
Flash point	-	146°C

1.2 PROPERTIES OF KEROSINE:
Kerosene has a boiling range between 150 to 300°C. They fall between gasoline and gas oil fractions. Kerosene was primarily a fuel for lamps, but its main use nowadays is for heating. Other important properties of kerosene according to[9] are:
i.   **Volatility**; this affects ease of ignition and 'smooth' vaporization for combustion.
ii.   Smoke point; is the height to which the flame may be turned before smoking commences, when the kerosene is burned in a standard lamp under closely controlled conditions.
iii.   **Viscosity**; viscosity determines the behavior of kerosene in practical application such as atomization, flow and pumping. The viscosity of kerosene for wick burners should be less than 12.5 cst. Low viscosity is an inherent property of kerosene. Its viscosity at 40°C is 2.0 cst.
iv.   **Flash Point**; is the temperature to which the oil must be heated, in a standard instrument, to give an inflammable mixture with air. The flash point of kerosene is always less than 50°C.
v.   **Calorific Value**; the calorific value of the volatile kerosene is determined using a gas calorimeter

TABLE 1.2: PROPERTIES OF KEROSENE

PROPERTIES		VALUE
Gross Calorific Value		46.5 Mi/Kg
Net Calorific Value		43.5 Mi/Kg
Thermal expansion coeff.		0.001 *1°C*
Relative density at 15°C		0.78
Flash point (Apel)		312 K
C: H ratio		6.3
Composition	C	85.8
	H	14.1
	S	0.10
Volatility vapour pressure		1.3 KN/m2
		36 KN/m2
Boiling point	-initial	413 K
	-mid	469 K
	-final	588 K
Viscosity at 40°C		2 cst
At 310 K		0.009 x i0 m2S
At 336 K		0.65 04m2S

(Source: [9])

II. Experimental Procedure.

A certain quantities, both of kerosene and used-engine oil are filtered and mixed in a mixing chamber. The resulting mixture is fed by gravity and with aid of a high pressure air (up to 2bar) through a fine nozzle measuring between 0.5 to 0.75 mm in diameter, to produce a spray of droplets of the oil by pressure jet atomization process.

The high viscosity used-engine oil is pre-heated with aid of a heater immersed in the oil. The viscosity is reduced to between 15.5 to 24 cst depending on the size of the nozzle.

The high pressure air is regulated and measured with aid of a valve and pressure gauge respectively. The control of the vapour oil to the burner is obtained by adjustment of the air pressure. The oils flow rate from the engine oil tank and kerosene tank was obtained by measuring the change in height(H) of the oil in a unit time(t). Then, the volume flow rate from the oil or kerosene tank is given by:

$$Q = \frac{\pi r D2H}{4t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(2.1)$$

Where D is the internal diameter of the tank
And the mass flow rate (m) is:

$$m = \rho Q = \frac{\pi D2\rho H}{4t} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(2.2)$$

where p is the density of the oil at its measured temperature.

II.   Results And Discussion:

TESTS AND RESULTS

The test was carried out in a laboratory at an ambient temperature. The mass of kerosene per unit mass of the used engine oil required providing a good quality, but economical, mixture for burning was deduced. Other parameters measured included the flow rate, the air pressure supplied and the temperature of the oils. The mass and volume flow rate were calculated using the formulae in equation (2.1) and (2.2) and tabulated as follows:

TABLE 3.1 USED ENGINE OIL TANK

Reading No.	Pressure (bar)	Temperature (°C)	Change in height x10⁻³m	Time,t (seconds)	Volume flow rate Q x 10⁻⁷ (m³/s)
1	3.551	ambient	5.24	600	3.94
2	3.379	ambient	4.19	600	3.15
3	3.413	ambient	3.14	420	3.38
4	3.448	ambient	2.10	300	3.16

TABLE 3.2: KEROSINE TANK

Reading No.	Pressure (bar)	Temperature (°C)	Change in height x10⁻³m	Time,t (seconds)	Volume flow rate Q x 10⁻⁷ (m³/s)
1	4.206	ambient	4.19	600	3.15
2	3.689	ambient	4.19	600	3.15
3	3.517	ambient	3.14	420	3.38
4	3.413	ambient	2.10	300	3.16

TABLE 3.3: MIXTURE OF THE OILS

Readings	Pressure(bar)		Change in height (10⁻³m)		Time	Mass of mixture collected	Mass flow of mixture
	Kerosene	used oil	Kerosene	used oil	(seconds)	(grammes)	(g/s)
1	2	2	6.81	6.29	720	495	0.688
2	2	2	4.71	5.24	660	360	0.546
3	2	2	3.67	2.67	600	278	0.463
4	2	2	3.67	4.19	600	298	0.497

The mass of kerosene required per unit mass of engine oil is calculated for the first readings of table 3.1 and 3.2 as follows:

For used engine oil; m = ρQt = 920 x 3.94 x 10-7 x 600 = 217.5g

For kerosene; m = 780 x 3.15 x 10-7 x 600 = 147.4 g

I.e. 0.15Kg of kerosene is required per 0.22 Kg of used engine oil.

3.1 Heating value of the fuel; the amount of heat liberated through combustion of a unit mass of fuel is called the calorific value of the fuel. A distinction is made between the higher and lower calorific value. The difference between the two values per Kg fuel is

Q_{wh} — Q_{WL} = 2516.39 (w_1 + 9H) (KJ/Kg) (3.1)

Where w_1, and H are the percentage of water and hydrogen, respectively. The higher calorific value Q_{wh} corresponds to the condition that all water vapour formed through combustion are liquefied at 273 K. On the other hand, the lower calorific value Q_{WL} corresponds to the condition that water vapour contained in combustion products are cooled from 373K back to 293K. For soviet kinds of liquid fuel, the formulae proposed for calculating the calorific value by D.l. Mendeleev is:

Q_{wh} = 4.187 (81C + 300H — 26 (0 - S)) (KJ/Kg)……………(3.2)

And Q_{WL} 4.187 (81C + 300H — 26 (O - S) -6 (w +9H)) (KJ/Kg)…(3.3)

Where C, H, 0, S and H, are the percentage composition of the elements in the moisture content of the compound.

US Bureau of mines, (Cragoe, 1929) also gives an estimation of the gross or higher calorific value of petroleum oil as:

Q_{wh} = 51916-8792 d^2 (KJ/Kg)……………..(3.4)

Where d is the relative density at 288°K

Also, BS 2869 gives formulae for calculating the calorific value as:

Q_{wh} = (51.916 — 8.792 d^2)(1(x+y+S)+9.42S) (MJ/Kg)……………………. (3.5)

Q_{WL} = (46.392 —8.79 d2 + 3.187 d)(1- (x+y+S)+9.42 S -2.449 x) (MJ/Kg)… (3.6)

Where x = fraction by weight of water, y = fraction by weight of ash, S = fraction by weight of Sulphur and d = relative density of water at 15°C.

3.2 COMBUSTION OF THE ATOMIZED FUEL.

The combustion process consists of two stages:

i. Mixing the mixture of oil and air and

ii. Burning the fuel.

But at the second stage, first, the ignition of the fuel should precede the burning.

The fuel and air are intimately mixed in a suitable chamber, which dispenses it through the nozzle into droplets which then vaporize before burning.

There must be sufficient air to complete both the atomization and the combustion of the fuel. However, the air should not be too large, ie in excess, to cool the product of combustion. The air must be present uniformly in the combustion zone otherwise partial combustion of the fuel will take place, giving rise to solid carbon. An excess of combustion of air will produce an oxidizing flue gas, and a fuel rich mixture (mixture with too little air for stoichiometric combustion) produces a reducing flue gas. A neutral atmosphere may be produced by burning the fuel in its stoichiometric proportions of air.

(a) Kerosene

This composed of 85.8% C, 14.1% H and 0.1% S. Full combustion of kerosene is described by the reaction:

$C_{12}H_{26}$ + 37/2 O_2 -> 12 CO_2 + 13H_2O………………(3.7)
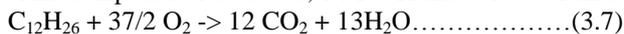
i.e 37/2 Kmoles of O_2 are needed to completely burn 1 Kmol of kerosene, and 37/2 Kmoles of O_2 weights 37/2 (16x2) = 592Kg and lKmol of kerosene weights
(12 x 12)+ (1x26) = 170Kg. 1kg of kerosene requires for combustion 592/170 = 3.482Kg of O_2. But since the mass percentage of O_2 in air is 23.2% and that of Nitrogen is 76.8%. The mass ratio of Nitrogen to oxygen in air is 76.8 /23.2 = 3.31. The mass of nitrogen that will be brought together with oxygen is 3.482 x 3.31 = 11.572Kg. Thus, the mass of air required to burn 1Kg of kerosene is 3.482 + 11.572 = 15Kg. or 15/1.293 = 11.6m3 in terms of volume.

(b) Engine oil
The complete combustion reaction of the oil, say C21H44, is
$C_{21}H_{44} + 32O_2 - 21\ CO_2 + 22H_2$…………………..(3.8)
lKmol of oil requires 32Kmols of O_2 or 296Kg of oil requires 1024kg O_2, then 1kg of oil requires for combustion 1024/296 = 3.46kg of 02. The mass of nitrogen that will be brought in together with the O_2 is 3.46 x 3.31 = 11.45kg. Thus, the mass of air required to burn 1kg of the oil is 11.45 + 3.46 = 14.91kg or into volume unit it is 14.91/1.293 = 11.532 m3. The practical result obtained is 1kg of oil mixing with 0.6kg of kerosene for efficient burning.

(c) Determination of composition of product of combustion
For kerosene,
From above, 1kg kerosene + 15kg air yields 3.106kg CO_2 + 1.377kg H_2O + 11.53kg N_2 16kg of products

Then CO2 is 3.106/16 x l00 = 19.4%
H_2O is 1.377/16 x 100 = 8.6% and N_2 is 11.53/16 x l00 =72%

For oil
1kg of oil + 9.094kg air yields 1.91kg CO_2 +0.817kg H_2O +6.984kg N_2
Total mass of product = 1.91 + 0.817 + 6.984 = 9.71kg
CO_2 is 1.91/9.71 x 100 = 19.67% H_2O is 0.817/9.71 x 100 = 8.41%
N_2 is 6.984/9.71 x 100 = 7 1.93%
(d) Determination of Calorimetric temperature T_c

For kerosene
The volumetric specific heat of CO_2, H_2O, and N_2 at that temperature is respectively 2.3636, 1.8389 and 1.447 kJ/m^3.K
1m^3 of combustion products contains 0.1264m3 CO_2, 0.1369m3 H_2O and 0.7367m3 N_2. Therefore, specific heat of 1m3 of combustion products kJ/m3.K is

CO_2………………………………………………2.3636x0.1264=0.2988
H_2O………………………………….. 1.8389 x 0. 1369 = 0.25 18
N_2 …………………………………………1.447 x 0.7367 = 1.066

Total = Cv = 1.6166 kJ/m^3 .K

Kerosene is not preheated so Qph = 0
Then calorimetric temperature is;
Tc =QwL + Qph = (43.54 + 0)/(9.762 x 1.6166) =2.76 x 10^3 K
VCP. CV
The relation for **QwL** is obtained from equation (3.3)
For Used-engine oil:
The densities of products are
CO_2 = 1.964 kg/m^3, H_2O = 0.804 kg/m^3, N_2 = 1.250 kg/m^3 and oil = 0.93 kg/m^3
So 1/0.93m^3 oil + 9.094/1.293 m^3 air -> 1.91/1.964 m^3 CO_2 +0.817/0.804 m3 H_2O + 6.984/1.250m3 N2
i.e 1m3 oil +6.54 m3 air -0.9m3 CO2 + 0.945m3 H_2O + 5.196m^3 N_2
Volume of combustion product is 0.9 + 0.945 + 5.196 = 7.04m3
i.e CO2 is 0.9/7.04 x 100 =12.78%, H20 is 13.42%, and N2 is 73.8%
CO_2 …………………………………2.3636 x 0.1278 = 0.302
H_2O…………………………………1.8389 x 0. 1342 = 0.247
N_2………………………………….1.447 x 0.738 =1.068

Total C, = 1.617 kJ/m3.K

Then, Tc = **QwL + Qph** = $(41.34 \times 106 + Q_{hp})/(7.04 \times 1.617 \times 10^3)$
VCP. CV
 = $3631.52 + 0.878 \textbf{ X } 10\, Q_{ph}$

III.   Conclusion

Combustion of the used-engine oil was found to be practicable in specially designed equipment. The used-engine oil was atomized into a combustion chamber, fired with an auxiliary fuel (kerosene). Efficient dispersion is required to provide a large surface area and good mixing with air. The used-engine oil is organic in nature, as such has a significant calorific value.

The auxiliary fuel-kerosene is one of the cheapest petroleum product available in Nigeria. The used oil, which will have been discarded, is virtually free. Saving could be made by burning the atomized fuel, which is more than 50% used-engine oil.

Once a sound technology is established, this fuel, can be used in areas such as domestic cooking, combustion in small furnaces, steam raising, bakery ovens, and metallurgical heating. The amount of thermal energy liberated by the combustion of the new fuel is connected with its composition and was calculated for unit mass of the oil.

Acknowledgements

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