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The Influence of Waste Crankcase Oil Blended Fuel Samples on Flame and Thermal Behaviour of Atomising Swirl Oil Burner

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ABSTRACT

The price volatilities of liquid hydrocarbon fuels in the international crude oil market, the consequent hike in energy cost, and environmental challenges resulting from the indiscriminate disposal of waste crankcase oils has necessitated the quest for alternative low cost energy option in Nigeria. This has prompted deliberate research efforts to recover energy from waste oils for the purpose of industrial heating. In this paper, waste oils drained from spark ignition engine sump, were collected and pre-treated to rid the oil samples of particulate matter, ferromagnetic materials and water. The oil was prepared and separated into two batches, one was blended with diesel and the other one with kerosene at the following blending ratios; B0 (unblended pre-treated oil samples), B10 (90% pre-treated oil samples, and 10% fuel blend), B20, B30, B40 and B50 (v/v %) respectively. The densities, and viscosities of each blend were determined in accordance to ASTM test protocols, and spot tests were also carried out to ascertain the homogeneity of all blended oil samples. Each oil sample was combusted in an atomising swirl oil burner, and their flame temperatures were recorded using a Type-K thermocouple, the flame length and flame widths were measured from a calibrated horizontal/vertical linear scale, and their photographic images were captured with a direct still digital camera. It was observed that the densities and viscosities of both diesel and kerosene blended fuels decrease somewhat as the blending ratio increases, and B30 diesel fuel blended sample generated the highest flame temperature (1396℃), longest flame (360mm) and widest flame (115mm). While, B30 kerosene blended fuel samples recorded the highest flame temperature (1350℃), and the longest flame (380mm) and widest flame (110mm).Even though all categories of blended fuel samples analysed demonstrated good combustibility in terms of their flame and thermal performance, diesel fuel blended oil samples were more homogenous than kerosene blended fuels samples, and the energy cost analysis tend to favour kerosene blended fuel samples over its diesel fuel blended counterpart.

Keywords: Diesel, kerosene, waste crankcase oil, fuel blends, swirl burner, flame behaviour

INTRODUCTION

There is an ever- increasing demand for petroleum products as a source of energy in the developed and developing countries of the world with the fuel market is almost 100 times the size of the lubricant market. In 2011, the global lubricant market was 11.73 billion gallons (38.1 million MT) with 4.22 billion gallons (13.7 million MT) was lost in use, being leaked on the road or burned in the engine; 1.94 billion gallons (6.3 million MT) illegally dumped contaminating soil and water, 4.13 billion gallons (13.4 million MT) collected and burned as fuel, and 10.29 billion gallons (33.4 million MT) were lost directly to the environment, leaving the left-over balance for collection and re-refining as downshifted base stock, and for other uses such as firing of industrial boilers and furnaces [1-2].

Going by a projected growth rate of 11.1 per cent per annum, the Nigerian lubricant market is expected to grow by over 100 per cent in2022 due to oil prices volatilities and the devaluation of the Nigeria currency. The local consumption of the product is expected to hit 805,000 metric tonnes by that year, up from 350,000 to 400,000 metric tonnes per annum, which is the current consumption level. The phenomenal growth in the motor oil segment is hinged on the unprecedented rise in vehicular population [3-4], which consequently, will leave behind a significant volume of waste crankcase oil (WCO), requiring effective management and utilization within established environmental guideline [5].According to Sote, [6] three methods are recommended for proper and safe disposal of waste oil, that is; burning as fuels, incineration and pumping into the soil, with burning waste oil as fuel as the safest and most economical method in industry. All over the world, WCO is widely combusted as fuel with more prominent application in cement kilns and asphalt mixing plants for energy recovery purposes; it could be burnt as single fuel or blended fuel [6].

To improve the quality of waste crankcase oil as combustion fuel, the fuels need to be pre-treated to remove water, metal scrapings, and particulate matters (i.e. pre-treated), and then blended with fuels of superior thermo-physical properties due to its relatively higher viscosity, flash point and density with a view of increasing its combustion temperature. When WCOs are to be blended with fuel oils as heating fuels, it is essential to determine their heterogeneity when mixed with primary hydrocarbon fuels as an important parameter [7]. In oil burners, high waste crankcase oil viscosity is mostly surmounted by pre-heating the oils to improve its atomization quality, as high oil viscosity causes poor combustion and fuel carbonization at the nozzle [7]. Conversely, pre-heating waste crankcase oil to certain high temperature also causes fuel carbonization [8-10]. Hence, for the overriding reasons of improving the combustion performance of the oil, makes blending WCOs a worthwhile endeavour to meet the rising energy demands of the nation's small and medium scale industries.

From existing literatures, the thermal performance of typical WCOs has been investigated for different applications. Fakolujo *et al*[11] carried out an experimental analysis of kerosene blended WCO using a furnace ensuring atomization, ignition and combustion, and reported that: 100%, 95% and 90% volume of WCO gave low pour point hence could not ignite efficiently; 85%, 80% and 75% volume of the fuel blends produced carburized flame; 55% and below of volume of the blended fuels samples generated oxygenated flame; and 57%-70% volume of the fuel blends produced neutral flame which is ideal for melting on the other hand, 70% of blended WCO had the highest calorific value of 70,780 kj/kg, and were found to be cheaper. In a related study, Al-Omar [12] reported that by co-firing small amount of WCO with liquefied petroleum gas (LPG) in furnaces the flame thermal radiation potential was found to improve by 80%. Aji *et al*, [13] carried out an experimental investigation of used engine oil blended with kerosene in crucible furnace, and found that 6:1 v/v% of WCO blend was more efficient for melting 10kg of zinc in 22 minutes. Yahaya and Diso [14] investigated the combustion of WCO blended with kerosene, and reported that 14.3/85.7 % kerosene to waste oil blend is the optimum blending ratio for the fuels to burn without pre-heating. Madu *et al* [15] designed and constructed a straight waste oil burner that uses kerosene blended WCO as fuel, and reported that 1:5 kerosene to WCO blending ratio fired at 15:1 air-fuel ratio is the most effective combination that melts copper, aluminum, brass and lead within the shortest time.

However, no research evidence has been reported on the flame and thermal behavior of diesel blended WCOs or kerosene blended WCOs in an atomizing swirl oil burner. Hence, the experimental investigation of the flame and thermal behavior of diesel blended, and kerosene blended WCOs as heating fuels, will represent the fundamental objective of this study.

DESIGN, MATERIAL, PROCEDURE, AND METHODS

Characterization of Primary Fuels Samples

Diesel and kerosene fuel samples were purchased from the officially approved retail outlet of the Petroleum Product Marketing Company of the Nigeria National Petroleum Corporation in Bauchi state, Nigeria. The physical analysis of the fuel samples was carried out in-line with the ASTM standard test protocol to determine the oils specific gravity, kinematic viscosity, flash point, calorific value, and sulphur contents of the oils. Other properties that were also investigated are; self-ignition temperature, boiling point, ignition delay and flame propagation rate [16].

Collection and Preparation of Waste Crankcase Oil

The waste crankcase oil was collected from the lubrication bay of Mobile service station, Bauchi. The oil was drained from the sump of spark ignition engines, the oil sample collected was allowed to settle in a container for 5 days to reduce sludge and particulate that could clog up the burner nozzle. The collected oil was then decanted and heated in an open container for 45minutes to allow water molecules that might be present in the oil to evaporate. The oil sample was filtered thrice using 177 microns (UBS-177) stainless steel mesh screen to further remove particulate matter in accordance with the method reported by Abu-Ellela *et al* [17], magnetic separation technique was employed by placing pieces of nickel-plated neodymium magnetic cubes in the filtered oil for 48 hours in accordance with the method reported by Owolabi ,*et al*[18] to attract and rid the oil samples of ferromagnetic materials.

Two batches of pre-treated oil sample were prepared, the first batch was blended with diesel, and the second batch was blended with kerosene at the following blending proportions; B0 (unblended pre-treated oil samples), B10 (90% pre-treated oil samples, and 10% fuel blend), B20, B30, B40 and B50 (v/v %) were each blended with a homogeniser. The lubrication properties of the processed and unblended waste oils were also carried out in accordance with ASTM-D-1298, ASTM-D-445, ASTM-D-97, and ASTM-D-92test methods for; specific gravity, kinematic viscosity, pour point, and flash point respectively. Other tests on kinematic viscosity @ 100℃, specific gravity and homogeneity of blended fuel samples were also determined using standard ASTM methods [16].

Description of the Atomizing Swirl Oil Burner

An atomizing oil burner (refer to plate I) with technical specifications presented in table 2 below was used to combust WCO, and blended fuel samples. The fuel oil is pumped from the oil tank kept below the burner level with the aid of an oil pump to the burner oil preheating tank. Inside the preheating tank is an electric heater connected to an electric source and a thermostat to regulate the temperature of the oil. A compressor connected to the nozzle and driven by the motor supply primary air lifts the oil from the oil tank and atomizes it into fine spray using siphon nozzle under pressure, while a blower connected to the motor supply the secondary air to ventilate the flame. The swirler is of a vane type. This spray is usually ignited by an electric spark generated by a transformer. A glow bar which operates more like glow plugs in diesel engine ignite the fuel and a photo resistor or Cad cell detects the flame [19].

Plate I: Atomizing swirl waste oil burner

Table -1 Technical Specification of the Swirl Waste Oil Burner

Parameter	Units	Value
Model	-	STW 120 P
Capacity	kW	10-50
Power rating	W	90
Flow rate	Kg/s	1-4
Pump rating	W	110
Power supply	V/Hz	230/50

Fuel Samples Flow Rate and Equivalent Combustion Air Flow Rate

The tested fuel samples' flow rate was determined by calculation using the Bernoulli equation the burner was fired at 0.4 bar (manufacturer's recommended atomizing pressure for waste crankcase oil at 100℃ oil preheating temperature); burner nozzle diameter is 0.004m and the calculated area is $1.25\times 10^{-5}m^2$.

Hence, the mass flow rate (m) $=C_f\rho v A$ [1]

Where, C_f is the correction factor, and A is the nozzle cross sectional area.

The mass of oxygen required for the combustion of 1kg of waste crankcase oil is 2.66kg [15].

The mass of oxygen required to completely burn 1kg of diesel fuel was calculated from the combustion equation;

$$C_{13}H_{28}+20O_2\rightarrow 13CO_2+14H_2O \quad [2]$$

The calculated mass was obtained to be 3.47kg

The mass of oxygen required to completely burn kerosene fuel was also calculated from the combustion equation;

$$2C_{12}H_{26}+37O_2\rightarrow 24CO_2+26H_2O \quad [3]$$

The calculated mass was obtained to be 3.48kg.

The calculated mass of oxygen was used to calculate the mass of air and stoichiometric ratio of each fuel blend and the required secondary air mass flow rate according to Williams and Rothamer [20], the calculated combustion air mass flow rate (kg/s) was converted to volumetric flow rate, cubic feet per meter (cfm) using the relationship;

$$1cfm= 0.0283 \text{ kg/s} \quad [4]$$

The combustion air volumetric flow rate for all the blended fuel samples fall between 0.296 cfm to 0.341cfm, the burner combustion air control is calibrated at 0.25, 0.50 and 0.75 cfm Hence, 0.25cfm was adopted for all the blended fuel samples with the assumption that atomizing air from the compressor will supplement the deficits to surmount the challenges of over-ventilation.

Experimental Methods

Before the commencement of any experiment, the oil burner was adjusted to vessel pressure of 0.4 bar and 100℃ oil preheating temperature and 0.25 cfm equivalent (B0) was pumped from the oil tank kept below the burner level with the aid of an oil pump to the preheating tank set at 100℃.Compressed air creates suction in the burner preheating tank and the fuel sample was pulled from the preheating tank utilizing venturi effect and atomized into fine spray at the nozzle and combustion-flame was initiated with the help of high voltage spark electrode. The flame temperature was carefully measured using a K-type high temperature digital thermometer (TM-902C) clamped to a retort stand close to the burner head at the continuous flame region until a steady temperature reading was obtained. The experiment was conducted under an ambient temperature of 21 to 28℃.

A vertical and horizontally calibrated scale was marked –out on a transparent plastic plate, and placed beside the burner. Direct photographs of flame structures emanating from the burner were taken using a still digital camera through the transparent plastic plate. The flame length and width were read and recorded from the photographic images. Three pictures were taken and their average flame dimension in terms of the length, and width were computed. The experiment procedure was repeated for all blended fuel samples under study.

RESULTS AND DISCUSSION

Properties of Diesel and Kerosene Fuel Samples

The result of the characterisation of combustible liquid hydrocarbon fuel samples is presented in table 2. It is clearly evident from available results in table 2 that the Diesel fuel exhibited relatively higher viscosity, flash point than kerosene fuel sample, and conversely, demonstrated lower specific gravity, calorific value and sulphur content than kerosene fuel counterpart. Furthermore, in the result of thermal properties test of the primary fuels under study are presented in table 3, and conformed with that of Presser *et al*[21]. The result revealed the superior self-ignition and boiling temperature of Diesel fuel samples over its kerosene counterpart, and the shorter ignition delay period and higher flame propagation rate of kerosene over diesel fuel, and is likely to enhance the combustion performance of kerosene fuel, with comparatively shorter flames.

Table -2 Properties of Secondary Fuels Used [21]

Properties	Unit	Diesel	Kerosene
Chemical formula		$C_{12}H_{26}$	$C_{10}H_{22}$
Specific gravity @ 15.6/15.5℃	-	0.893	0.943
Kinematic viscosity @ 39℃	mm^2/s	2.7	2.2
Flash point	℃	153	108
Calorific value	Kj/kg	44,500	45,400
Sulphur content	%wt	0.2	0.6

Table -3 Thermal Properties of Diesel and Kerosene Fuel Samples [21]

Properties	Unit	Diesel	Kerosene
Self-ignition temperature	℃	725	640
Final boiling point	℃	385	300
Ignition delay period	S	0.0002	0.0015
Flame propagation rate	Cm/s	10.5	11.8

Table -4 Properties of Lubrication Oil Base Stock [23]

Properties	**Units**	**Test method**	**Typical value**		
			150N	500N	BS 150
Crude oil			Paraffinic	Paraffinic	Paraffinic
Chemical formula			C_nH_{2n+2}	C_nH_{2n+2}	C_nH_{2n+2}
Specific gravity		ASTM-D-1298	0.861	0.888	0.903
Kinematic viscosity @ 40℃	mm^2/s	ASTM-D-445	24.38	95.48	77.80
Kinematic viscosity @ 100℃	mm^2/s	ASTM-D-445	4.55	10.89	30.99
Viscosity index	-	ASTM-D-2270	98	98	96
Pour point	℃	ASTM-D-97	-23	-10	-13
Flash point	℃	ASTM-D-92	210	244	290
Sulphur content	%wt	ASTM-D-1552	0.2	0.7	0.8

Table -5 Thermo-Physical Properties of Diesel Blended Waste Crankcase Oil

Fuel Blends	Calorific value (kJ/kg)	Flash point (℃)	Viscosity @40℃(Sct)	Viscosity @100℃(Sct)	Pour point (℃)	Density (kg/m^3)
B0	41,421	82.12	154.63	10.13	-24	853
B10	-	-	-	9.33	-	849
B20	-	-	-	8.17	-	844
B30	-	-	-	7.10	-	840
B40	-	-	-	6.33	-	835
B50	-	-	-	5.54	-	831

Table -6 Thermo-Physical Properties of Kerosene Blended Waste Crankcase Oil

Fuel blends	Calorific value (kJ/kg)	Flash point (℃)	Viscosity @ 40 ℃ (Sct)	Viscosity @ 100 ℃ (Sct)	Pour point (℃)	Density (kg/m^3)
B0	41,421	82.12	154.63	10.13	-24	853
B10	-	-	-	9.09	-	851
B20	-	-	-	7.70	-	848
B30	-	-	-	6.64	-	846
B40	-	-	-	5.71	-	843
B50	-	-	-	5.01	-	841

Thermo-Physical Properties of Unblended and Blended Waste Crankcase Oil Samples

The results of the thermal and rheological properties of WCO samples derived primarily from lubrication oil base stock with properties presented in table 4, could be found in table 5 and 6 respectively. A typical lubricant contains about 90% base oil (most often petroleum fractions called mineral oils) and less than 10% additives which impart performance characteristics to the lubricants [22].The blending of the waste oil with combustible liquid hydrocarbon fuel, such as diesel and kerosene fuels, predicated on the fact that lubricating oils decreases in quantity during usage, and after reclamation the additive levels of the oils are depleted considerably, and blending enhances the secondary use of waste oils as fuels by removing any contaminants and low flash points products, like fuels and sediments, that may put a limit on their thermal values [6].

It could be reconciled from tables 2-6 that blending WCO samples with Diesel and kerosene fuel is intended to achieve the following objectives: i). To improves the heat content by raising the calorific values of the WCO blended samples, ii). To raise the flash point of waste oils and make them less flammable and safer to handle, iii). To make the WCOs less viscous and less dense to enhance oil flowability and, iv). To raise the self-ignition temperature of waste oil samples, and reduce their ignition delay periods for enhanced combustion performance. On the whole, it was observed that diesel fuel blended WCOs are comparatively more viscous, denser and are more likely to exhibit lower calorific values than their kerosene fuel blended WCO samples.

The Effect of Diesel Fuel Blend and Kerosene Fuel Blend on Flame Length

Understandably, longer flame may be undesirable in shorter combustion chambers, as it causes chamber or process tube impingement, and consequently results in material degradation. The flame length is nonetheless highly desirable in other applications, such as; in glass melting furnaces, and hence remains as a crucial combustion characteristic when setting burner combustion. The flame length of B10, B20, B30, B40 and B50 diesel blended fuel samples were found to be 10.00%, 25.00%, 35.00%, 55.00% and 80% higher than B0 benchmark. While, the flame length of kerosene blended fuel samples at B10, B20, B30, B40 and B50 blended mixtures were found to be 5.00%, 5.00%, 40.00%, 80.00% and 90.00 % higher than B0 waste oil sample (refer to table 8). The increase in flame length above B0 sample for all the blended diesel and kerosene fuel samples could be ascribed to the decrease in the fuel sample's kinematic viscosity and increasing blending ratios [23]. Diesel blended WCO samples produced longer flame sizes at B10, B20 and B40 against kerosene blended WCO, such difference could be explained in terms of the lower flow rate of kerosene blended fuel samples (refer to figure 1),

This point was further corroborated by Ahmed *et al,* [24], with explanation that a decrease in flow rate brings about a higher pressure drop index at the nozzle, an increase in fuel drop size diameter, and reduces escape velocity of the fuel, with the consequence of shorter flame length. Nonetheless, the comparatively shorter flame length recorded for B30 kerosene blended WCO sample over its diesel fuel blended counterpart could be explained in terms of compact flame with higher intensity [25]. Conversely, B50 kerosene blended fuel sample produced a longer flame compared to diesel fuel blended counterpart for reasons of its decreasing kinematic viscosity, which tend to promote the 'swirler' effect, due to less fuel mixture resistance to flow, and higher kerosene flame propagation rate (refer to tables 3,7 and 8).

The Effect of Diesel Fuel Blend and Kerosene Fuel Blends on Flame Width

Flame width is a very important combustion characteristic when making combustion adjustment in most furnaces, because a wider flame predisposes the combustion chamber to higher fire risk. It could be seen from the experimental results in tables 7 and 8 that the flame width of B10, B20, B30, B40 and B50 diesel blended fuel samples are 12.50%, 12.50%, 25.00%, 43.75%, and 43.75 % higher than B0, while kerosene blended fuel samples are 6.25%,0.00%, 6.25%, 25.00% and 37.50 % higher than B0 WCO sample. The increase in flame width by both diesel fuel blends, and kerosene fuel blends with increasing blending ratio could be attributed to the resulting decrease in the kinematic viscosity of the blended fuel samples. This view was further corroborating the work documented in literature that; the lower the fuel viscosity, the wider the burner nozzles spray angle, and flame width [26]. Diesel fuel blends produced wider flames than kerosene fuel blends due to their higher mass flow rate as earlier mentioned (refer to figure 1), and this implies that, a lower pressure drop in diesel blended fuel samples generated better fuel atomization characteristics and wider flames sizes.

Table -7 Flame Characteristics of Some Diesel Fuel Blended WCOs

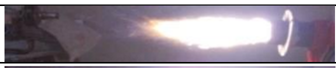
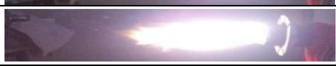
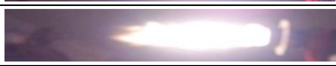
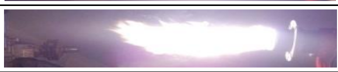
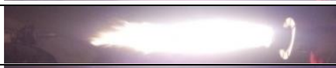
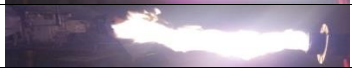
Fuel sample	Flame structure	Length (mm)	Width (mm)	Temperature (℃)
B 0		200	80	1265
B 10		220	90	1275
B20		250	90	1326
B30		270	100	1334
B40		310	115	1368
B 50		360	115	1396

Table -8 Flame Characteristics of Some Kerosene Fuel Blended WCOs

Fuel sample	Flame structure	Length (mm)	Width (mm)	Temperature (℃)
B 0		200	80	1265
B 10		210	85	1326
B20		210	80	1315
B30		280	85	1350
B40		260	100	1290
B 50		380	110	1296

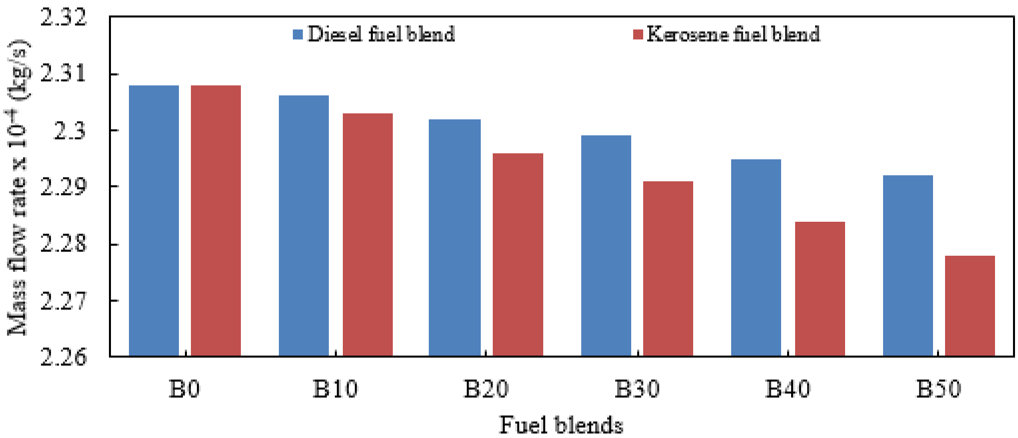


Fig. 1 Mass flow rate versus fuel blending ratio of blended waste oils

The Effect of Diesel Fuel Blend and Kerosene Fuel Blends on Flame Temperature

The flame temperature of B10, B20, B30, B40 and B50 diesel fuel blended waste oil samples are 1.19%, 4.82%, 5.45%, 8.14%, and 10.36 % higher than the B0 benchmark. B50 fuel sample produced the highest flame temperature of 1396℃, while kerosene blended waste oil samples are 4.82%, 3.95%, 6.72%, 1.98% and 2.46 % higher than B0 test samples, and B30 produced the highest flame temperature of 1350℃.

The increase in flame temperature as the fuel blending ratios increase for both diesel and kerosene fuel blends could be attributed to the comparatively higher calorific value of kerosene and diesel over waste crankcase oil. It could also be seen from table 9 that blended fuel sample' homogeneity plays a vital role in temperature profile of the blended fuel samples, diesel blended fuel samples are gave increasing flame temperature owing to improved conditions of homogeneity in all its blended samples. It could also be observed that no inner ring was formed in all the blended fuel samples with exception of B50 samples. This means from B10 to B40 samples, the blended fuels samples are homogenous and the appearance of inner ring in the spot indicates incompatibility, instability and heterogeneity in fuel blends. According to Presser *et al*, [21] lower fuel viscosity generate smaller fuel drop size which promotes efficient air-fuel mixture. The conditions of oil mixture homogeneity in kerosene blended waste oil samples could also be responsible for the increase of flame temperature for B10-B30 blended WCO samples, and the temperature drops recorded for B40 and B50 oil samples, could be explained in terms of the gradual loss in oil homogeneity (refer to table 8 and 9).

Experimental Uncertainty

Direct photographs of the flame were taken three times and the mean values of the flame length and flame width are presented in tables 10, 11, 12, and 13. The mean, standard deviation and percentage error were calculated according to [29, 30] using the formula:

$$\text{Mean Value } (\bar{X}) = \frac{1}{n}\sum_{i=1}^{n} Xi \qquad [5]$$

$$\text{Standard Deviation}(\delta) = [\frac{1}{n-1}\sum_{n-1}(X-\bar{X})^2]^{1/2} \qquad [6]$$

$$\text{Uncertainty error (\%)} = \frac{Standard\ deviation}{Mean\ Value} \times 100 \qquad [7]$$

The calculated results for both diesel fuel blends and kerosene fuel blends are presented below;

Table -9 Spot Homogeneity Test Results of Blended WCO Samples

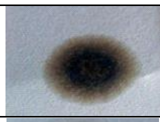
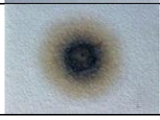
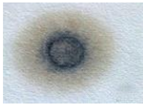
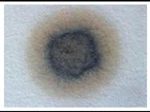
Fuel types	Blending ratio					
	B0	B10	B20	B30	B40	B50
Diesel fuel and WCO blends						
Kerosene fuel and WCO blends						

Table -10 Uncertainty Level of Measured Flame Width of Diesel Fuel Blends

Fuel blending sample	FL1 (mm)	FL2(mm)	FL3 (mm)	Mean($\bar{X}$)	Standard deviation (δ)	Error %
B0	198	200	202	200	2.83	1.4150
B10	223	220	217	220	3.16	1.4364
B20	251	252	247	250	3.74	1.4960
B30	271	270	269	270	1.41	0.5222
B40	312	311	307	310	3.74	1.2064
B50	360	365	357	360	4.24	1.1778

Table -11Uncertainty Level of Measured Flame Width of Diesel Fuel Blends

Fuel blending ratio	FW1 (mm)	FW2 (mm)	FW3 (mm)	Mean($\bar{X}$)	Standard deviation(δ)	Error %
B0	81	80	79	80	1.41	1.7625
B10	91	90	89	90	1.41	1.5667
B20	89	91	99	90	1.41	1.5667
B30	101	100	100	100	1.41	1.4100
B40	115	114	116	115	1.41	1.2261
B50	115	116	114	115	1.41	1.2261

Table -12Uncertainty Level of Measured Flame Width of Diesel Fuel Blends

Fuel blending ratio	FL1(mm)	FL2(mm)	FL3(mm)	Mean($\bar{X}$)	Standard deviation(δ)	Error %
B0	201	202	197	200	3.74	1.8700
B10	210	211	209	210	1.41	0.6714
B20	212	211	207	210	3.74	1.7810
B30	282	279	279	280	2.45	0.8750
B40	260	261	259	260	1.41	0.5423
B50	381	382	377	380	3.74	0.9842

Table -13Uncertainty Level of Measured Flame Width of Kerosene Fuel Blends

Fuel blending ratio	FW1(mm)	FW2(mm)	FW3(mm)	Mean($\bar{X}$)	Standard deviation(δ)	Error %
B0	82	80	78	80	2.83	3.5375
B10	84	84	87	85	3.32	3.9059
B20	80	80	79	80	1.41	1.7625
B30	86	86	83	85	2.24	2.6353
B40	100	100	99	100	1.41	1.4100
B50	112	111	107	110	3.74	3.4000

The percentage error for all the measured experimental parameters falls between 0.5423 to 3.9059%, the error level is quite acceptable since they are less than 5% according to [31].

Statistical Validation

To ascertain and investigate the validity of the difference between all the measured parameters, the experimental results were subjected to t-test analysis, the results shows that the p-values of flame length, flame width and flame temperature are 0.363, 0.011 and 0.438 respectively at 95% confidence bound which indicates no significance difference in measured flame length and flame temperature between diesel fuel blends and kerosene fuel blends but the flame width significantly differ.

Comparison of Energy Cost of Blended Fuels

Going by the price regime of petroleum products in Nigeria, the cost of one litre of diesel fuel and kerosene fuel obtained from NNPC retail outlet in Bauchi are is ₦180 and ₦150 respectively, while the average price of WCO obtained from the lubrication bay of vehicle service station is ₦109 per litre. The cost of obtaining 1℃ flame temperature from burning 1 litre of each blended fuel sample was calculated based on the ratio of the price of each fuel blend to the flame temperature according to Felder and Rousseau[32] and, Wilson and Morril[33]. The result of cost analysis presented in figure 2, show the cost of obtaining a flame temperature of 1℃ from combusting 1 litre of diesel fuel blends are higher than that of the kerosene fuel blended counterpart by 7.05%, 4.49%, 8.89%, 3.09% and 4.00% for B10, B20, B30, B40, and B50 blended fuel samples. It could be observed from the economic point of view that, kerosene fuel has proven to be cheap to be cheaper and more cost effective additive for waste crankcase oil as combustible fuel, than its diesel counterpart.

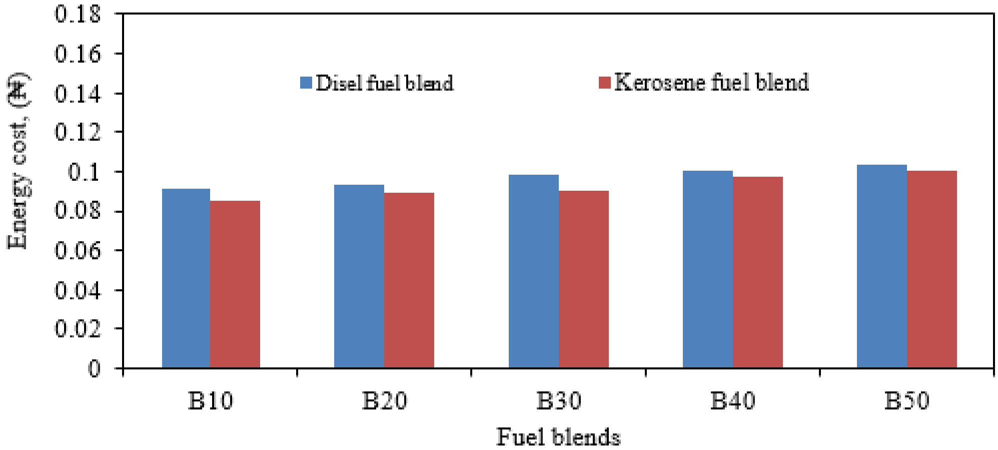


Fig. 2 Energy cost of the blended fuel samples

CONCLUSION

Experimental analysis was carried out to compare the flame and thermal performance of diesel and kerosene blended WCOs, and the following could be deduced:

- Diesel and kerosene blending improved the the flame and thermal behaviour of WCOs.
- WCOs blended with Diesel fuel outperform their kerosene blended counterpart in overall thermal performance.
- The challenge of heterogeneity of fuel mixture at higher blending proportions of kerosene (i.e. B40 and B50 WCO samples) exhibited a tendency of thermal underperformance.
- In terms of the Nigerian pricing regime of petroleum products, kerosene fuel blended WCOs generated a comparatively lower energy cost than diesel fuel blended WCOs.

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