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Robinson I. EJILAH
Abiodun A. OGBANEME
Osazoduwa O. AGBONENI
Sikiru O. ADEKUNLE

Combustion Engines
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Analysis of jatropha oil-kerosene fuel mixtures on the performance of a variable-load direct injection CI engine

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Jatropha oil was blended with kerosene in ratios; JOK0, JOK20, JOK30, JOK40 and JOK50 and benchmarked against conventional diesel fuel. The blended fuel samples was test-run on a TD110-TD115 TQ small CI engine test rig, and emission levels for the fuel samples were examined using an SQV automobile exhaust gas analyser. The JOK20 fuel sample offered a better performance in terms of higher BP, BTE, and EGT followed by; JOK30, JOK40 and JOK50 blends; and also exhibited lower SFC, BSEC and AFR, hence less fuel consuming than diesel fuel. A reduction in CO emission was recorded for JOK20, and a significant cut was also observed for JOK30, JOK40 blends with load increase.; while, JOK30, JOK40 and JOK50 samples exhibited higher CO_2 and lower UHC emission levels than diesel. No traceable level of NO_x emission was recorded for JOK20 fuel sample.

Key words: *jatropha oil, kerosene, CI engine, performance, emission*

1. Introduction

Over the years there has been a worldwide search and move towards the application of alternative, and renewable fuels with low environmental impact. Crude oil reserve depletion, price uncertainty and negative effect of fossil fuels on the environmental are responsible for this move. Alternative fuels have superior performance and environmental emission reduction abilities. Oils from plant sources have demonstrated very good potentials to be used as alternative fuels; due to their renewability, and ability to lower greenhouse emission while improving energy security [1].

Jatropha curcas is one of such promising energy crops, with high seed oil content ranging from 30 to 50% by weight [2]. Studies have shown that the usage of non-edible oils in neat form is possible but not preferable [3]. The crude jatropha oil contains 21% saturated fatty acids and 75% fuel diesel fuel blends produce remarkable results in fuel economy, brake power and minimal combustion chamber wear in compression ignition engines. Nonetheless, in longer term usage, the high viscosity of non-edible oils and the low volatility affects the atomization and spray pattern of fuel, leading to incomplete combustion and severe carbon deposits, clogging of fuel filter, coking of injector tips, and piston ring sticking, would be common place engine durability challenges [4–13]. However, to surmount these challenges, the transesterification or blending of jatropha curcus oil would be required to reduce the oil's viscosity profile [14–16].

Azad et al. [17] found that the result of; calorific value (CV), brake specific fuel consumption (BSFC) and brake thermal efficiency (BTF) of mustard seed oil blended with kerosene at 20% and 30% of the blends, were close to that of the diesel fuel. The resulting blends also gave better engine performance behavior when compared with other fuel blends in the group, thus making it suitable for use in compression ignition (CI) engines.

Ghormade et al. [18] in a study compared the performance of two vegetable oil blends with kerosene (i.e. soybean oil with kerosene, and rapeseed oil with kerosene) with conventional diesel fuel. It was observed that; blends of 20% vegetable oil with 80% kerosene by volume fairly improves the thermal efficiency of the test engine under high loading conditions. Huzayyin et al. [19] reported fairly improved thermal efficiency in the case of heavy loading for high pressure injection engine during the performance test of blends of heavy fuel, and low grade oil kerosene compared with diesel fuel at 60% fuel oil and 40% kerosene by volume.

Sanjid et al. [20] found that the palm and jatropha oil blend (PBJB10) showed 20.49% reduction in carbon monoxide (CO) emission compared with diesel fuel. This blend demonstrated better results with unburnt hydrocarbon (UHC) emissions and sound levels. In a related study, Nalgundwar et al. [21] tested dual biodiesel palm and jatropha oils with diesel fuel; the blend D70JB15PB15 exhibited a 14.5% CO reduction in emission. While, the blend D90JB5PB5 shows 5.3% increase in NO_x emission. In addition, Agarwal et al. [22] found that CO, UHC and carbon dioxide (CO_2) emissions were less in the B20 engine compared to the emission arising from the use of conventional diesel fuel. However, in the same study, the oxides of nitrogen (NO_x) emission levels was observed to be higher rate of emission due to the presence of fuel oxygen. The use of unprocessed jatropha oil as fuel may be difficult due to its high density and density. However, other than blending with kerosene, the high viscosity could also be significantly reduced with the addition of n-hexane, save that it could generate a negating ecological condition due to the increased concentration of nitrogen oxides, as it is with canola oil [23]. Existing literature has also revealed that that fish waste and jatropha oil can be used as alternate fuel for engines without modifying any specifications of the engine, and also, the emissions from the engine showed a better result except NO_x which is higher [24]. Jatropha oil is gaining a lot of attention on account of the fact the ecological impact in CO_2 reduction and climate change mitigation as a safe aviation fuel is also been considered. Due to the fact that aviation sector has no near-term alternative to liquid hydrocarbon fuels, the SAF produced from variable renewable feedstock-including jatropha, seems to be the best option for modern aviation fleet [25].

Furthermore, in a study by Hemanandh et al. [26], the performance and emission characteristics of hydro treated jatropha oil and kerosene blends was reported. The results showed a decrease in CO, UHC, CO_2 and NO_x emissions for HK10, HK20 and HK30 blends. An observable increase in BTE, decrease in BSFC and increase in smoke emission for HK10, HK20 and HK30 blends where also reported. Madiwale et al. [27] showed improvement in brake power (BP), BSFC, and BTE at various loading conditions. Several works have been published on the performance and emission behavior of vegetable oils blended with diesel and kerosene, However, the objective of this paper is evaluate the effect of jatropha oil blended with kerosene, and varying engine load on the performance and emission of an air cooled-single cylinder, 4-stroke direct injection (DI) diesel engine, and identify which blended sample(s) offers significant potential as sustainable fuel for modern diesel engines.

2. Materials and Methods

The jatropha, kerosene and diesel oil were used for this experiment. The diesel and kerosene fuel were purchased from a government approved fuel station in Bauchi-Nigeria, while the jatropha oil with fatty acid composition and chemical structure presented in Table 1 below was purchased from a local supplier. The proportion of fuel blends used are presented in Table 2. Physical properties of jatropha oil, kerosene and diesel oil and jatropha oil-kerosene blends (refer to Tables 3 and 4) were determined in accordance with standardized ASTM test procedures; ASTM D97-93, ASTM D2015-85, ASTM D 93-94, ASTM D D613, ASTM D 445 for density, higher heating value, flash point, octane number and kinematic viscosity respectively [28].

Table 1. Fatty acid composition (%) and chemical structure of jatropha curcas oil [13]

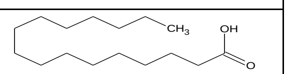
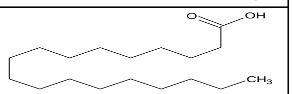
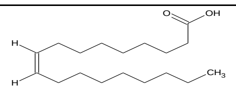
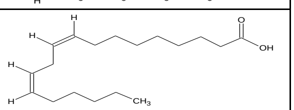
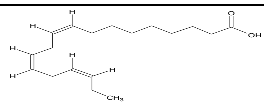
Name	Composition [%]	Structure
Palmitic acid	12.6	
Stearic acid	3.9	
Oleic acid	41.8	
Linoleic acid	41.8	
Linolenic acid	7.8	

Table 2. Samples of fuel mixtures used

Blend name	Percentage of blends
Diesel	100% Diesel
JOK0	100% jatropha oil
JOK20	80% jatropha oil and 20% kerosene
JOK30	70% jatropha oil and 30% kerosene
JOK40	60% jatropha oil and 40% kerosene
JOK50	50% jatropha oil and 50% kerosene

Table 3. Physico-chemical and fuel properties of jatropha curcas, kerosene, and diesel oil [13, 29]

Properties	Jatropha oil	Kerosene oil	Diesel oil
Viscosity (cp) @35°C	40.4	1.067	2.7
Specific density @35°C	0.917	0.79	0.835
Cetane value	33.7–51	42	47.8
Flash point [°C]	274	37.8	65.5
Carbon residue [%]	0.64	–	< 0.05
Sulfur [%]	0.13	0.04 -0.3	< 1.0
Acid value	38.2	–	–
Saponification value	198	–	–
Iodine value	112.5	–	–
Calorific value	39,862	46,520	45,457

Table 4: Summary of the properties of jatropha oil with kerosene and diesel blends

Fuel property	JOK0	JOK20	JOK30	JOK40	JOK50
Density at 30°C [kg/m^3]	917	884	878	869	856
Kinematic viscosity at 40°C [mm^2/s]	50.93	3.85	3.67	3.51	3.19
Flash point [°C]	274	195	191	187	180
Pour point [°C]	2	< 2	< 2	< 2	< 2
Cloud point [°C]	14	10	7	6	4
Specific gravity	0.917	0.888	0.882	0.873	0.860
Calorific value [MJ/kg]	39,862	40.874	41.122	41.687	42.125

2.1. Experimental setup and procedure

The neat jatropha oil was blended with kerosene at various proportions such as JOK0, JOK20, JOK30, JOK40, and JOK50 on volumetric basis and was tested in a single cylinder, air-cooled, 4 stroke and DI diesel engine mounted on an engine test bed, coupled to a hydraulic dynamometer was used (refer to Fig. 1 for schematic diagram and Table 5 for technical specification of the test rig). A SV-5Q automobile exhaust gas analyzer incorporated to the test rig's exhaust tail pipe was also used to measure the CO, CO_2, UHC and NO_x emissions from the engine. For a constant speed and variable load engine test rig with a hydraulic dynamometer, the time taken by the engine to consume 8 ml of the fuel was recorded at a constant speed 1400 rpm and at varying load of 500 g, 1000 g, 1500 g, 2000 g and 2500 g. The torque, exhaust temperature, oil temperature for all fuel samples were recorded. Engine performance measurements such as BSFC, air flow rate, BP, Brake specific energy consumption (BSEC), BTE, and air-fuel ratio (AFR) were taken. Engine performance test for diesel was also conducted as a basis for comparison. Technical specifications of the engine test rig are shown in Fig 1. A multi gas analyzer was used to measure the concentration of gaseous emissions CO, CO_2, UHC, and NO_x, in order to determine the emission characteristics of the various blends. The performance and emission characteristics of fuel samples were analyzed and discussed.

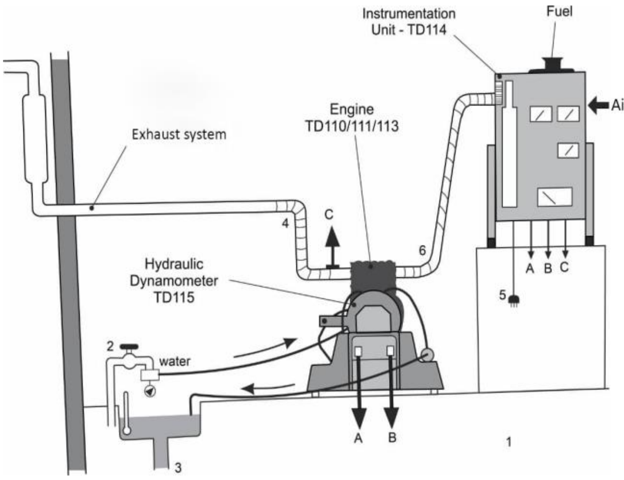


Fig. 1. An illustration of a complete TD110-TD115 TQ small engine test rig [30]

Table 5. Technical specifications of engine [30]

S/N items	Engine data
1. Model	TD110-115
2. Method of starting	manual starting
3. Engine type	single cylinder, 4-stroke diesel
4. Bore stroke	79.5× 955 mm
5. Piston stroke/stroke	115 mm
6. Displacement	1896 cm^3
7. Rated speed	1500 rpm
8. Maximum output	5.6 kW
9. Compression ratio	12:1 to 17.5:1
10. Maximum MEP	1400 kPa
11. Cooling method	air cooled
12. Fuel and lube oil	filter present
13. Injection pump	Bosh VE VP 37

3. Results and discussions

3.1. Effect of load and fuel samples on engine performance

Figure 2 shows the influence of diesel, jatropha oil, jatropha oil and kerosene (JOK) blends on brake power as a function of load. The pure jatropha oil (JOKO) exhibits the same behaviour with diesel as there was no significant change in engine BP at minimum and maximum loads. Nonetheless, the BP of JOK0 increased by 1.73% at 2000 g, while the BP of JOK20 fuel sample increased by 71% and 28% at minimum and maximum loads respectively, and reached a maximum at 2500 g. It was observed that the BP for JOK30 blend increased by 33% at minimum load. At maximum load the change in brake power is negligible. While, it was also noted that the JOK 40 fuel sample exhibited no significant changes in BP at minimum and maximum loads. The brake power for JOK50 increased by 29% at minimum load. There were no significant changes in BP at maximum load even though, a simulation study have shown that engine load some what affects; the axial movements of the rings in the grooves, elastic contact of the ring and cylinder surface asperities, and causes power losses due to the ring friction [31]. Furthermore, it could be seen that all tested fuel samples registered their highest BP under the condition of maximum load. These results show that JOK20 blend exhibited a comparably higher BP at minimum and maximum load points when compared with diesel [27]. The BP increased with increase in the engine load for all test fuels because of the enhanced combustion and decrease in frictional losses at higher loads [32].

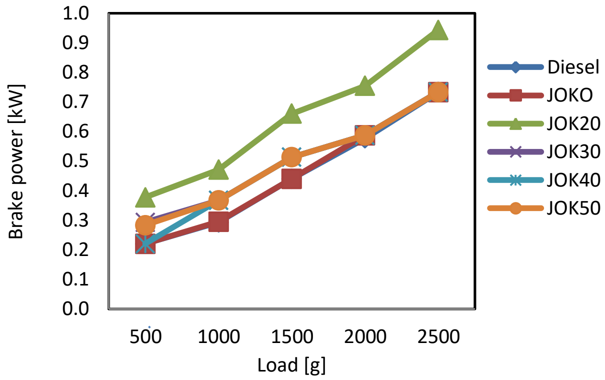


Fig. 2. Variation of BP for JOK blends with increase in load

Figure 3 shows the variation of SFC for JOK blends and diesel under different loading condition. In general, the BSFC was found to decrease with increase in the engine load for all test fuels. This was because of improved combustion in the cylinder at higher loads [32]. The trend of JOK0 fuel sample shows no significant change in SFC when compared with conventional diesel fuel.

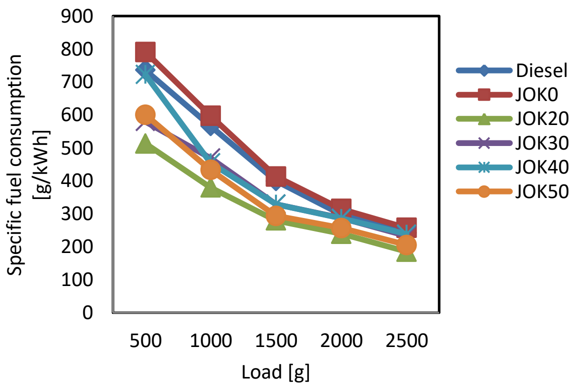


Fig. 3. Variation of SFC for JOK blends with increase in load

The SFC behavior for other blends under consideration at minimum and maximum loads are discussed as follows; JOK20 decreased from 71% to 28%, JOK30 decreased from 33% to 0%, JOK40 exhibits the similar behavior with diesel at minimum and maximum loads. However, at 1000 g engine load JOK20 sample exhibited the best SFC performance. While, JOK50 decreased from 28% to 0% from 1000 g to 1500 g. The improvement in SFC of JOK20 fuel sample ascribed to better combustion behavior of the fuel blend largely influenced by the presence of oxygen in the blend [32], and the addition of higher composition of kerosene lowers the viscosity of the blends (refer to table 4) and improves fuel spray atomization and subsequently the fuel combustion. However, recent finding have also shown that The use of nanoparticles (such as; Al_2O_3 and TiO_2) in fuels could also be employed to improve engine efficiency and reduce fuel consumption with no observed changes in the exhaust gas temperature after addition of nanoparticles [33].

The Fig. 4 presents the variation of AFR of diesel and other blends as a function of load. The trend of the effect of the variations caused by tested fuel samples at minimum and maximum loads are observed as follows; JOK0 sample decreases by 6.8% and 5.8% respectively with its lowest AFR occurring at 2000 g; JOK20 fuel sample decreases by 16.4%, and increased by 1.7%, exhibiting its highest AFR at maximum load; JOK30 fuel sample decreases by 4.7%, and increased by 4% revealing its highest AFR occurring at the intermediate load points; JOK40 fuel sample increases by 1.8% and 1.7% with its highest AFR recorded at the minimum load; and JOK50 blended sample decreases by 7.9%, and increases by 18%, with its highest AFR is at maximum load.

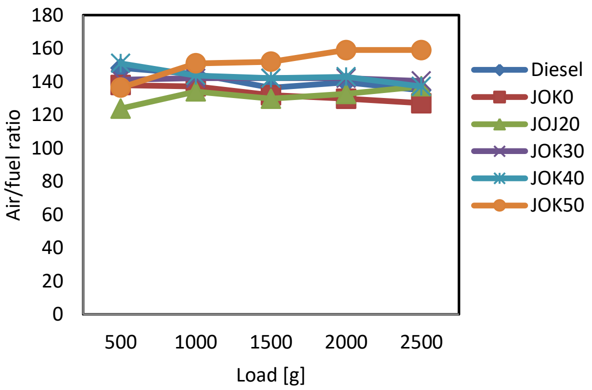


Fig. 4. Variation of AFR for JOK blends with increase in load

The illustration of BSEC variations for tested fuels and blends as a function of load is presented in Fig. 5. The trends in BSEC at minimum and maximum loads are discussed as follows: JOK0 fuel sample decreased from 6.7% to 2.7%; JOK20 blends decreases from 37% to 31.2%; JOK30 fuel decreased from 28.7% to 13.1%; JOK40 sample decreased from 9.9% to 9.8%. JOK50 blended fuel sample decreased from 24.4% to 21.4%. A general decrease in BSEC with increase in load was observed for all tested fuel samples under the varying loading condition.

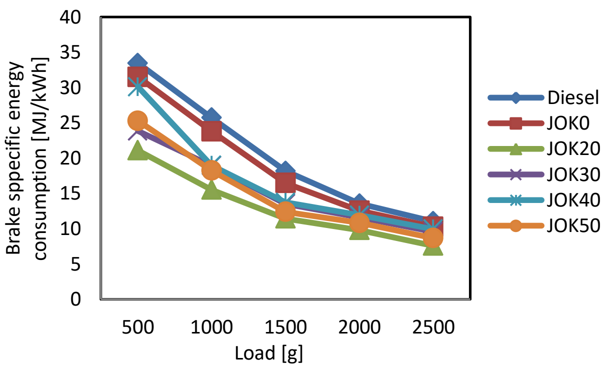


Fig. 5. Variation of BSEC for JOK blends with increase in load

The main reason for this could be credited to the fact that the percent increase in the amount of fuel required to operate the engine is less than the percent increase in BP. The blended samples appear to produced lower BSEC compared to diesel fuel. This lowering of the BSEC could be explained in terms of the availability of the oxygen in the fuel blends. BSEC is the energy input required to develop unit brake power, and is independent of the fuel used. When two different fuels of different heating values are blended together, the fuel consumption may not be reliable, since the heating value and density of the two fuels are different. In such cases, the BSEC will give more reliable value [34].

The BTE gives an idea of the output generated by the engine with respect to heat supplied in the form of fuel. Figure 6 shows variation in thermal efficiency for the fuels with increase in engine load. An increase in BTE was observed for all tested fuel blends for all loading condition. The variations in BTE at minimum and maximum loads for all samples is as follows: JOK0 sample increased from 15.3% to 36.5%; JOK20 blend increased from 17% to 47.5%; JOK30 fuel blend increased from 15.1% to 37.5%; JOK40 fuel sample increased from 11.9% to 36.2%; and JOK50 fuel blends increased from 13.7% to 41.5%. For all tested samples, JOK20 fuel samples exhibited the highest thermal efficiency, this too can be attributed to the commensurate increase in engine power with load increment. The BP increased with increase in the engine load for all test fuels – so does the BTE, because of enhanced combustion and decrease in frictional losses at higher loads [35]. The frictional losses could be further enhanced by the lubricity properties of the jatropha oil occasioned by its high saponification values (refer to Table 3). In addition, the SFC of an engine is inversely proportional to its BTE, hence decrease in SFC resulted in increase of the BTE. From the foregoing, it could be observed that the BTE of JOK fuel samples were observable higher than diesel under varying loading conditions.

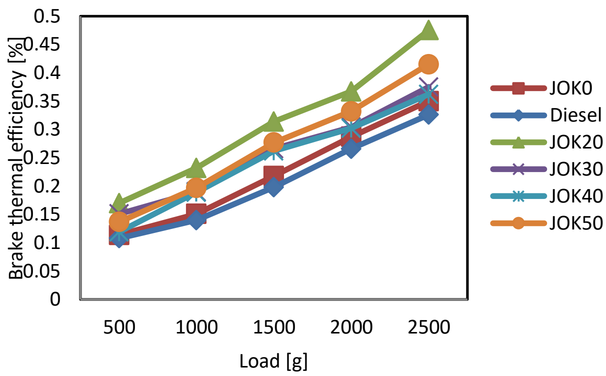


Fig. 6. Variation of BTE for JOK blends with increase in load

Figure 7 illustrates the results of the variation of EGT with load for diesel and various fuel blends under study. Under all loading condition, JOK and blends were found to have lower EGT compared to diesel. JOK30, JOK40 and JOK50 fuel samples demonstrated a comparatively lower EGTs when compared with JOK 20 and JOK0 fuel samples. The high EGT in this case is traceable to the presence of higher concentration of jatropha oil (JOK0 and JOK20) in the fuel sample, with its relatively lower heating value than kerosene and diesel fuel (refer to Table 3), and this would require higher amount of fuel in the engine to generate that extra power needed to take on the additional loading. From the foregoing engine performance results (refer to Fig. 6), a relationship could also be established between EGT and BP, on account of the fact that, a rise in combustion temperature brings about an increase in the pressure acting on the piston, to improve mechanical power output [36].

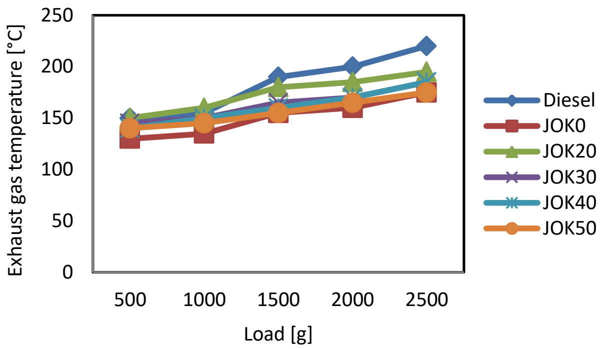


Fig. 7. Variation of EGT for JOK blends with increase in load

3.2. Effect of load and fuel samples on engine tailpipe emission

The variation of CO emission with load is shown in Fig. 8. CO is an intermediate combustion product that is formed mainly due to incomplete combustion of fuel. If combustion is complete, CO is converted to CO_2. If the combustion is incomplete due to shortage of air or low gas temperature, CO will be formed. As the load increases there is a significant decrease in CO emission in fuel blends with lower concentration of jatropha oil [20].

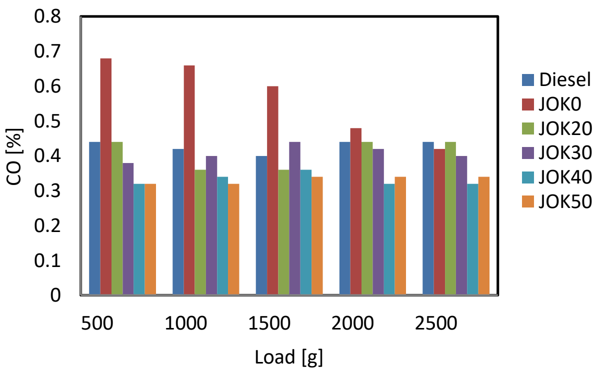


Fig. 8. Variation of CO for JOK blends with increase in load

Figure 9 showed the emission levels of CO_2 for various blends and diesel. JOK0 fuel sample shows lower CO_2 emission at minimum and maximum loads. The following fuel samples; JOK20, JOK30, JOK40 and JOK50 fuel samples exhibited higher CO_2 emission than diesel with load increment.

HC in exhaust occur as a result of incomplete burning of the carbon compounds in the fuel. The trend of UHC emission variation for different blends is illustrated in Fig. 10. Apart from the pure JOK and blended samples exhibited lower UHC values than conventional diesel fuel. The blend with the lowest UHC emission is JOK50 with 84 ppm and 86 ppm at minimum and maximum loads. The lower HC emissions of JOK and blends can be attributed to the presence of oxygen in JOK and blends and its contribution to the give a near complete combustion process.

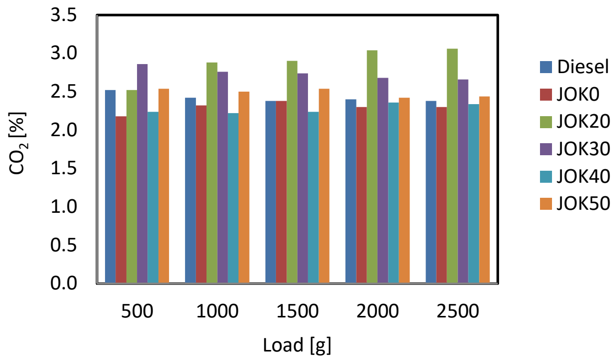


Fig. 9. Variation of CO_2 for JOK blends with increase in load

It could be seen from Fig. 10 that, at lower engine loads oxidation reactions were very slow due to lower temperature and lean mixture. UHC are formed in the core of the spray and the regions just outside the flame zone [37]. They are also formed at the point where the fuel spray touches the wall and thereby gets quenched. UHC emissions increased with load for all the fuels. At higher loads, the mixture was too rich causing incomplete combustion and higher UHC emission [38]. As the load increased, heat released by the fuel also increased which improved combustion and consequently UHC level start decreasing. Above the rated load value UHC emission started increasing due to poor combustion [39]. HC emissions drop at all brake power by doping with kerosene. Increasing the kerosene content reduces the HC emissions significantly. This was caused by the lower viscosity of blends by kerosene blending.

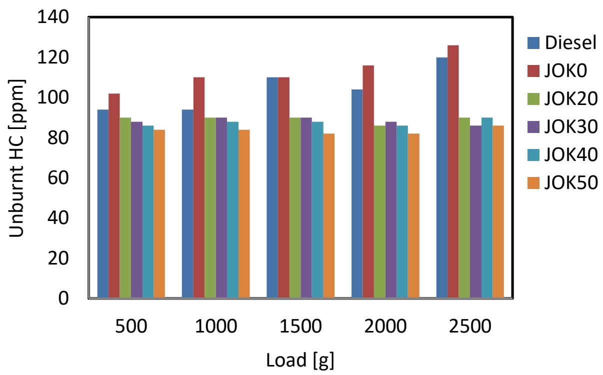


Fig. 10. Variation of UHC for JOK blends with increase in load

Figure 11 shows the variation of NO_x with respect to load and fuel sample variations. It could be seen that conventional diesel fuel produces 31 ppm of NO_x at 1500 g engine load, while JOK30 blended sample produces similar emission level with diesel at 2000 g load. JOK40 fuel sample also generated similar emission level with diesel under varying engine load condition. The highest emission of 74 ppm was observed for JOK50 samples under all load conditions. There was no noticeable production of NO_x emission for JOK0 and JOK20 blended samples could probably be caused by the reduction of the peak engine temperature due to less excess air, or a slight leak in the sampling system affecting the sensitivity of the analyzer.

It could also be observed that the NO_x emission level exhibited occurred as the oil temperature increased. Hence, it could be inferred that the increase in NO_x emission is very much dependent on the combustion chamber temperature. At the higher chamber temperature, the reaction N2 + O_2 = 2NO takes place, and this promotes the formation of NO_x. Temperature drops rapidly during expansion and exhaust strokes, but the reverse reaction or dissociation of NO is not rapid enough to establish equilibrium and therefore higher amount of NO_x appears in the exhaust at higher loads [39]. Further studies have suggested that addition of antioxidant such as, N,N′-diphenyl-1,4-phenylenediamine (DPPD) has been found to reduce NO_x emissions significantly with a slight penalty in terms of engine power and brake specific been found to reduce NO_x emissions significantly with little negative effect on engine power and brake specific fuel consumption (BSFC) as well as CO and HC emissions [40].

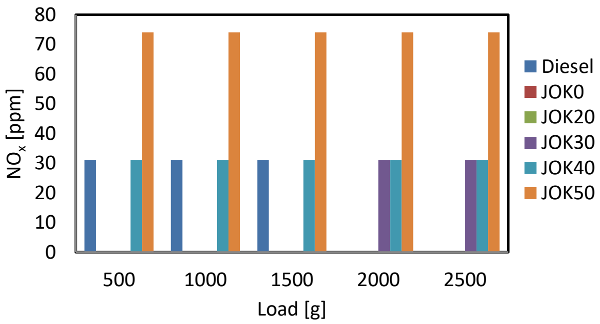


Fig. 11. Variation of NO_x for JOK blends with increase in load

4. Conclusion

This work was an attempt to explore the usability of jatropha oil-kerosene mixtures as combustion fuels for CI engines. From the finding the following conclusions can be drawn:

i. The JOK20 blended samples offered significant potential as sustainable fuel for modern diesel engines.
ii. JOK20 fuel blend exhibited the highest BP, BTE, and EGT followed by JOK30, JOK40 and JOK50 blends than diesel fuel.
iii. JOK20 blended fuel sample exhibited the lowest SFC, and is hence more economical in terms of fuel consumption.
iv. JOK20 sample has the lowest BSEC and AFR followed by JOK30, JOK40 and JOK50 blends than diesel fuel.
v. There was slight reduction in CO emission level for JOK20 compared to diesel fuel.
vi. significant reduction was noticed for JOK30, JOK40 and JOK50 blends as the load increases.
vii. In comparison to diesel fuel, JOK20, JOK30, JOK40 and JOK50 fuel samples exhibited higher CO_2 emission level than diesel as engine load increases.
viii. Other than JOK0 sample, all other fuel blends exhibited lower UHC emission than diesel fuel.
ix. JOK50 fuel sample released the highest NO_x emission. JOK30 and JOK40 had the same level of NO_x formation than diesel fuel, while there was no noticeable trace of NO_x formation in JOK0 and JOK20 fuel samples.

Acknowledgement

This work was assisted by Automotive Engineering Technology Workshop, Federal Polytechnic, Bauchi Nigeria for providing the test facilities throughout the course of this research.

Nomenclature

AFR	air fuel ratio
BMEP	brake mean effective pressure
BP	brake power
BSEC	brake specific energy consumption
BSFC	brake specific fuel consumption
BTE	brake thermal efficiency
CI	compression ignition
CO	carbon monoxide
CO_2	carbon dioxide
DI	direct injection
EGT	Exhaust gas temperature
NO_x	nitrogen oxides
SFC	specific fuel consumption
UHC	unburnt hydrocarbon

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Ass. Prof. Robinson I. Ejilah, PhD. – Faculty of Engineering and Engineering Technology, Dept. of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi-Nigeria.

e-mail: *irejilah@atbu.edu.ng*; *rejilah@gmail.com*

Abiodun A. Ogbaneme, Research Student – Faculty of Engineering and Engineering Technology, Dept. of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi-Nigeria.

e-mail: *attegba@yahoo.com*

Osazoduwa O. Agboneni – Nenis Automotive Engineering Consultant, Nenis Engineering Co. Ltd., Ikorodu, Lagos.

e-mail: *oduwa.agboneni@gmail.com*

Sikiru O. Adekunle – School of Engineering Technology, Department of Mechatronics Engineering Tech., Federal Polytechnic, Bauchi-Nigeria.

e-mail: *olusikiru2009@gmail.com*