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Investigation of the Endurance Characteristics of a Compression Ignition Engine runs on Jatropha Biodiesel

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Abstract

The need to ensure diversity in energy supply and its long-term sustainability necessitated the quest for renewable energy sources. Jatropha biodiesel is a renewable energy source that can be used to run a diesel engine without any modification to the engine. This work investigated the endurance characteristics of a compression ignition engine run on Jatropha biodiesel in comparison to fossil diesel. Results of the investigation indicate that an engine run on Jatropha biodiesel blends could endure longer hours of operation due to lower engine operating temperatures, than when it is run on diesel fuel. The maximum engine temperature recorded when the engine was run on diesel fuel was 161 oC. Whereas, the maximum engine temperature recorded when it was run on the Jatropha biodiesel blends was 147 oC. However, an engine run on Jatropha biodiesel blends would result to more frequent choking of oil filters and earlier lubrication oil change.

Keywords: Renewable Energy Source; Sustainability; Biodiesel; CI-engine; Endurance; Poverty Alleviation

1. Introduction

The quest for renewable energy sources emanated from the need to diversify the supply of energy and reduce the dependence on fossil fuels as major source of energy. This need was to ensure sustainable and secure energy supply in order to satisfy the growing demand for energy. In addition, there was growing paranoia on the various forecasts made on fossil fuels depletion. Asif and Muneer [1] made noteworthy analysis on fossil fuels depletion. They averred that the world's ultimate conventional oil reserve was estimated at 2000 billion barrels. This was the amount of production (sic) that would have been produced when production eventually ceases. They went further to state that the expert consensus was that the world's midpoint of reserve depletion would be reached when 1000 billion barrels of oil have been produced. That is to say, half the ultimate reserve of 2000 billion barrels. It was estimated that around 1000 billion barrels have already been consumed and 1000 billion barrels of proven reserve are left in the world. This paranoia made biomass a major source of diversifying the supply of energy.

Biomass is material derived from recently living organism. This includes plants, animals and their by products for example, manure, garden waste and crop residues. It is a renewable energy source based on the carbon cycle, unlike other natural resources such as fossil fuels derived from biological material. Humans have used biomass fuels in the form of solid bio fuels for heating and cooking since the discovery of fire, liquid bio fuels have been used since the early days of the automobile industry. Nikolaus August Otto, the German inventor of the Internal Combustion Engine (ICE) conceived his invention to run on ethanol. Rudolf Diesel, the German inventor of the diesel engine, designed it to run on peanut oil, and Henry Ford originally designed the Ford Model T, a car produced from 1903 to 1926, to run completely on hemp derived bio fuel. [2]

Venkateswara et al [3] noted that Pryde [4] reviewed the reported successes and shortcomings for alternative fuel research. Long-term engine test results showed that durability problems were encountered with vegetable oils because of deposit formation, carbon build up and lubricating oil contamination. It was concluded that vegetable oils must either be chemically altered or blended with diesel fuel to prevent premature engine failure. They further noted that blending, cracking/pyrolysis, emulsification or transesterification of vegetable oils could overcome these problems. Heating of vegetable oils may reduce the viscosity and improve volatility of the oils but its molecular structure remains unchanged. Hence, polyunsaturated character remains. Blending of vegetable oils with diesel, however, reduces the viscosity drastically and the fuel handling system of the engine can handle vegetable oil-diesel blends without any problem. Based on experimental investigations, it was found that converting vegetable oils into simple esters is an effective way to overcome all the problems associated with the vegetable oils. Fangrui and Hanna [5], Pryde [4] and Srivastava and Prasad [6], all noted that most of the conventional production methods for biodiesel use basic or acidic catalyst. A reaction time of 45min to 1hr and reaction temperature of 55–65^{o}C are required for completion of reaction and formation of respective esters.

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Biodiesel consists of methyl esters of fatty acids produced by the transesterification of vegetable oils. The use of biodiesel in diesel engines requires no hardware modification. In addition, biodiesel is a superior fuel than diesel because of lower sulphur content, higher flash point and lower aromatic content. Biodiesel fuelled engine emits fewer pollutants. Biodiesel can be used in its pure form or as a blend of diesel. It can also be used as a diesel fuel additive to improve its properties. [3] Agarwal and Das [7] observed significant improvement in engine performance and emission characteristics for the biodiesel-fuelled engine compared to diesel-fuelled engine. Thermal efficiency of the engine improved, brake specific fuel consumption reduced and a considerable reduction in the exhaust smoke opacity was observed.

Venkateswara et al [3] blended Jatropha biodiesel with fossil diesel to several blends, with which they ran diesel engine tests and investigated the performance and emission characteristics of the engine. The blends were B5, B10, B20, B25, B30, B40, B60, B80 and B100. 'B' denotes a blend of biodiesel and fossil diesel, while the figure indicates the percentage of biodiesel in the blend. The results of their study indicated that the kinematic viscosities (at room temperature of 35^{o}C) of the different blends were higher than the viscosity of diesel. However, up to B20 the viscosities of the blends were very close to the viscosity of diesel. Their densities were also close to the density of diesel, so the blends of B5, B10, B15 and B20 can be used without any heating arrangement and are alternative fuels for diesel. While the flash points of different blends increased with increase in biodiesel percentage, the efficiency dropped, smoke density reduced and carbon monoxide reduced compared to diesel. However, for higher blends (B60–B100), smoke density and carbon monoxide increased due to insufficient combustion.

Generally, after design and fabrication are completed, an engine or component is tested for reliability and endurance. Long–term engine or component operations on a continuous basis are conducted to verify their durability and reliability. Specially equipped test cells provide a comprehensive range of test capabilities including engine health monitoring, low/high temperature simulation, diffusive/premixed combustion simulation, ignition delay/advance simulation, and low-load running simulation. In addition, blow-by monitoring, combustion-heat release analysis, continuous and real-time oil consumption measurement, exhaust emission evaluation, and failure analysis can be carried out. Moreover, fuel analysis, in-cylinder combustion pressure measurement, torsional (sic) vibration testing, and used oil analysis are conducted. Furthermore, the study of combustion processes in the cylinder using laser diagnosis can be carried out. [8]

Kaufman and Ziejewski [9] carried out an endurance test on a 4-cylinder Allis Chalmers diesel engine run on sunflower methyl ester. The test results indicated that some difficulties were experienced with engine starting when run on the methyl ester. At a test cell temperature of 170C, one minute of cranking time was necessary to start the engine. For an additional minute, the engine speed remained at 400 to 500rpm irrespective of throttle position. Thus, there could be problems associated with the use of transesterified vegetable oil at low ambient temperature. They reported that McCutchen [10] durability tested a turbocharged Caterpillar 3306, direct injection diesel engine using methyl ester of rapeseed oil for 150hrs and found no performance deterioration. In addition, Bacon and Co-workers [11] found much less nozzle coking with methyl stearate than with ethyl oleate or ethyl ester of sunflower oil, and that injector coking was less severe for all of these ester fuels than with unmodified vegetable oils. Furthermore, Fort and Co-workers [12] noted in endurance tests with transesterified cottonseed oil a ring-groove deposit effect, but in general, the appearance was about the same as when diesel fuel was used.

Hawkins [13] however, reported no problems in completing 1500hrs on a Massey Ferguson tractor with a Perkins 4.236 direct injection engine running on an ethyl ester of sunflower oil. German et al [14] also carried out field endurance test of diesel engine fuelled with sunflower oil/diesel fuel blends. Engine inspection after the tests showed no difference from what could be expected from such a test carried out with diesel fuel. Quick and Co-workers [15] observed a 10% reduction in power after just 7hrs of operation using filtered raw linseed oil in a Lombardini single cylinder, air-cooled, direct-injected engine. However, with a methyl ester of linseed oil, the engine operated for 1000hrs. All these tests confirm that transesterified vegetable oils are good fuel for direct injected engines. The greatly reduced viscosity, increased volatility, and improved cetane number of the ester compared to the neat vegetable oil leads to more efficient injection and combustion, even though the iodine numbers, as measures of unsaturation, remain essentially the same for the esters as for the neat vegetable oil. These earlier endurance tests utilising the vegetable oil and methyl esters of various seeds served as guides for this study on Jatropha biodiesel.

The most important parameters for determining engine endurance are engine operating temperature and lubrication oil. High engine temperature leads to overheating, burning of cylinder head gaskets and cylinder liner ferrules, reduction in lubrication oil viscosity and engine seizure. While low lubrication oil viscosity leads to friction, overheating and engine seizure, high lubrication oil viscosity leads to choking of filters, oil starvation and, engine seizure. On the other hand, low engine temperature leads to high fuel consumption and incomplete combustion. The endurance test for this study involved running a diesel engine with nine test fuels and analysing the engine's endurance characteristics. The test fuels used were; fossil diesel, B20, B30, B40, B50, B50, B60, B70, B80 and B100, and the endurance characteristics analysed were; engine operating temperatures and, lubrication oil and blow-by.

2. Test Fuels and Lubrication Oil Properties

The reference diesel fuel was obtained from MOBIL fuel filling station, which satisfied the ASTM D975 2-D diesel standard. On the other hand, National Research Institute for Chemical Technology (NARICT), Zaria (NIGERIA) extracted the Jatropha oil from the Jatropha seeds. The fatty acid profile of the oil are; 47.3% linoleic, 12.5% oleic, 11.3% palmitic, 17.0% stearic and 4.7% arachidic. NARICT also transesterified the oil into the methyl ester – Jatropha biodiesel – and analysed both the test fuels, using American Society of Testing and Materials standard procedures. Table 1 show several important properties of the fuels that influenced the engine performance and eventually, its endurance. Compared to the reference diesel fuel, the density, flash point, cetane number, water content and kinematic viscosity of the methyl ester were significantly higher, though it has lower calorific value.

Table 1: Test Fuels Properties.

Serial	Fuel property	Unit	ASTM D975 2-D Diesel	NARICT Produced Jatropha Biodiesel	ASTM Limits for Biodiesel
1.	Density at 15^oC	kg/m^3	850	879	860 - 900
2.	Flash Point	^oC	80	191	130 min.
3.	Viscosity at 40^oC	mm^2/s	2.37	4.84	1.9 – 6.0
4.	Calorific value	MJ/kg	42.7	38	-
5.	Cetane number	-	50.1	51	47 min.
6.	Water Content	Vol.%	0.02	0.16	0.05 max.

Source: National Research Institute for Chemical Technology. [16]

The properties of the biodiesel test fuel satisfied the ASTM limits for biodiesel except the water content, which was significantly high. The biodiesel has a water content of 0.16 as against the ASTM limit of 0.05. SAE 40 OLEUM heavy-duty motor oil was used as the engine lubrication oil throughout the engine tests. It has a viscosity of 137.5 cSt at 40^oC and 17.8 cSt at 100^oC. It has ash content of 0.85 and flash point of 230^oC.

3. Engine Set-up and Procedure

A single cylinder, 4-stroke Petter diesel engine was used for the endurance test. The engine specifications are given in Table 2.

Table 2: Test Engine Specifications.

Serial	Description	Specification
1.	Engine Manufacturer/Model	Petter AA1
2.	Type	Single Cylinder, Air Cooled, Naturally Aspirated 4-Stroke Diesel Engine
3.	Bore/Stroke	70mm/57mm
4.	Compression Ratio	17:1
5.	Maximum Torque	8.2 Nm at 2700 rpm
6.	Maximum Brake Power	2.6 kW at 3600 rpm
7.	Fuel Injection Timing	24 to 33^o BTDC
8.	Fuel Injection Pressure	180psi

Source: Cussons Educational Technology. [17]

The engine, which was mounted on a test bench and then connected to a hydraulic dynamometer and control panel, has accessories for monitoring speed, torque, temperature and fuel consumption. The engine temperature, exhaust temperature and fuel consumption were measured at various speeds and loads. Fig. 1 shows the engine set up and control panel.

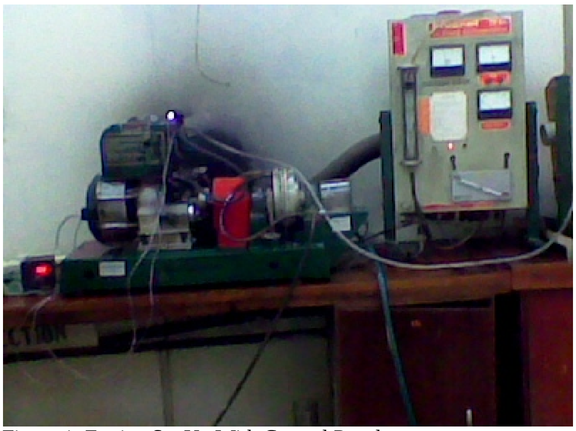

Figure 1: Engine Set Up With Control Panel.

The test Cycle adopted for this study consists of five test runs with the engine speed and torque manually simulated as required. In Test run 1, the engine was operated as an automobile engine for duration of 60 minutes, with the load determining the speed. The engine speed was initially set to 2800rpm with minimal load; this was followed with a step increase of the load on the engine. Test run 2 was a hybrid engine operation for 3 hours duration carried out to initiate durability problems. The engine was simulated to operate as a ship engine/generator in test runs 3 and 4 (3 hrs each), while test run 5 was low-load running operation to determine the engine's endurance on low-load, with the remedial action taken after the low-load operation (1hr 10mins). The differences in the simulated modes of operation of the engine depend on its governing action. It should be borne in mind that the purpose of operating the engine as an automobile engine, a ship engine or a generator was to fully exploit it and see its response to various load settings (and thus its performance), since that is the essence of a durability/endurance test.

The test engine was first run on the reference diesel fuel and then on the different blends of Jatropha methyl ester. It underwent a Test Cycle consisting of five tests runs on each test fuel. The total duration of each test cycle thus was 11 hrs 10 minutes. After each test cycle, the engine oil was drained and replaced with fresh oil, while the fuel system was flushed with the next test fuel. Fuel consumption in all the test runs was measured on volume basis. The test cycle duration was sufficient to cause a change in the condition of the oil and thus, gave a predictive idea of the condition of the oil after 100 hours of operation. This is especially with the hybrid engine operation and the simulation of low-load running operation condition. By the end of the engine tests runs, 10 lubrication oil samples where obtained (the reference lubrication oil sample, diesel run oil sample, and a sample each from the B20, B30, B40, B50, B60, B70, B80 and B100 engine test cycles). These samples where analysed by AMMASCO International Limited, Club Road, Kano-Nigeria.

4. Result and Discussions

4.1. Performance analysis:

Figs. 2 and 3 shows the performances of a diesel engine run on diesel fuel and Jatropha biodiesel blends when operated as an automobile engine.

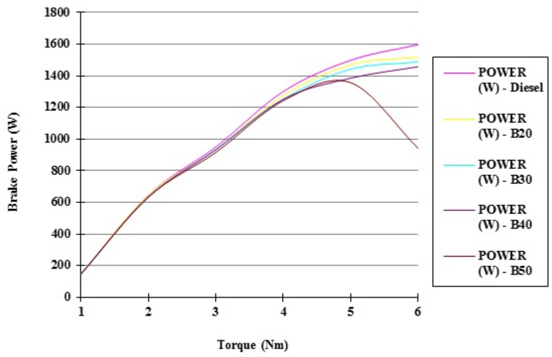

Figure 2: Performances of a Diesel Engine Run on Diesel Fuel, Jatropha Biodiesel Blends B20, B30, B40 and B50, when Operated as an Automobile Engine.

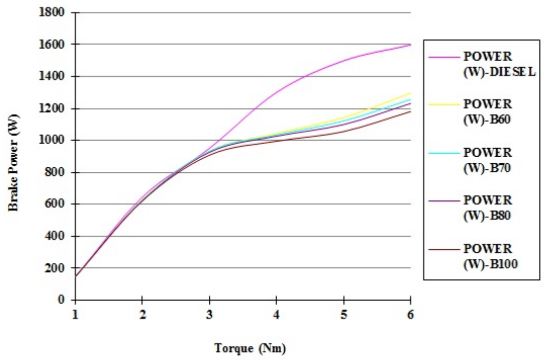

Figure 3: Performances of a Diesel Engine run on Diesel Fuel, Jatropha Biodiesel Blends B60, B70, B80 and B100, when operated as an Automobile Engine.

From the figures, the brake power from the diesel run engine was higher than that recorded from the blends. The power of the engine reduced with increase in the blend percentage. It was observed that the power output from the B20, B30 and B40 runs were closer to that of the diesel run. In addition, B50 exhibited the performance of a real engine at much lower loading than B20, B30 and B40. However, from B60 to B100, there was sharp drop in the power output of the engine at higher engine loading as compared to diesel fuel.

The performances of a diesel engine run on diesel fuel and Jatropha biodiesel blends when operated as ship engine or generator, are shown in Figs. 4 and 5.

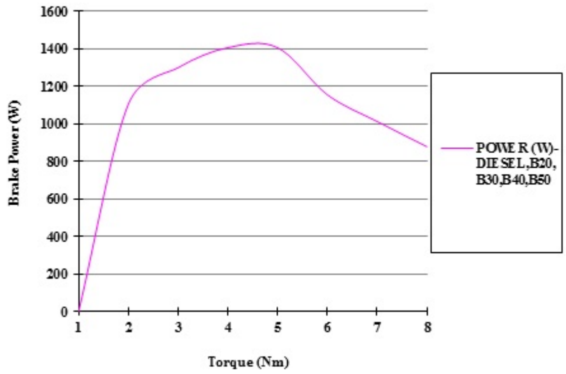

Figure 4: Performances of a Diesel Engine Run with Diesel Fuel, Jatropha Biodiesel Blends B20, B30, B40 and B50, when Operated as Ship Engine or Generator.

As a ship or generator, the engine produced the same power when run on diesel fuel, B20, B30, B40 and B50. However, the power output reduced considerably with increase in the Jatropha biodiesel blend percentage. It should be noted that in Fig. 5, with B100 the engine produced the same power output as when it was run with B80 (the B100 brake power curve is superimposed on the B80 curve).

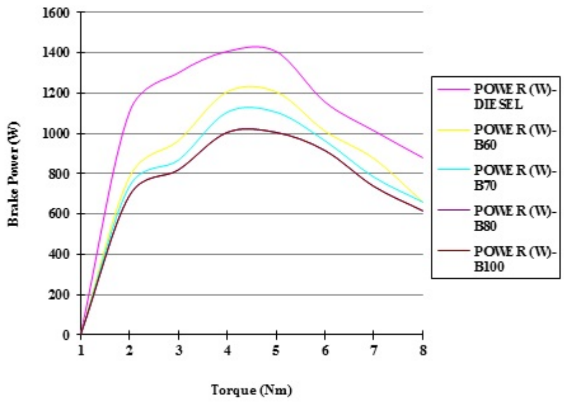

Figure 5: Performances of a Diesel Engine Run with Diesel Fuel, Jatropha Biodiesel Blends B60, B70, B80 and B100, when Operated as Ship Engine or Generator.

Generally, knocking sound of the engine was not noticed throughout the engine test runs, and low-load running of the engine did not result to overheating of the engine. Thus, the possibility of the formation of hot spots in the engine, and crankcase explosion when running an engine with Jatropha biodiesel blends are very unlikely. However, hard starting of the engine was experienced when it was run on B80 and B100. This corresponds to the findings of Kaufman and Ziejewski [9], when they carried out a diesel engine endurance test using sunflower methyl ester.

4.2. Endurance characteristics:

4.2.1. Engine operating temperature:

Figs. 6 and 7 shows comparisons of the variation of engine temperature with load, of an engine run with diesel fuel and that run with Jatropha biodiesel blends, when operated as an automobile engine.

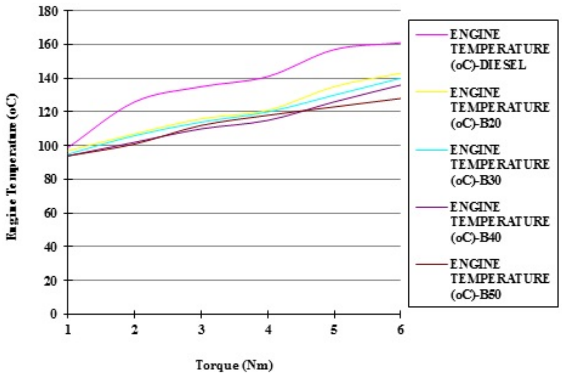

Figure 6: Comparison of the Variation of Engine Temperature with Load, of an Engine Run with Diesel Fuel and that Run with Jatropha Biodiesel Blends B20, B30, B40 and B50, when Operated as an Automobile Engine.

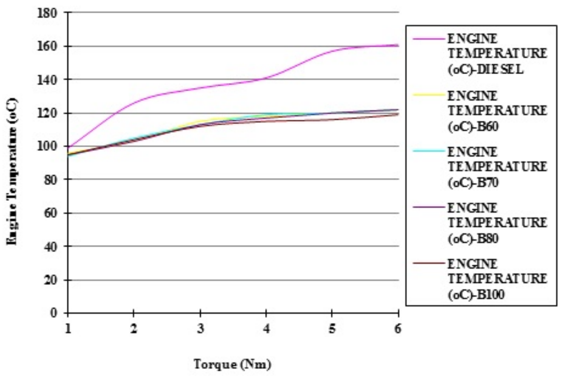

Figure 7: Comparison of the Variation of Engine Temperature with Load, of an Engine Run with Diesel Fuel and that Run with Jatropha Biodiesel Blends B60, B70, B80 and B100, when Operated as an Automobile Engine.

The figures indicate that the maximum engine temperature recorded on test runs with diesel fuel was 161^{o}C. However, the maximum engine temperature recorded with the biodiesel blends was 143^{o}C; this was with the B20 blend. The engine temperature reduced further with increase in the biodiesel blend percentage. The lowest engine temperature recorded at high loading was 119^{o}C, which was with the B100 blend. The high water content in the Jatropha biodiesel could be the factor responsible for the low temperature recorded. Thus, a diesel engine operated as an automobile engine could endure longer hours of operation when run on Jatropha biodiesel blends, than when it is run on diesel fuel. The blend B20 could be an alternative to diesel fuel for use in an automobile engine.

Comparisons of the variation of engine temperature with load, of an engine run with diesel fuel and that run with Jatropha biodiesel blends, when operated as a ship engine or generator are shown in Figs. 8 and 9.

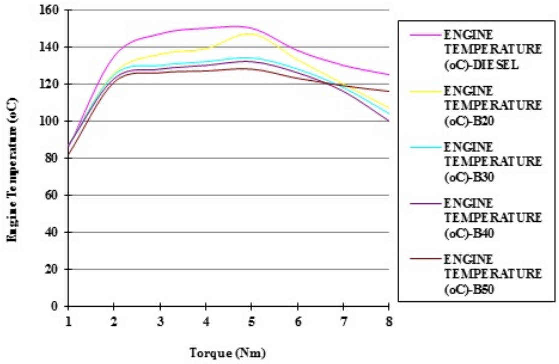

Figure 8: Comparison of the Variation of Engine Temperature with Load, of an Engine Run with Diesel Fuel and that Run with Jatropha Biodiesel Blends B20, B30, B40 and B50, when Operated as Ship Engine or Generator.

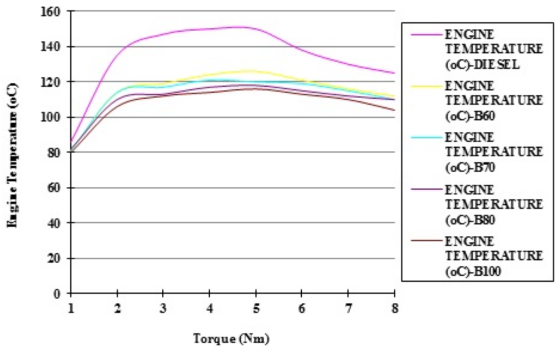

Figure 9: Comparison of the Variation of Engine Temperature with Load, of an Engine Run with Diesel Fuel and that Run with Jatropha Biodiesel Blends B60, B70, B80 and B100, when Operated as Ship Engine or Generator.

From the figures, the maximum temperature recorded with diesel fuel was 152^{o}C, and that recorded with the biodiesel blends was 147^{o}C; this was with the B20 blend. This temperature was too close to that of diesel fuel. The next maximum temperature recorded with the biodiesel blends was 135^{o}C; this was with the B30 blend. It should be noted from Fig. 5 that the power output from an engine run on B50 is the same as that run on diesel fuel, when operated as ship engine or generator. The highest temperature recorded at higher loading from this engine was 128^{o}C. The engine temperature reduced further with increase in the biodiesel blend percentage. The lowest engine temperature recorded at high loading was 114^{o}C, which was with the B100 blend. The high water content in the Jatropha biodiesel could be the factor responsible for the low temperature recorded. Thus, a diesel engine operated as ship engine or a generator could endure longer hours of operation when run on Jatropha biodiesel blends, than when it is run on diesel fuel. The B50 blend could be an alternative to diesel fuel for use in ship engine or generator.

4.2.2. Lubrication oil and blow-by:

The comparison of kinematic viscosities at 40^{o}C of the reference oil, and used oil samples of diesel fuel run and Jatropha biodiesel blends' runs is shown in Fig. 10.

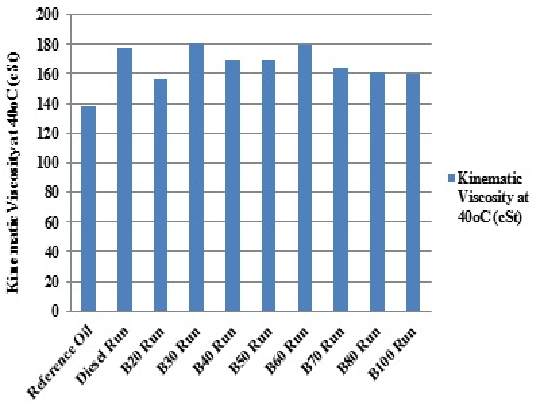

Figure 10: Comparison of the Kinematic Viscosities at 40^{o}C of the Reference Oil and Used Engine Lubrication Oil Samples.

From the figure, the kinematic viscosities at 40^{o}C of the used oils from the engine runs on diesel fuel, B30 and B60 were above the tolerated limits (± 25% of the viscosity of reference/new oil), and are almost of the same value. This implies that the endurance of engines run on B30 and B60 are closer to the endurance of engines run on diesel fuel. The figure also indicates that the kinematic viscosities of the used oil from the engines run on B20, B80 and B100 were closer to that of the reference oil.

Now, consider the kinematic viscosities at 1000C of the used oils for B20, B80 and B100 engine runs in Fig. 11.

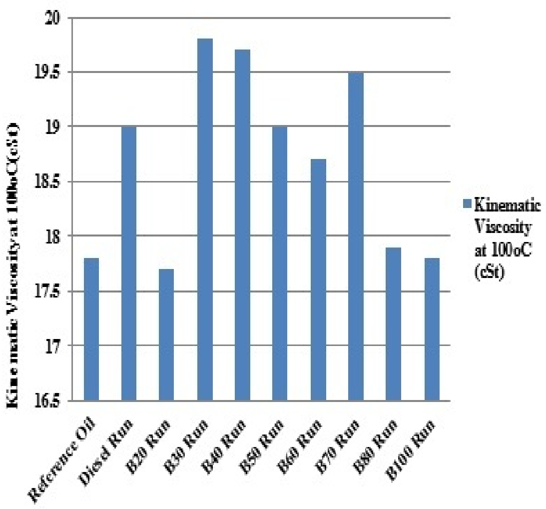

Figure 11: Comparison of the Kinematic Viscosities at 100^{o}C of the Reference Oil and Used Engine Lubrication Oil Samples.

The figure indicates that they were within tolerated limits, and were closer to that of the reference oil in comparison to that of the diesel run. Thus, engines run on Jatropha biodiesel blends B20, B80 and B100 have superior endurance characteristics based on the viscosities of the lubrication oil, than the engines run with diesel fuel.

Fig. 12 shows a comparison of the flash points of the reference oil, and used engine oil samples of diesel fuel run and Jatropha biodiesel blends' runs.

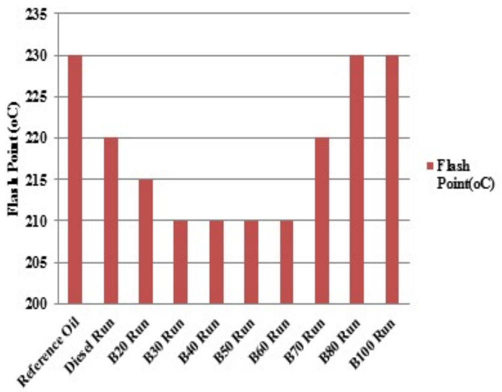

Figure 12: Comparison of the Flash Points of the Reference Oil and Used Engine Lubrication Oil Samples.

The lower flash points of the used oils for B20 to B60 runs as shown in the figure may suggest symptom of fuel dilution during the test runs. This was not the case as the viscosities of the used oils at 40^{o}C indicated there was no fuel dilution during these test runs (the viscosities were not below the tolerated limits). In addition, the flash points of the used oils for all the test cycles were within/closer to the standard limit (≥ 220^{o}C).

Fig. 13 shows the comparison of ash content of the reference oil, and the used engine oil samples.

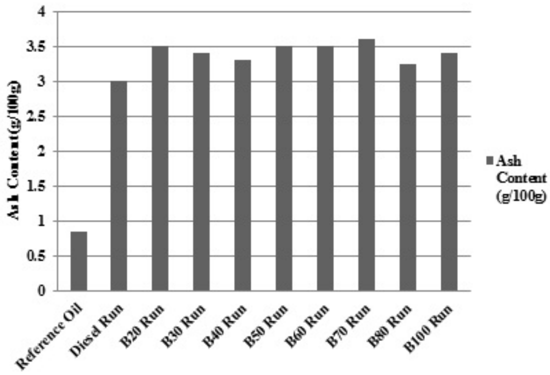

Figure 13: Comparison of the Ash Content of the Reference Oil and Used Engine Lubrication Oil Samples.

From the figure, the ash content in the used oils from test runs with the Jatropha biodiesel blends were higher than that of the diesel fuel test run. Their values were also higher than the standard specification (max. 3%). The lower calorific value of the blends and thus, incomplete combustion could be the reason for this. Therefore, engines run on Jatropha biodiesel blends would result to more frequent choking of filters and earlier lubrication oil changes, than the engines run with diesel fuel.

It should be noted, that the increase in the lubrication oil viscosities at 40^{o}C recorded in test runs with diesel fuel and the Jatropha biodiesel blends, was evidence of the build up of total insoluble/ash content caused by blow-by. However, this did not result to the formation of hot spots in the engine during the test runs and as such, there was no danger of crankcase explosion throughout. In addition, just as with the diesel fuel run, low-load operation of the engine when it was run on the biodiesel blends did not result to dilution of the lubrication oil with fuel. Thus, engines run on Jatropha biodiesel blends would endure low-load running operation.

5. Conclusion

The experimental results were obtained after operating single cylinder 4-stroke cycle diesel engine that was fuelled with Jatropha biodiesel blends B20, B30, B40, B50, B60, B70, B80 and B100. The endurance characteristics of the engine were thus analysed and compared to that when the engine was run with diesel fuel. Following are the conclusions based on this investigation:

- A diesel engine operated either as an automobile engine, ship engine or generator could endure longer hours of operation based on the operating temperatures, when it is run on Jatropha biodiesel blends (B20, B30, B40, B50, B60, B70 , B80 or B100), than when it is run on diesel fuel.
- A diesel engine run on Jatropha biodiesel blends B20, B80 and B100 have superior endurance characteristics based on the viscosities of the engine lubrication oil, than the engine run on diesel fuel.
- An engine run on Jatropha biodiesel blends (B20, B30, B40, B50, B60, B70, B80 or B100) will result to more frequent choking of oil filters and earlier lubrication oil change, than the engine run on diesel fuel.
- An engine run on Jatropha biodiesel blends (B20, B30, B40, B50, B60, B70, B80 or B100) will endure low-load operation in the same way as that run on diesel fuel.
- Hard starting of the test diesel engine was encountered when it was run on Jatropha biodiesel blends B80 and B100. This corresponds to the findings of Kaufman and Ziejewski [9] when they carried out a diesel engine endurance test using sunflower methyl ester.
- The Jatropha biodiesel blend B20 could be an alternative to diesel fuel for use in an automobile engine.
- The Jatropha biodiesel blend B50 could be an alternative to diesel fuel for use in ship engine or generator.

References

[1] M. Asif, T. Muneer, "Energy Supply, its Demand and Security Issues for Developed and Emerging Economies". Renewal and Sustainable Energy Reviews. Elsevier; 19 December 2005, p.3.

[2] A.T. Marshal, "Bio energy from Waste: A Growing Source of Power". Waste Management World Magazine. New York; April 2007, p. 34-37.

[3] T. Venkateswara Rao, G. Prabhakar Rao, K. Hema Chandra Reddy, "Experimental Investigation of Pongamia, Jatropha and Neem Methyl Esters as Biodiesel on Compression Ignition Engine". Jordan Journal of Mechanical and Industrial Engineering, Vol. 2, No. 2, 2008, 117-122.

[4] E. H. Pryde, "Vegetable Oil Fuels Standards". American Society of Agricultural Engineers' International Conference on Plant and Vegetable oil Fuels. 1982.

[5] M.A. Fangrui, M.A. Hanna, "Biodiesel Production: A Review", Bio Source Technology, Vol.70, 1999, 1-15.

[6] A. Srivastava, R. Prasad, "Triglycerides-Based Diesel Fuels". Renewable Energy Reviews, Vol. 24, 2004, 111-133.

[7] A.K. Agarwal, L.M. Das, "Biodiesel Development and Characterization for use as a Fuel in Compression Ignition Engine". Journal of Engineering, Gas Turbine and Power (ASME), Vol. 123, 2000, 440-447.

[8] M. Megel, "Engine Durability and Reliability Testing". San Antonio. Southwest Research Institute, 2000, p. 3.

[9] K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[10] McCutchen, (1981). In: K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[11] Bacon, Co-workers, (1981). In: K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[12] Fort, Co-workers, (1982). In: K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[13] Hawkins, (1983). In: K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[14] T.J. German, K.R. Kaufman, G.L. Pratt, J. Derry, "Field Endurance Test of Diesel Engines Fuelled with Sunflower Oil/Diesel Fuel Blends". Society of Automotive Engineers, Paper 850239, 1985.

[15] Quick, Co-workers, (1983). In: K.R. Kaufman, M. Ziejewski, "Sunflower Methyl Esters for Direct Injected Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 27, No. 6, 1984, 1626-1633.

[16] National Research Institute for Chemical Technology. Fuels Standards and Specifications. Zaria. Federal Ministry of Science and Technology. 2009.

[17] Cussons, G. Cussons Educational Technology. Manchester. G Cussons Limited. 1985.

[18] B. K. Barnwal, M.P. Sharma, "Prospects of Biodiesel Production from Vegetable Oils in India". Renewable and Sustainable Energy Reviews, Vol. 9, 2005, 363-378.

[19] P. De-Filippis, C. Giavarini, M. Scarsella, M. Sorrentino, "Transesterification Processes for Vegetable Oils: A Simple Control Method of Methyl Ester Content". Journal of the American Oil Chemists' Society, Vol. 72, No. 11, 1995, 1399-1404.

[20] M.R. Goyal, "Performance, Emissions, and Durability Testing of Diesel Engine with Bio fuels". Bio Oils Symposium. Saskatoon, Saskatchewan, Canada, 1994.

[21] C. Guangyi, Q. Daren, "A Brief Discussion on the Alternative Fuel for Internal Combustion with Plants Oils". Trans Chin Soc Agric Eng, 1987, 90-97.

[22] Y. Ishii, R. Takeuchi, "Transesterified Curcas Oil Blends for Farm Diesel Engines". Transactions of the American Society of Agricultural Engineers, Vol. 30, No. 3, 1987, 605-609.

[23] F. Karaosmanoplu, "Vegetable Oil Fuels: A Review". Energy Sources, Vol. 70, 1999, 221-231.

[24] M. S. Kumar, A. Ramesh, "An Experimental Comparison of Methods to Use Methanol and Pongamia Oil in a

Compression Ignition Engine". Biomass and Bio Energy, Vol. 25, 2003, 309-318.

[25] M. S. Kumar, A. Ramesh, B. Nagalingam, "Experimental Investigation of Jatropha Oil Methanol, Dual Fuel Engine". SAE Journal, 2001.

[26] A.S. Ramadhas, S. Jayaraj, C. Muraleedheeren, "Use of Vegetable Oils as I.C engine Fuels: A Review". Renewable Energy, Vol. 29, 2003, 727-742.

[27] A.S. Ramadhas, S. Jayaraj, C. Muralidheeren, "Characterization and Effect of using Rubber Seed Oil as Fuel in C.I Engine". Renewable Energy, Vol. 30, 2004, 795-803.

[28] R. Sarin, M. Sharma, "Jatropha Palm Biodiesel Blends: An Optimum Mix for Asia". FUEL, Vol. 86, 2007, 1365-1371.