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Cetane Improvers and Ethanol Performance and Emission Characteristics Using Pyrorated Biodiesel

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Abstract

There is growing demand for power generation and energy from alternative fuels at low cost and friendly to natural environment. Waste plastic pyrolysis oil (WPPO) and Ethanol are attractive renewable energy sources, as ethanol has a high content of oxygen. However, for this work direct blending of conventional diesel, WPPO and ethanol with 2-ethyl hexyl nitrate (EHN) was attempted. The purpose was to improve the combustion and performance characteristics of the WPPO blends. Secondly EHN has potential power to reduce emissions of CO, CO_2, UHC, NO_X and PM. Thirdly ethanol improves viscosity and miscibility, besides increasing the oxygen content of WPPO. Five mixing ratios were chosen in the following order, 50/WPPO25/E25, 60/WPPO20/E20, 70/WPPO15/E15, 80/WPPO10/E10 and 90/WPPO5/E5 for conventional diesel (CD), Waste Plastic Pyrolysis Oil and ethanol and respectively. However, for EHN the mixing ratio was based on the total quantity of blended fuel and the ratio was put at 0.01%. Complete miscibility was observed throughout the experiment, with no phase separation from the blended mixture allowed. Performance and emission characteristics of a stationary single cylinder water cooled diesel power generator was evaluated. The results obtained were compared carefully to ASTM standards and discussed using tables and graph figure curves. The conclusion was that ethanol and WPPO blends can be used in diesel engine power generators as alternative fuel without or with modification, as their densities 792 kg/m^3, 825 kg/m^3 are close to CD fuel at 845 kg/m^3. Additionally, these combinations with EHN, reduced emissions than earlier thought and improved engine performance, equalling that of conventional diesel fuel.

Keywords: 2-ethyl hexyl nitrate, Ethanol, High Content of Oxygen, Ignition Quality, Waste Plastic Pyrolysis Oil.

1.0 INTRODUCTION

The increase of automobile personal transportation has significantly increased the demand for energy especially in the primary sources of energy. Therefore, alternative solutions to meet this increasing energy demand associated with modern day development need to be increased. Diesel engines since their discovery by Rudolph Diesel in 1893, have proved superior, power efficient and good in fuel economy compared to gasoline engines. However, diesel engines emit high emission levels of NO_X, CO_2, UHC, PM and smoke emissions. These emissions have been shown to affect human health and the environmental health [1]. Diesel exhaust is now classified as carcinogenic [2] to humans with exposure linked to increased risk to lung cancer and cardiovascular diseases [3]. Diesel exhaust emissions is considered the primary source of providing ground level ozone [4], sick building syndrome [5], acid rain [6] and smog [7]. Therefore, the road to find an alternative source of fuel energy with desirable characteristics as those of petroleum based fossil fuels cannot be emphasized [8].

As a result of growing concern over fossil fuel depletion, oil prices fluctuations, escalating energy demands and stringent emission regulation and control. The research family has been pushed to search for better alternative renewable resources of energy, as a replacement for fossil based petroleum diesel fuel as a source of primary energy [9]. Early alternatives developments in fuel energy studies utilized food based sources as alternatives to petroleum fuels. However due to the poor food security in low middle income countries (LMIC). This development has faced opposition and arguments from all sectors and the world leading organizations such as FAO and united nations security council on human rights. The first generation food based biodiesels lead to cultivation of large swathes of land for commercial purposes eventually supressing the edible food crop acreage. Consequently this increased food insecurity leading to increased food prices and economic inflation [9].

There has been a recent increase in the awakening of interest in higher level alcohols due to their high energy levels, higher cetane numbers, better blend stability, less hygroscopic tendencies, increased carbon chain length and improved ignition quality of the alcohol fuel molecules [10], compared to the lower alcohols ethanol and methanol. Alcohols are classified under oxygenated fuels with a hydroxyl (OH) group. The availability of oxygen inherent in their molecular structure during combustion reduces smoke emissions in diesel engines particularly during high engine loads as reported by [11]. The reduction in smoke emissions and opacity is directly linked to the oxygen content of the blends of diesel and alcohol produced as observed by [12]. Through research and collaboration with various biotechnology research groups there has been improvement in the yield of higher level of alcohols through processing cellulose by modern fermentation processes such as using clostridium species [13], biosynthesis from glucose using genetically engineered micro-organisms like Escherichia coli [14], cyanobacteria [15] and saccharomyces cerevisiae [16].

Research on WPPO has shown that using the pyrolysis technique to extract liquid fuel from plastic waste material is a viable alternative to diesel fuel production and is sustainable. This is true especially when waste plastic oil is used with fuel additives [17]. Statistics show that as of 2016, only a paltry 9

% world wide of waste plastic has been recycled with almost 80 % going to landfills to continue degrading the natural environment as plastics are non-biodegradable. This is poor response and alarming as the gap between generation and recycling continues to increase, thus requiring bridging [18]. Plastic pyrolysis can also be done using catalytic pyrolysis and other thermal processes. The catalytic method uses low levels of temperature to cause plastic degradation and decomposition compared to the thermal technique which requires very high temperature to produce high and greater liquid fuel. This has helped in recycling waste into energy, a development that has been captivated and motivated a current crop of researchers such as [19-21].

There are a number of researchers who have used fuel additive in their work on WPPO biodiesel and other biodiesels:[11, 22-40]. [41] studied how to reduce NO_X and PM emissions in a diesel engine. To achieve this aim they employed both ethanol and selective catalytic reduction over catalyst Ag/Al_2O_3, using blends of biodiesel-ethanol fuel (BE). These researchers reported increased UHC, CO and PM emissions of 14 % due to the increase in the SOFs in the PM emissions. However, they additionally reported the Bosch smoke number reduced by between 60 % to 80 % based on the ESC standard. Consequently, the NO_X emissions were reduced by a significant margin of 73 %, thus leading them to conclude that a combination of BE and SCR catalyst arrangement could provide a good platform for NO_X and PM reduction and control.

[42] studied to determine cold flow features and characterization of ethanol based biodiesel compared to diesel fuel. Their study presented the relationship of these fuels to torque, brake thermal efficiency, BSFC and emission characteristics in diesel engines. As a result of their research work in the last decade, developed and emerging countries have now made it mandatory for instance in Europe and America for fuel manufacturers and distributors to add between 1 % to 5 % biofuel to most commercially available diesel fuel. In the united states of America, the renewable fuel standard (RFS) program now requires blending of advanced biofuels in an increasing amount, with fossil fuel used in transportation. The government has been targeting to achieve an annual projection growth escalation of 36 billion gallons by the year 2022 [43].

There are two reasons ethanol is considered as an additive to WPPO blends, ethanol is produced from raw material of plant or plant waste origin, qualifying as alternative renewable source of energy and secondly because of its high oxygen content and solubility in WPPO blends [44-48]. However, a number of studies have shown that increase in the ethanol fraction decreases the auto-ignition properties of diesel due to ethanol's low propensity to auto-ignite as reported by [46, 49-57]. This finding show decrease in the cetane number value of the blends with diesel as the fraction of ethanol increases [49, 51, 54, 57].

Reduced CN fuel values are undesirable because of their nature to prolong ignition delay. This causes increased engine peak cylinder combustion pressures [58, 59], increased engine combustion noise and wear in addition to increased NO_X emissions. This impacts resulting from alteration of CN has been extensively studied and concluded by researchers such as [60-70]

Plastics have a lot of stored potential energy of hydrocarbons inherent in their molecular structure. They are readily available as waste in municipal solid waste management sites where they are posing an environmental danger. Altering them through modern methods of decomposition, they can be converted to liquid fuels and used as biodiesels. Therefore, this work seeks utilization of development in fuels that are derived from renewable feedstock sources such as municipal solid waste (MSW) disposed plastics. Through blending this work intends to utilize waste by turning it energy in line with the motto of energy sustainability studies. Additionally, this work provides and makes a strong case for alternatives fuels to replace petroleum based fossil fuels like diesel commonly used as the primary propulsion fuel in the transport industry and power generation.

2.0 METHODOLOGY AND EXPERIMENTAL SET-UP

This experiment is making a case for blending of WPPO whose n-alkenes are very low by 25 % in auto-ignition, compared to diesel fuel whose n-alkenes are good for auto ignition. The aromatics which affect PM emissions are very low in WPPO blends. According to [71] and [72] WPPO consists of iso-alkanes, n-alkanes and olefins in the areas of 27 %, 25 %, and 9 % respectively with over 30 % content being undefined due to complicated chemical bond structures. However, aromatics cyclo-alkanes (naphthalene) and others poor in auto-ignition were also found to be 40 % by [73]. Blending was preferred to improve the low pour point of WPPO so as to improve it's cold starting characteristics. Secondly blending was used to improve the fuel spray characteristics, by using ethanol which is soluble and miscible in WPPO blends. Thirdly blending helped this experiment to reduce the viscosity of WPPO biodiesel, thus aiding and improving spray characteristics.

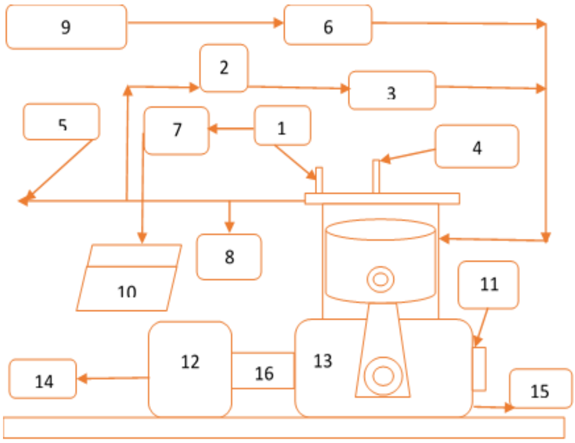

Fig. 1. Schematic diagram of the test engine set up rig

Figure 1 Schematic Diagram of the experimental engine test rig set up and its nomenclature. 1. Cylinder pressure sensor, 2. EGR control valve, 3. EGR cooler, 4. Injection Control Unit, 5. Exhaust gas exit, 6. Air box, 7. Signal amplifier, 8. Gas analyser, 9. air flow meter,10. Data acquisition system, 11.

Crank position sensor, 12. Dynamometer, 13. Engine, 14. Air flow rate meter, 15. Cooling water exit to the cooling tower, 16. Dynamometer drive coupling

2.1 Engine Tests

The experiment was conducted using a naturally aspirated single-cylinder diesel engine power generator, water cooled, direct injection, Kirloskar TV1, in the Mechanical Engineering Department Laboratory, University of KwaZulu Natal in Durban, South Africa. The details of the engine and specifications are described in Table 1. Fig. 1 shows a schematic of the engine test setup.

Table I. Experimental engine specifications

Parameters	Position value
Ignition Type	4 (Stroke)DICI
Number Of Cylinders	1
Model	TV 1
Cooling Medium	Water
Manufacturer	Kirloskar
Revolutions Per Minute	1500
Brake Power	3.5 kW
Cylinder Bore	87.5 mm
Piston Stroke	110 mm
Compression Ratio	18.5:1
Connecting-Rod Length	234
Engine Capacity	661cc
Dynamometer Make	234
Injection Timing	23.4◌̊ bTDC
Maximum Torque	28 Nm @1500
Injection Pressure	250 Bar

2.2 Physicochemical Property Analysis.

WPPO by pyrolysis was obtained from a commercial plant, ethanol, conventional diesel and EHN were purchased from local outlets and blended using a homogenizer for 5 min at 3000 rpm. The properties of all samples were measured in the Department of Chemical Engineering Laboratory, University of KwaZulu Natal in Durban, South Africa. Table 2 shows some important physicochemical properties of the fuels before blending. Table 3 shows physicochemical properties of blended mixtures fuels and their determined fuel properties after blending.

Table II. Properties of Diesel, WPPO and ethanol before blending and addition of EHN

PROPERTIES	UNIT	CD	WPPO	ETHANOL
Density @ 20^0C	kg/M^3	845	825	792
Visc.@ 40^0C	cSt	3.04	2.538	1.05
Cetane Number	_	55	_	8.5
Flash Point	^{0} C	50	43	16
Fire Point	^{0} C	56	45	53
Carbon residue	%	22	0.015	_
Sulphur content	%	<0.028	0.248	_
Gross Calories	kJ/kg	46500	43340	29700
Cetane index	_	46	65	_

Table III. Properties of blended ratio mixtures of diesel, ethanol, WPPO with EHN.

Property	Unit	CD	90/5/5	80/10/10	70/15/15	60/20/20	50/25/25	STANDARD
Density	Kg/M^3	845	838.5	834	830	825	823	ASTM D1298
KViscosity@40	cST	3.452	2.38	2.37	2.365	2.340	2.325	ASTM D445
Cetane Number	-	45	59	62	64	65	69	ASTM D4737
GCV	kJ/kg	44840	40125	39985	38700	36800	34500	ASTM D4868
Sulphur Content	%	<0.0124	0.0248	0.0249	0.0251	0.0253	0.0257	ASTM D4294
Oxygen	%	12.35	13.80	14.75	15.15	16.25	17.35	ASTM D5622
Carbon Residue	%	74.85	75.35	76.40	77.55	78.25	79.65	ASTM D 7662
Flash point	^{0}C	56.5	38.5	37.55	37.35	37.15	36.85	ASTM D93
Hydrogen	%	12.38	7.5	7.55	7.65	7.75	7.95	ASTM D7171

3.0 RESULTS AND DISCUSSION

3.1 Brake Specific Fuel Consumption (BSFC)

Fig. 4 is a variation of BSFC with engine load. The BSFC compared to the engine load in Fig. 1 reveals or shows that as the load increases there is an equal increase in the amount of fuel consumed by the test engine. The values obtained at full engine load for the blends of 90/WPPO5/E5, 80/WPPO10/E10,70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 and CD were 0.04g/kW.h, 0.041g/kW.h, 0.042 g/kW.h, 0.043 g/kW.h and 0.035g/kW.h respectively.

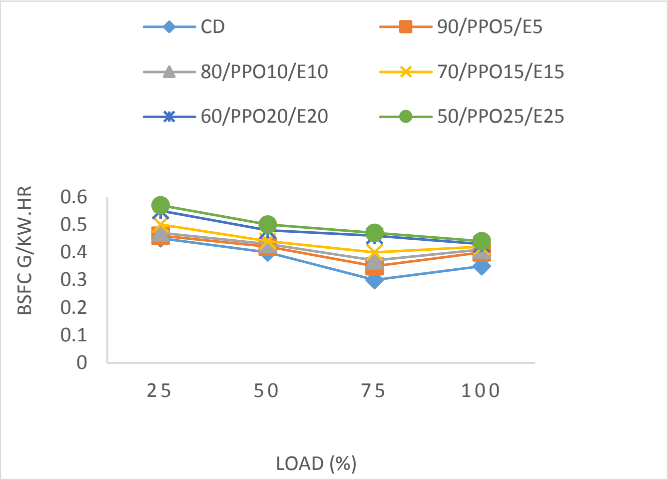

Fig.4. Brake specific fuel consumption versus load

At high engine loads the conversion of heat energy to mechanical energy increases with increase in combustion temperature, leading to increased BSFC for the biodiesel, this increase is proportional to the difference in their heating values which is identical to the findings of [74]. This blends of WPPO compares well to conventional diesel fuel and sometimes other biodiesel blends with comparative differences in the heating values.

As the blend ratio increased there was a decrease in the BSFC across all the test fuels although the values for all WPPO blends were slightly higher compared to CD test fuel. The closeness of the values and the packed graph reveal a close resemblance and identical BSFC characteristics of WPPO, ethanol and EHN compared to CD fuel. For example, at 50 % engine load the blend of 80/WPPO10/E10 had a value of 0.043 g/kW.h compared to full engine load with 0.041g/kW.h, this value is higher than CD test fuel with 0.04g/kW.h at 50 % engine load and 0.035g/kW.h at full engine load.

3.2 Brake Thermal Efficiency (BTE)

The BTE variations with engine load are shown in Fig. 5. The graphs show that as the load increased there was increase in the BTE across all the test fuel blends of WPPO and CD. At 50 % engine load thevaluesforblends90/WPPO5/E5,80 /WPPO10/E10,70/WPPO15/E15,60/WPPO20/E20,50/ WPPO25/E25 and CD were 22 %, 21 %, 20 %, 18 %, 16.5 % and 22.5 % respectively. As the blend ratio and engine load increased, there was increase in BTE across the blends of WPPO but with a decrease in the BTE within the blends. At 25 % engine load 90/WPPO5/E5 had values of 14 %, 22 %, 26.5 % and 25 % compared to 70/WPPO15/E15 with 12.5 %, 20 %, 22.5 % and 23 % respectively.

The highest BTE value was reported by blend 90/WPPO5/E5 at 25 % engine load compared to any other blend of WPPO, ethanol and addition of EHN. Fig. 5 shows values of 24.8 %, 23 %, 21 % and 19 % respectively for blends 80/WPPO10/E10,70/WPPO15/E15, 60/WPPO20/E20, 50/ WPPO25/E25. However, blend 50/WPPO25/E25 reported the lowest values compared to the other blends. At 25 % engine load the BTE value was 9.5 % compared with full load at 19 %, this are the lowest values of BTE as shown in Fig. 2 for all the blends tested.

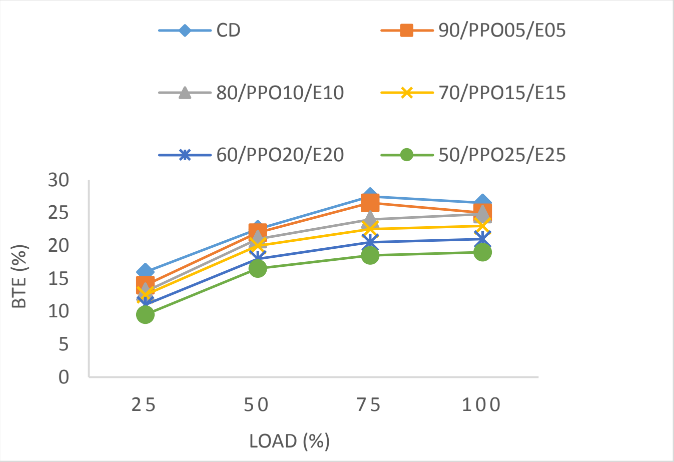

Fig. 5. Brake thermal efficiency versus load

3.3 Exhaust Gas Temperature (EGT)

The variation of the EGT and the engine load is shown in Fig. 6. The graph reveals that as the load increases the value of the EGT increased significantly especially for the blends. At 25 % engine load the blends 90/WPPO5/E5, 80/WPPO10/E10,70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 reported values of 165 ^{0}C, 195 ^{0}C, 226 ^{0}C and 256 ^{0}C compared to CD with 155 ^{0}C, 175 ^{0}C, 205 ^{0}C and 240 ^{0}C for all engine load conditions.

As the engine load increased from 25 % to full load (100 %) the graph curves tend toward unitary and similar to the values of CD test. This can be concluded that the blends of WPPO, ethanol and fuel additives have identical temperature characteristics to those of CD test fuel especially as the engine load hits 75 % heading to 100 % (full load). This was attributed to the presence of ethanol which decreased ignition delay thus lowering the combustion temperature.

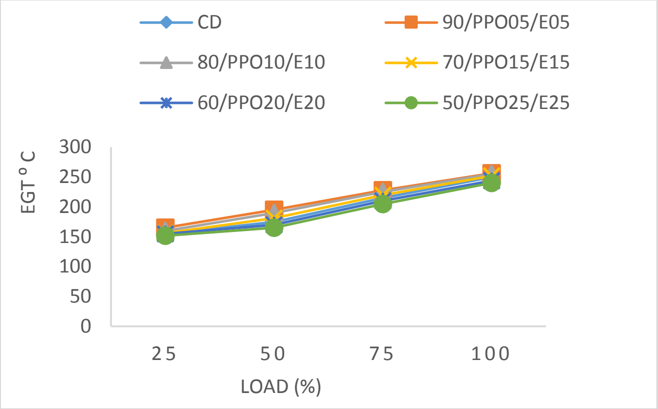

Fig. 6. Exhaust gas temperature versus load

3.4 Carbon Monoxide (CO)

Fig. 7 is a variation of CO with engine load. The graph reveals that as the engine load and the blend ratio increased the values of blends 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 had CO emissions decreased up to 75 % of engine load. There after the blends reported a continuous increase as the engine load was approaching full load. At 25 % engine load the blends of 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 reported values of 0.055 %, 0.0565 %, 0.06 %, 0.0615 % and 0.0625 %.

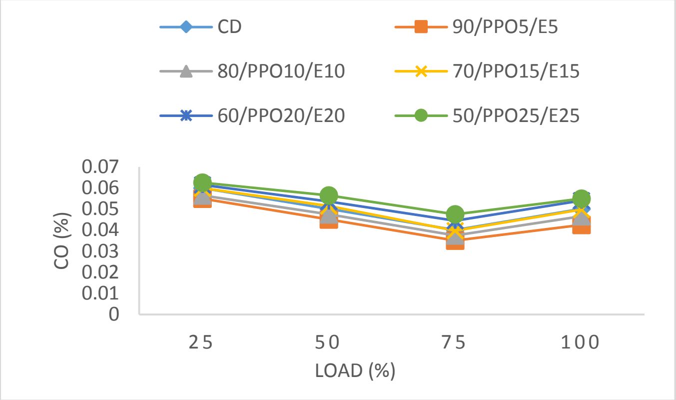

Fig. 7. Carbon monoxide versus load

However, as the load is increased to 75 % the values are 0.035 %, 0.0375 %, 0.0445 % and 0.0.0475 respectively. At full load all the test fuels showed increased CO emissions with blends 90/WPPO5/E5 and 80/WPPO10/E10 reporting the lowest emissions among the test blends across all the engine load conditions. At 50 % the blends reported values of 0.0445 % and 0.0475 % compared to full load with 0.0425 % and 0.0465 % respectively. The increased CO emissions though lower as compared to diesel fuel can be attributed to partial combustion [75] as the load increased and the presence of ethanol which shortened ignition delay, thus increasing CO emissions.

As the engine load and the blend ratio increased there is an increase in the carbon monoxide emission across the all engine loads and within the blends and CD test fuel. At 50 % engine load the values of the blends and CD were 0.045 %, 0.0475 %, 0.0515 %, 0.0535 %, 0.0565 % and 0.05 % for 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 and CD respectively. The above values obtained from Fig.4 suggest that there is a reduction of CO emissions across all test fuel irrespective of blend ratio and type of fuel except at high engine loads exceeding 75 % to full engine load. After this point there is a steady increase in the emissions of CO.

CO emissions are a direct result of poor oxidation of the hydrocarbon fuels in the combustion chamber. It is however determined by the local fuel/air equivalence ratio. Compared to CD, all other biodiesels tested showed decreased CO emissions due to the high oxygen content in the test biodiesels and the addition of EHN which greatly increased the CN. This is identical to studies by [61, 76]. However, as the engine load increased from 75 % towards full load (100 %), there is an observed increase in CO emissions, despite the oxygen content of the biodiesel and increased CN of the blends of WPPO, ethanol and EHN. This disagreement in results is due to differences in CN for the different biodiesel test fuel blends used. The increment in CN as the blend ratio increased led to increase in fuel quantity burnt during diffusive combustion hence increased CO emissions as the quality of combustion decreased.

3.5 Carbon Dioxide (CO_2)

Fig. 8 is the variation of CO_2 with engine load. The graph shows that as the blend ratio and engine load increased CO_2 emissions increased, but compared to CD their emission levels are still lower and almost identical. At 50 % engine load the values of CD, and the blends of 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 were 3.58 %, 3.35 %, 2.95 %, 2.6 %, 2.55 % and 2.25 % respectively.

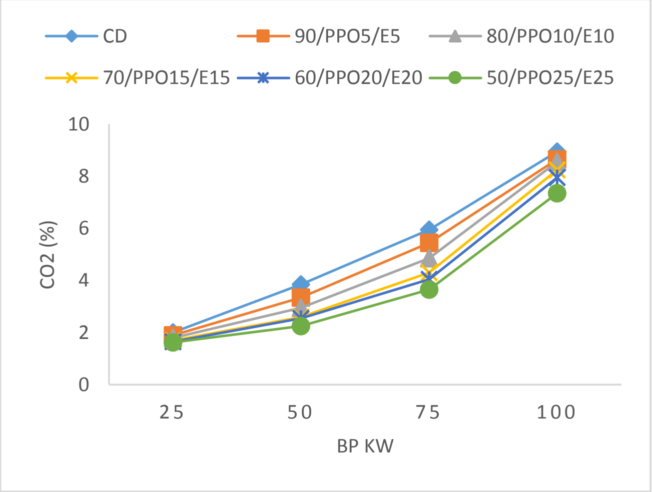

Fig. 8. Carbon dioxide versus load

Fig. 8 also reveals from its graph plot that as the load increased there was a significant increase in the CO_2 emissions across all test fuels, although with lower values as the blend ratio increased. For example, CD fuel had values of 2 %, 3.85 %, 5.95 % and 8.95 % for engine loads of 25 %, 50 %, 75 % and 100 % compared to blend 80/WPPO10/E10 with 1.8 %, 2.95%, 4.85 % and 8.55% for a similar load. The blend with the lowest value of CO_2 emission was 50/WPPO25/E25 with values of 1.62 %, 2.25 %, 3.65 % and 7.35 % respectively for engine loads of 25 %, 50 %, 75 % and 100 % respectively.

3.6 Oxides of Nitrogen (NO_X)

The variation of engine load with NO_X emissions is shown on Fig. 9. The graph plot shows that as the engine load was increased there was increase in the NO_X emissions irrespective of fuel, blend ratio or EHN. However, the value of NO_X emissions from the blends 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15 reported lower values compared to CD fuel. For example, at 50 % the value of the blends, were 385 ppm, 396 ppm and 415 ppm, compared to CD fuel at 425 ppm.

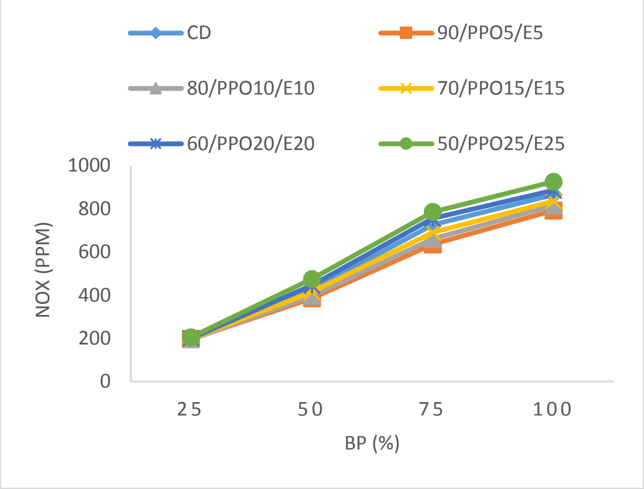

Fig. 9. Oxides of nitrogen versus load

Blend 60/WPPO20/E20 and 50/WPPO25/E25 had the highest NO_X emissions compared to the other blends of 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15 across all the engine load conditions tested. At 25 % engine load the two blends had values of 205 ppm and 200 ppm respectively. However, at full engine load the NO_X emissions values increased to 925 ppm and 885 compared to blend 90/WPPO5/E5 at the same load with 197 ppm and at full load at 792 ppm.

From the graph plot in Fig. 9 it is noticed that as the blend ratio increased there was direct increase in the emissions of NO_X across all the blended test fuels. However, blend 90/WPPO5/E5 reported the lowest values of NO_X emissions compared to all the other blends that were tested in this experiment.

The formation of NO_X in biodiesel combustion strongly depends on the combustion temperatures and combustion zone oxygen concentration. However, with high blend ratios of 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 the combustion process is shortened, thus leading to failure to provide enough cooling effect to decrease peak combustion temperatures leading to increased NO_X.

These findings seem to show that there is a correlation between the alcohol content in the fuel and peak flame temperatures, content of nitrogen, and oxygen availability [77]. Increased NO_X emissions can be attributed to presence of nitrogen from the cetane number improver ENH and other contaminants from the WPPO composition. Additionally it could be due to the generation of radicals of hydrocarbon through molecular unsaturation being identical to the findings of [78, 79]. However, the NO_X levels are still low which is attributed to high CN numbers of the tested biodiesels in Table 3, and as the CN and blend ratios increased (oxygen content). This findings are identical to the findings of [80].

3.7 Unburnt Hydrocarbons (UHC)

Fig. 10 is a variation of UHC emission with engine load. As the engine load was increased the UHC emissions increased too. However, the increase is more significant as the engine load was in intermediate loads of 75 % moving to or approaching full load. For example, at 50 % engine load the values of blends 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 were 22 ppm, 21 ppm, 20 ppm, 18 ppm and 15 ppm respectively compared to full load with 35 ppm, 34 ppm, 32 ppm, 29 ppm and 26 ppm. This leads to the conclusion that at high engine loads the values of UHC emissions are significantly high for all the blends od WPPO, ethanol and EHN, although comparatively low compared to CD fuel.

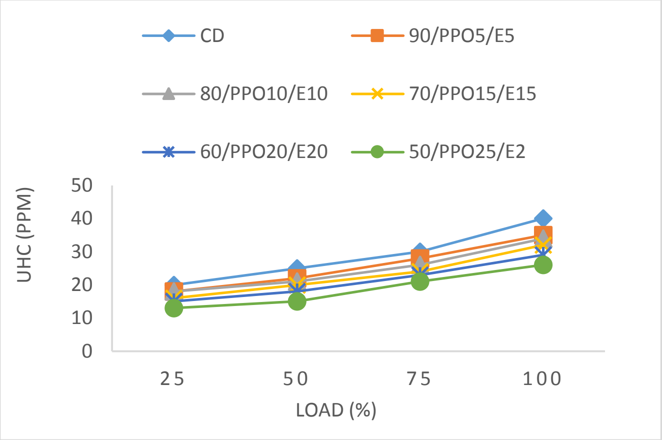

Fig. 10. Unburnt hydrocarbons versus load

The UHC emissions from the blends 90/WPPO5/E5 and 80/WPPO10/E10 had higher values although from the graph plot in Fig. 10, the values are still low compared to the values of CD test fuel. However, the general trend reported by the graph in Fig. 10 shows that as the blend ratio increased there was significant reduction in the UHC emissions, observed across all the test fuels irrespective of the engine load condition, for all the blends tested compared to CD fuel.

The higher hydrocarbon emissions may be due to hydrogen radicals in the diesel-ethanol-WPPO-EHN blends. High fraction of ethanol in blends 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 contributes to increase in the emissions of UHC which is identical to the findings of [81] and [50]who observed it in SI engine cylinder walls, crevices and quenched cylinder walls especially when richer air-alcohol mixtures were introduced.

4. CONCLUSION

- The lower blend ratios 90/WPPO5/E5 and 80/WPPO10/E10 exhibit identical BSFC of conventional diesel test fuel compared to the other blends. This blends show lowest BSFC values compared to the other blends.
- The BTE of blend 90/WPPO5/E5 showed values which were very close to the values of conventional diesel fuel values. This was attributed to close density values and the gross calorific values of WPPO blends, which showed very small and marginal differences. This case is made apparent especially at lower blend ratios of all the mixtures and blends tested.
- There is a reduction of UHC emissions with the use of WPPO blends, ethanol and EHN, with a notable reduction in NO_X emissions especially for the blend 90/WPPO5/E. This is a clear indication that this blend performed well when it is compared to petroleum conventional diesel.
- Although there is indicated increase in the emissions of CO, CO_2 NO_X and UHC, for all the blends of WPPO, ethanol and EHN. There is a clear indication in all the reports graphs discussed in this work, that the emission levels are very low compared to the emission levels of conventional petroleum diesel. This comparison is as to the ASTM standards during experimentation. However, when the overall value of emissions is compared to other emissions standards the WPPO blend performed well on emission level tested.
- During experimentation it was observed and reported that the blends of WPPO, ethanol and EHN have identical temperature characteristics to those of CD test fuel especially as the engine load hits 75 % heading to 100 % (full load). This was attributed to the presence of ethanol responsible for decreased ignition delay.
- The presence of high oxygen enrichment, is seen as a factor of decreased CO emission for the tested biodiesels compared to conventional diesel fuel. Although there is increases of CO emissions as fuel CN and blend ratio is increased. The probable reason may be due the deterioration of the combustion characteristics especially as the CN increases and the blend ratio alcohol ratio. The biodiesels with extremely high CN in the tested fuel need further investigation as a fuel improver.

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