

CETANE IMPROVERS AND ETHANOL PERFORMANCE AND EMISSIONS CHARACTERISTICS USING PYRORATED BIODIESEL

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ABSTRACT

Alternative fuels available at low cost, friendly to natural environments and meet the energy needs and demands, have witnessed a growing demand and use today. Ethanol is an attractive renewable energy source with a high content of oxygen. Ethanol can be produced through ethanolysis, however for this work direct blending of conventional diesel, waste plastic pyrolysis oil and ethanol with commercial fuel improver CI-0808 purchased from Innospec company was attempted. The primary purpose of adding a cetane improver was to improve the combustion characteristics of the blends by at least 1- 3 ignition quality points. Five mixing ratios were chosen in the following order, 50:25:25, 60: 20:20, 70: 15:15, 80: 10:10 and 90: 5:5 for Waste Plastic Pyrolysis Oil (WPPO), ethanol and conventional diesel (CD) respectively. However, for the fuel additive mixing ratio the total volume percentage was considered and the ratio put at 0.01% of the total quantity of blended fuel. In this work WPPO, diesel blends and fuel additives improvers were used as alternative fuel. This was to evaluate their performance and emission characteristics in a stationary single cylinder water cooled experimental diesel engine. The CI-0808 was added due to its potential power to reduce emissions of CO, UHC, NO_x, PM and improved engine performance. The results obtained were compared carefully to ASTM standards and discussed using graph curves figures and tabulated values. The conclusion was that ethanol and WPPO blends can be used in diesel engines as alternative fuel without modification. Used in combination with cetane improvers the emissions reduce significantly and performance improved equalling that of conventional diesel fuel.

KEY WORDS: Carbon Dioxide, Carbon Monoxide, Cetane Improver, Ethanol, High Content of Oxygen, Ignition Quality, Waste Plastic Pyrolysis Oil.

1.0 INTRODUCTION

The sharp rise in the number of automobile personal transportation has significantly increased the demand for energy especially in the primary sources of energy. Therefore, it has become imperative and important to seek alternative solutions to meet this need of increasing energy demand associated with modern day development. Since the discovery of the diesel engine by Rudolph Diesel in 1893, diesel engines have proved themselves as superior, power efficient and with good fuel economy compared to gasoline engines. However, despite all advantages diesel engines have continually been accused and proven guilty of emitting high emission levels of NO_x, CO₂, UHC, PM and smoke emissions. These emissions have been shown not only to affect human health but also the environmental health especially atmospheric air and land [1].

Diesel exhaust is now classified as carcinogenic [2] to humans and exposure has been linked to increased risk to lung cancer and cardiovascular diseases [3]. Besides human effects 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]. Early alternatives developments in fuel energy studies utilized food based sources as alternatives to petroleum fuels. However due to the poor food security in most developing countries this development has faced opposition and arguments from all sectors and the world leading organizations such as FAO and the 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 as reported by [9].

However, when it comes to second generation biodiesel fuels especially the higher alcohols it has been observed they can be produced from biomass lignocellulosic sources like wood, waste cooking oil and non-edible oils, thus minimizing or eliminating the issue of food security associated with first generation biodiesels. This biodiesel fuel or higher alcohols portend merits that have made them quite appealing to more researchers such as better miscibility, better blend stability with diesel, high energy density and low cost of production due to lower energy production cost requirements when commercially producing alcohols [10]. This is in comparison to the demerits of low alcohols such as low energy density, high volatility, poor lubricity, high hygroscopicity and low solubility at low temperatures. Density is an important fuel component property which directly affects engine performance [11, 12] and sometimes even emission characteristics. Most fuel properties like heating values and cetane numbers are related to the density of the fuel. It's the density of the fuel that influences efficiency, atomization and combustion characteristics [13]. Consequently, any change in density of fuel affects and influences the power output of an engine as the mass of the injected fuel changes with change in density. Lower density and viscosity is responsible for poor lubricity of most of the bioethanol-diesel blends. In other words when the bioethanol is mixed with diesel the resulting mixture results into a low grade fuel [14].

Research on WPPPO has shown that using the technique of pyrolysis to extract liquid fuel from plastic waste material is a viable alternative to diesel fuel production. This is true especially when waste plastic oil is used with fuel additives [15]. 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 quite a poor response and alarming as the gap between generation and recycling continues to grow huge, thus requiring bridging [16]. Plastic pyrolysis can also be done using catalytic pyrolysis and the 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 current crop of researchers such as [17-19] and many more others in the preceding sections.

Production of WPPO by pyrolysis has proven itself as the most cost effective option in the extraction process for plastic waste that produces high good yield percentages compared to other plastic waste extraction methods as reported by [20]. However, production of higher alcohols which have been shown to be good additives to waste plastic fuels has been shown to be produced using biological pathways. This is where microbial or anaerobic fermentation of engineered micro-organisms in a chemical laboratory can be used on lignocellulosic biomass. Materials such as, rice straw, corn stocks, wood pulp and sugar cane bagasse [21] can be used to produce biodiesel without resorting to food crops based biodiesel. Biomass can be easily gasfied or steam reformed or partially oxidized in order to produce synthesis gases such as CO, H₂ and CO₂. By an addition of a catalyst, these gases are converted into high level alcohols by a process called high alcohol synthesis (HAS) [22]. However [23, 24] have expanded the understanding on the synthesis via syngas fermentation by application of catalysts leading to higher yield of n-pentanol. This high yield alcohol n-pentanol when added to WPPO blends has been reported to improve oxygen concentration and injection spray characteristics [25]. This causes the WPPO to ignite quite easily, improve the fire point qualities and the combustion behaviour and characteristics. The use of higher level alcohols in the early stages of research and development was slow due to the exorbitant cost of production and wide use in the food industry [26].

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]. The use of lower alcohols methanol and ethanol have had certain limitations due to their low cetane numbers, high latent heat of vaporization and high resistance to auto-ignition [27]. However, in order to deal with the limitations including low calorific value, poor miscibility with diesel fuel, and poor lubricity [28]. Several methods have been proposed and they include alcohol fumigation, dual fuel injection, alcohol diesel blends and alcohol diesel-emulsion in order to handle this limitations and demerits [29]. 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 [30]. 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 [31]. There has been a recent increase in the awakening of interest in higher level alcohols due to their high energy demand, higher cetane numbers, better blend stability, less hygroscopic tendencies, increased carbon chain length and improved ignition quality of the alcohol fuel molecules [32], compared to the lower alcohols ethanol and methanol.

The last decade has witnessed tremendous renewed and reinvigorated interest in higher level alcohols as a sustainable option in reducing dependency on the lower alcohols and fossil fuels. 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 [33], biosynthesis from glucose using genetically engineered micro-organisms like *Escherichia coli* [34], cyanobacteria [35] and *saccharomyces cerevisiae* [36].

There are a number of researchers who have used fuel additive in their work on WPPO biodiesel and other biodiesels:[25, 28, 31, 37-53].[54] 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/Al₂O₃, 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.

[55] 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 [56].

Therefore, this work seeks utilization of development in fuels that are derived from renewable feedstock sources such as municipal solid waste (MSW) disposed plastics. In addition, it will include lignocellulosic feedstock like ethanol and others in this category as best placed alternative to replace petroleum based fossil fuels like diesel commonly used as the primary propulsion fuel in the transport industry and power generation. Plastics have a lot of stored potential energy of hydrocarbons inherent in their molecular structure, thus by altering them through modern methods of decomposition, they can be converted to liquid fuels. This can be done through such processes as de-polymerization and pyrolysis to provide the alternative fuel energy source need [57].

2.0 EXPERIMENTAL SET-UP

The experimental setup consists of a diesel engine, gas analyser and a smoke meter. The engine used in the experiment is a constant speed Kirloskar engine, four stroke single cylinder, direct injection vertical tilting diesel engine. The engine is water cooled and rated at 3.75 kW at 1500 rpm with torque of 28 Nm. An electric dynamometer was used to apply engine load to the test engine by means of a loading device. The engine is mounted on concrete bed with suitable modification connections for water cooling and engine lubrication. The outlet temperature of water from engine is maintained at 85 °C to 90 °C by adjusting the flow of the coolant and insulating the outlet pipe. The schematic arrangement of experimental setup is shown in Fig.1. Data collection is done through a data collection machine with the aid of a computer interface and in built LabVIEW software application.

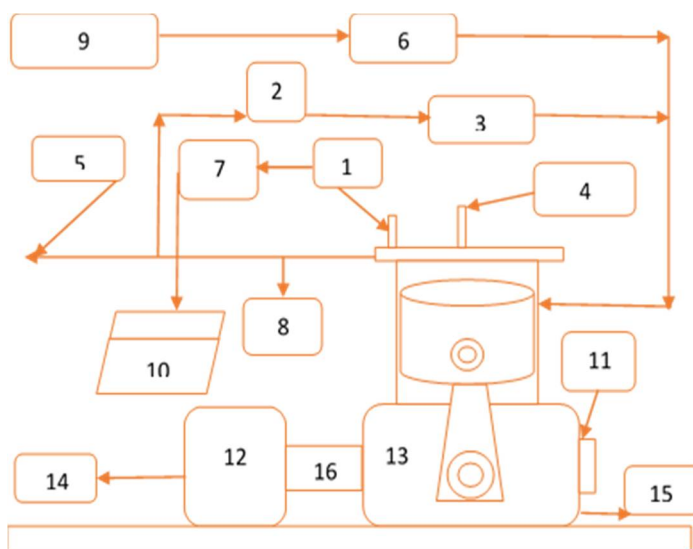


Fig.1. Schematic diagram of the test engine set up rig

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

Table II. Properties of Diesel, WPPO and ethanol

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

Table III. Properties of blended fuels diesel, ethanol, WPPO and fuel additive CI-0808

PROPERTIES	UNIT	E/WPPO/CD	E/WPPO/D/CI-0808
Density	Kg/M ³	835	833
viscosity@20 °C	°C	2.38	2.37
Cetane Number	—	54	62
Carbon Residue	%	0.013	0.014
Sulphur	%	0.045	0.043

3.0 RESULTS AND DISCUSSION

3.1 Brake Specific Fuel Consumption (BSFC)

Fig.1 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 increase in the amount of fuel consumed by the test engine as revealed in the graph in Fig.1. 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.

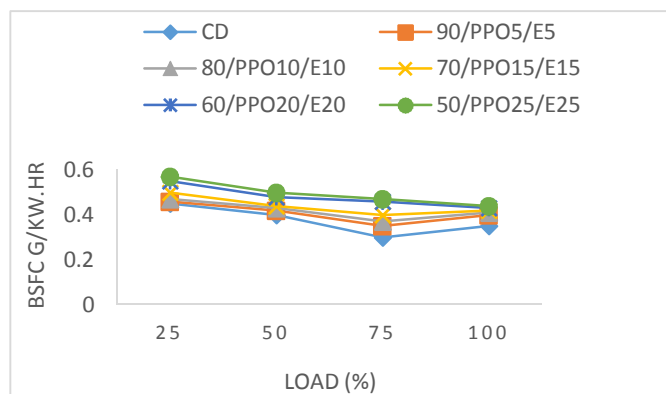


Fig.1. Brake specific fuel consumption versus load

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 fuel additives 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.2. 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 the values for blends 90/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 25 % reported by blend 90/WPPO5/E5 at engine full load compared to any other blend of WPPO and ethanol. Fig.2 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 blend. 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.

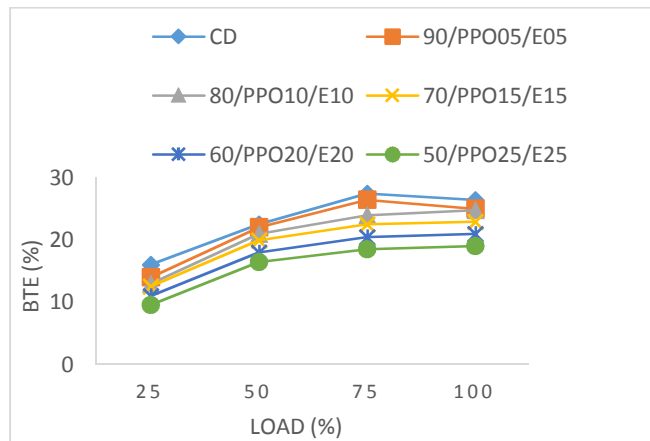


Fig.2. Brake thermal efficiency versus load

3.3 Exhaust Gas Temperature (EGT)

The variation of the EGT and the engine load is shown in Fig.3. 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 °C, 195 °C, 226 °C and 256 °C compared to CD with 155 °C, 175 °C, 205 °C and 240 °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).

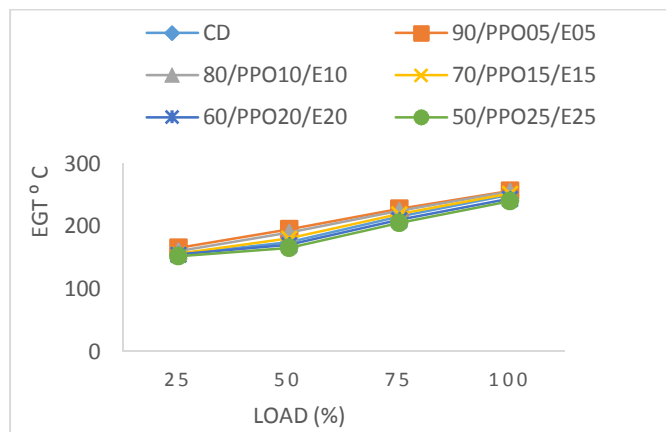


Fig.3. Exhaust gas temperature versus load

3.4 Carbon Monoxide (CO)

Fig.4 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 %.

However, as the load is increased to 75 % the values are 0.035 %, 0.0375 %, 0.0445 % and 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.

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.

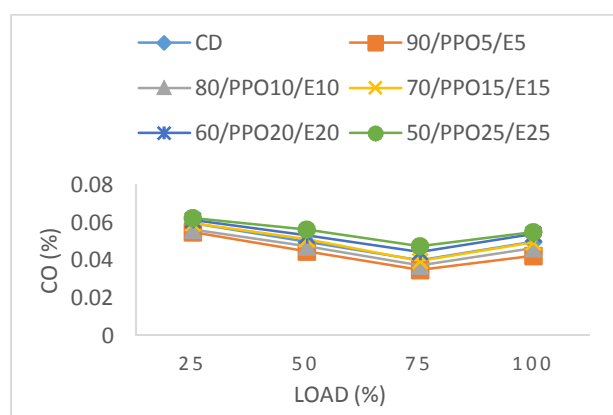


Fig.4. Carbon monoxide versus load

3.5 Carbon Dioxide (CO₂)

Fig.5 is the variation of CO₂ with engine load. The graph shows that as the blend ratio and engine load increased CO₂ 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.5 also reveals from its graph plot that as the load increased there was a significant increase in the CO₂ 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 CO₂ 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.

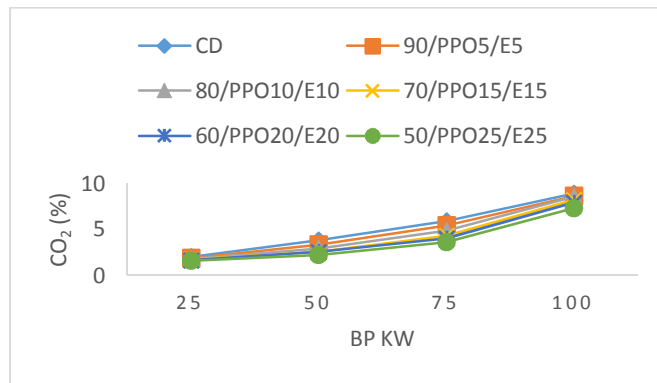


Fig.5. carbon dioxide versus load

3.6 oxides of nitrogen (NO_x)

The variation of engine load with NO_x emissions is shown on Fig.6. The graph plot shows that as the engine load was increased there was increase in the NO_x emissions irrespective fuel, blend ratio or fuel additive used. However, the value of NO_x emissions from the blends of ethanol, WPPO and fuel additive reported lower values compared to CD fuel. At 50 % the value of the blends 90/WPPO5/E5, 80/WPPO10/E10, 70/WPPO15/E15, 60/WPPO20/E20, 50/WPPO25/E25 were 385 ppm, 396 ppm, 415 ppm, 445 ppm and 475 ppm, while CD fuel had 425 ppm.

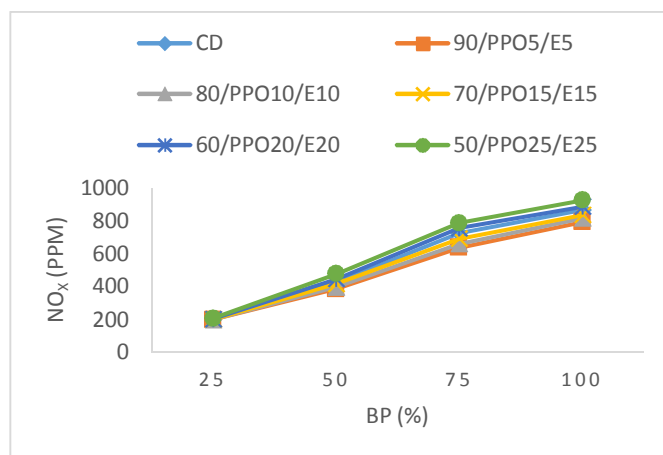


Fig.6. Oxides of nitrogen versus load

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.6 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.

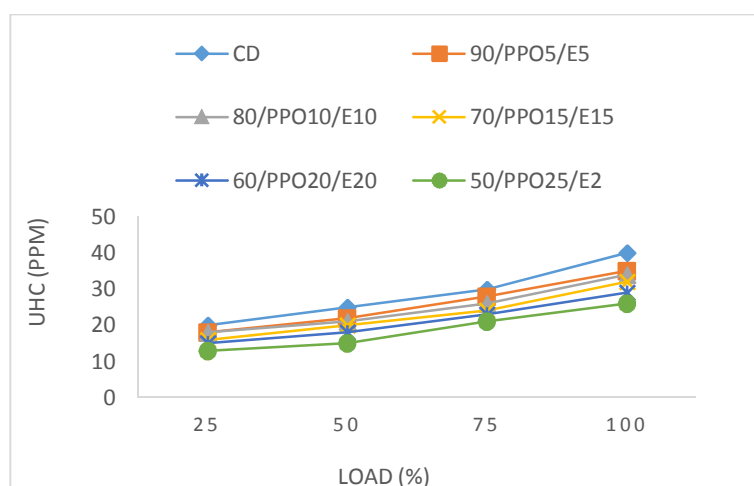


Fig.7. Unburnt hydrocarbons versus load

3.7 Unburnt Hydrocarbons (UHC)

Fig.7 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 NO_x emissions are significantly high for all the blends of WPPO, ethanol and fuel additive.

The UHC emissions from the blends 90/WPPO5/E5 and 80/WPPO10/E10 had higher values and from the graph plot in Fig.7 show almost similar and identical values as CD test fuel. However, the general trend reported by the graph in Fig.7 is that as the blend ratio increased there was significant reduction of UHC emissions observed across all the test fuels irrespective of the engine load condition.

4. CONCLUSION

- The general trend reported by the graph in Fig.7 is that as the blend ratio increased there was significant reduction of UHC emissions observed across all the test fuels irrespective of the engine load condition.
- The graph plot in Fig.6 shows 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 graph in Fig.5 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.
- Fig.4 shows that as the engine load and the blend ratio increased there is an increase in the carbon monoxide emissions across all engine loads and within the blends and CD test fuel.
- The graph in Fig.3 shows that as the engine load increased from 25 % to full load (100 %) the graph curves of EGT tend toward unitary, similar and identical to the values of CD test. This

can be concluded that the blends of WPPO and ethanol with fuel additives have identical temperature characteristics to those of CD test fuel especially as the engine load hits 75 % heading to 100 % (full load).

- Fig.2 indicates that 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.
- The BSFC across all the test fuels showed a decrease as the blend ratio increased for all WPPO blends. Although from the graph in Fig.1 the closeness of the values and the packed graph reveal a close resemblance to BSFC characteristics for the blends of WPPO, ethanol and with fuel additives compared to CD test fuel.

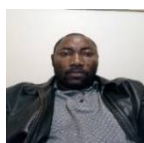
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