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Performance and Emission Characteristics of Ozonated Coconut Oil in a Single-Cylinder, Direct Injection Diesel Engine

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Abstract

This study investigated experimentally the performance and emissions characteristics of ozonated coconut oil blended with neat diesel fuel at 1, 3, 5, 7.5 and 10 % by volume used as biodiesel for a naturally-aspirated four-stroke, air-cooled, direct injection, single cylinder diesel engine. The experiment was conducted at four different engine loads; a full (100%) load and three partial (25, 50 and 75%) loads at three different speeds (3600, 3270 and 2945 rpm) of the engine.

Performance test results showed that the engine exhibited the highest specific fuel consumption (SFC) at lowest engine load of 25 % and lowest SFC at engine load of 75 % for all the test fuels (OCO-PBDF blends and neat PBDF). SFC also decreased with speed. Comparing with the base neat diesel fuel, results showed a little decrease in the SFC at lower loads especially at lower engine speeds.

Emission test results showed that carbon dioxide (CO_2) emissions decreased with load and speed for all blends but an exact opposite was observed for total hydrocarbon (THC) emission. Maximum carbon monoxide (CO) emission occurred at full engine load of 100 % and maximum for nitrogen oxides (NO_x) at 75 % load and minimum at 25 % load. Furthermore, in comparison with the neat diesel fuel, blended fuels decreased in CO emission especially at lower engine loads but an increase in NO_x and THC emission for almost all the test engine loads and speeds.

Keywords: specific fuel consumption, coconut oil, biodiesel,
alternative fuels, ozonation, diesel engines

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Introduction

The problem that the world is facing exhibits a domino-effect. Global energy requirement is continually increasing resulting in widespread exploitation of the petroleum-derived fuels, which in turn, result to their depletion and sharp increase in their prices in the world market. Globally, there are big issues regarding the excessive emission of many internal-combustion engines such as diesel engines, which are big contributors to air pollution and global warming that has prompted strict emission regulations, locally and internationally, for environmental protection and public health concerns.

These factors led to the regulations on the use of alternative fuels that could somehow minimize these problems. These alternative fuels must be easily available locally, at low cost, renewable, be environment friendly, and fulfill energy security needs without sacrificing engine operational performance. The best candidate for these alternative fuels is the biofuels or more specifically, biodiesel, for use in diesel engines.

In response to the above-enumerated problems, the local government must tap the available local resources in finding their own renewable alternative fuel resources such as biodiesel that could somehow answer these problems at hand. Ozonated coconut oil is a good candidate because the raw materials are available locally, the Philippines having an abundant supply of coconut-derived products such as coconut oil. Moreover, ozonation has gained attention among some of the common generally accepted procedures of producing biodiesel because of its efficiency and favorable kinetics in reacting with double bonds, which is a significant problem in biodiesel; it is non-toxic, convenient and does not require special storage, complicated handling procedure or expensive shipment or transportation protocols because ozone is produced or generated and used on sites [1], [2] and [3].

Furthermore, aside from being abundant in supply and available locally, low-cost, highly efficient and environmentally-friendly, the operational performance of these biodiesels must be, as much as possible, comparable to that of petroleum-based fuels, for such engines as internal combustion engines specifically the compression-ignition type are generally made for petroleum-based fuels. Thus, the performance and emission characteristics of ozonation of coconut oil used as biofuel for diesel engines, specifically single-cylinder engine, will be investigated thoroughly in this study.

Objectives of the Study

The main objective of this research is to determine and evaluate the performance and emission characteristics of different blends of ***ozonated coconut oil (OCO)*** and neat ***petroleum-based diesel fuel (PBDF)*** used as biofuel in a naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine at different engine speeds and loads.

Specifically, this study aims to:

1. Evaluate the performance characteristics of a diesel engine using the different blends of OCO and PBDF used as biofuel and compare their characteristics with that of the neat PBDF based on the engine's loads.
2. Evaluate the performance characteristics of a diesel engine using the different blends of OCO and PBDF used as biofuel and compare their characteristics with that of the neat PBDF based on the engine's speeds.
3. Evaluate the emission characteristics of a diesel engine using the different blends of OCO and PBDF used as biofuel and compare their characteristics with that of the neat PBDF based on the engine's loads.
4. Evaluate the emission characteristics of a diesel engine using the different blends of OCO and PBDF used as biofuel and compare their characteristics with that of the neat PBDF based on the engine's speeds.
5. Determine the best or optimum blend of OCO and PBDF among the different fuel blends.

Scope and Limitations

The scope and limitations of this study are as follows:

1. This study examines the production of biodiesel from different blends of ozonated coconut oil (OCO) and petroleum-based diesel fuel (PBDF). The fuel blends that will be used are 1, 3, 5, 7.5 and 10 % OCO by volume.

2. This study will use a naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine at four (4) different engine loads; a full load (100 % load) and three (3) partial loads (25, 50 and 75 % loads) at three different variable speeds.
3. The performance of a diesel engine using the different blends of OCO and PBDF used as biofuel will be determined based from data obtained in the experiments and their characteristics will be compared with that of the neat PBDF which will serve as the baseline of comparison.
4. The emissions of a diesel engine using the different blends of OCO and PBDF used as biofuel will also be evaluated such as the emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x) and total hydrocarbon (THC) and their characteristics will be compared with that of the neat PBDF which, as mentioned, will serve as the baseline of comparison.
5. The optimum blend of OCO and PBDF that will give the best blend among the five (5) different blends will be determined.

Review of Literature

Alternative Fuels

Recently, one of the most common types of alternative energy source that is being actively developed are the fuels of bio-origin or "biofuels" which are renewable ones and have the potential to both reduce fossil fuel reliance and the release of CO_2 to the atmosphere [4] and [5]. Various biofuels explored include primary alcohols, vegetable oils, biomass, biogas, etc. [4] and [6]. These include the biodegradable fraction of products, waste and residues from agriculture, forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste [7]. These alternative energy resources are largely environment-friendly but they need to be evaluated on case-to-case basis for their advantages, disadvantages and specific applications. Some of these fuels can be used directly while others need to be formulated to bring the relevant properties closer to conventional fuels. For diesel engines, a significant research effort has been directed towards using vegetable oils and their derivatives as fuels.

Scientists concluded that vegetable oils must be either chemically altered or blended with diesel to prevent the engine failure; thus, transesterification of the vegetable oil to form an ester can reduce or eliminate the effects or problems of using straight and raw vegetable oils [8] and [9]. The resulting fuel is what is referred to as "biodiesel". The process of transesterification, Figure 1, removes glycerin from the oil and replaces it with radicals from the alcohol used for the conversion process [9]. This process decreases the viscosity of the oil for ease of direct injection into the combustion chamber [7] and [9]. Another simple and effective mean of controlling and lowering the viscosities of vegetable oils is increasing the temperature of the crude vegetable oil [10]. Fuel preparation by pryolysis, dilution, and microemulsion can also give improved fuel properties over those of unprocessed vegetable oil [11] and [12].

Biodiesel

Biodiesel consists of methyl or ethyl ester of long-chain fatty acids from triacylglycerol and can be derived and produced from renewable lipid feedstocks of oil-bearing crops such as plants or vegetables (rapeseed, soybean, sunflower, coconut, etc.), animal fats or industrial waste fats/oils (waste restaurant grease, etc.) through a process of transesterification, formulated for use in compression ignition (CI) engines and whose properties are good enough to be used in diesel engines [5], [7], [13] and [14]. It is considered to be a low-carbon clean fuel, renewable, biodegradable, less polluting, nontoxic, and has low emission profiles [9] and [15]. Worldwide biodiesel production is mainly from edible oils such as the oils of soybean, peanut, coconut, sunflower canola, among others.

Ozonated Coconut Oil as Biodiesel for Diesel Engines

Coconut Oil for Diesel Engines

There are great opportunities to utilize coconut oil as a fuel. Coconut oil has been tested for its use in internal combustion engines. As an engine lubricant, the oil reduces fuel consumption, smoke emissions and allows the engine to run at a cooler temperature. Coconut oil has also been tested for use as a feedstock for biodiesel to be used as a diesel engine fuel. In this manner it can be applied to power generators and transport using diesel engines.

The main drawback to using coconut fuel oil in engines is that it starts to solidify at a temperature below 24 °C, and by 14 °C it is close to solid and does not flow at all. In tropical countries, temperatures fall below 24 °C on a significant number of nights throughout the year, and sometimes during the day in the cooler season. If the engine is started while the temperature is below 24 °C, the fuel filter is likely to become blocked [16].

To solve this problem, coconut oil can be blended with diesel fuel and under certain conditions totally replace it [17]. Since straight coconut oil has a high gelling temperature (22 to 25 °C), a high viscosity, and a minimum combustion chamber temperature of 500 °C (to avoid polymerization of the fuel), coconut oil is typically transesterified to make biodiesel. Furthermore, as Diaz, Rafael S. [18] described it, "the fatty acid component of the coconut oil is converted to another element called ester. Esters volatilize just as petroleum fuels. Glycerine and fatty acids are separated from each other by a process known as esterification. The coconut oil is reacted with an alcohol with the aid of a catalyst. If methanol is the alcohol reactant, the resulting element is Coco Methyl Ester. Coco Methyl Ester is the chemical name of Coco Biodiesel."

Coconut oil is one of the biofuels, which remains a white crystalline solid at temperature below 20 °C, but it is a clear liquid when it is blended with diesel fuel [13]. The fraction of coconut oil in blends does not create any separation or any layer on the inside wall of the fuel tank. Use of B100 (100 % biodiesel) is only possible in temperate climates as the gel point is approximately 10 °C.

The performance of vegetable oils as diesel fuel depends on the chemical composition of the plant oil particularly on the carbon chain length and the degree of saturation and unsaturation of the fatty acid molecules [19]. Diaz [18] pointed out that "although pure coconut oil can be used as diesel fuel, coconut oil esters or coco biodiesel shows the greatest potential as a suitable diesel fuel replacement or additive. Vegetable oils are currently being used as biodiesel additives in many countries to enhance engine performance and efficiency, but coco biodiesel is superior to them all. This is due to the medium chain saturated fatty acids in coconut oil, which gives the fuel unique characteristics not found with other biodiesel additives." Furthermore, as a fuel, the price of coconut oil is slightly higher than conventional petroleum fuel, but it would be least-cost alternative through the global emissions management cost, because coconut oil-based fuel produces low exhaust emissions [13].

Ozonated Coconut Oil for Diesel Engines

Fully ozonated coconut oil is made from bubbling ozone through slightly heated coconut oil at a specific ozone concentration and flow-rate [3] and [20]. The heating of the oil is necessary since natural coconut oil becomes a solid below 24 °C. Fully ozonated coconut oil has very few of the original properties of un-ozonated coconut oil. The texture is less viscous, the aroma is much stronger, and the taste is horrible. Ozonated coconut oil does not require refrigeration except in high summer temperatures (above 74 ° C) [20].

From the study of Truong, Pham Khanh [3] for the performance and emission characteristics of ozonated coconut oil for multi-cylinder diesel engines, chassis dynamometer test results showed that emissions of CO_2, NO, NO_2, NO_x, and THC for blends up to 10 % ozonated coconut oil were not considerably different from those of neat diesel fuel. The 20 % blend gave 9.5 % less CO_2, 14.6 % less NO, 10.5 % less NO_x, and 19.5 % less THC than neat diesel fuel. Application of multi-objective optimization software, together with an arbitrary set of reduced emissions and best fuel economy objective functions showed that the 20 % blend was the optimum among the ozonated coconut oil blends tested.

Materials and Methodology

This study examines the performance and emission characteristics of biodiesel from five (5) different blends which includes 1, 3, 5, 7.5 and 10 % by volume of ozonated coconut oil (OCO) and petroleum-based diesel fuel (PBDF) with the neat PBDF as baseline using a naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine at four different engine loads; a full (100 %) load and three partial (25, 50 and 75 %) loads at three different speed (2945, 3270 and 3600 rpm) of each load of the engine. The following sections show that different materials and methodology used for the conduct of this research.

Materials

Test Fuels

Petroleum-Based Diesel Fuel (PBDF)

The test fuel sample of neat petroleum-based diesel fuel (PBDF) was provided by Petron Corporation, one of the largest oil companies in the country, directly from their refinery located at Pandacan, Manila and was produced on the same batch.

Ozonated Coconut Oil (OCO)

A previous study of Truong [3] has been conducted on the determination or evaluation of the performance and emission characteristics of ozonated coconut oil used as biofuel for diesel engines with multiple cylinders. On the other hand, this study is similar with that one, but using a single-cylinder diesel engine. The same biofuel (ozonated coconut oil) was used in this study.

From the study of Truong [3], the ozonated coconut oil (OCO) used was produced from a coconut oil using the ozonation process developed and promoted by Frontier Japan, Inc. (FJI) which operates a waste cooking oil processing plant in Hiroshima, Japan. Filtered crude coconut oil from Senbel Fine Chemical Co., Inc. was utilized as feedstock for OCO production using the ozonation process parameters, which are based on FJI's process settings. The coconut oil was reacted with ozone from the PZH 12S Ozone generator in the presence of Fe_2O_3 and $Ca_3(PO_4)_2$ as catalysts. The Galeon Earth® zeolite was mixed with Ultra Shell® biodiesel for the filtration of ozonated biofuel.

Ozonated Coconut Oil (OCO) – neat Petroleum-Based Diesel Fuel (PBDF) Blends

In this study, the same blends of ozonated coconut oil and neat diesel fuel were used in the study of Truong [3]. On the production of the blends as he [3] explained it, "OCO was blended with neat PBDF with the volume percent of 1, 3, 5, 7.5 and 10. Each sample was mixed in 20 minutes at 350 rpm in a tank."

Test Apparatus and Instruments

Test Engine

This study used a naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine (Figure 2) to conduct the series of engine tests to evaluate the effect of the test fuels on the performance and exhaust emissions of the engine.

Methodology

This study is experimental in nature. The experiment was performed in a naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine at four different engine loads; a full (100 %) load and three partial (25, 50 and 75 %) loads at three different speed, (2945, 3270 and 3600 rpm) of each load of the engine.

Experimental Set-Up

Figure 3 shows the schematic diagram of the whole experimental setup. Data from the analog signals from the fuel mass flow meter and air mass flow meter go directly into the data acquisition box where the signal is converted from analog to digital then they are sent to the Man Machine Interface (MMI) PC. The Semtech-DS emissions analyzer is controlled by a separate computer where the data-logging is done as well. However, the MMI and Semtech-DS computer is connected and synchronized with the test engine's aid PC which acts as a trigger for simultaneous data logging.

Test Procedure

Preparation of the Test Engine

The test engine underwent pre-test inspection and maintenance to make sure that it was in good running condition, which included change of engine oil, etc. After which, the engine is run for several times to ensure it runs smoothly during the test runs.

The maximum and minimum speed of the engine was determined, as well as its maximum load, based on the following procedure:

1. The test load was connected to the engine.
2. Optical tachometer was stationed a few distances (approx. 1 ft. or 30 cm) from the engine wheel for the readings of speed.
3. Two multi-meters were also stationed at the test load to read the voltage and current, respectively, of the engine.
4. The test engine was powered and idled for approximately 10 minutes until it was sufficiently warmed up and stabilized before starting the determination of maximum and minimum speeds.
5. Maximum speed was determined by having the load and speed continuously increased simultaneously and the speed in which the engine produced a near black smoke corresponds to the test engines' maximum speed and the power at that speed corresponds to the maximum power of that test engine.
6. Minimum speed was determined by finding the lowest speed in which the engine was stable and its corresponding maximum power was also obtained similarly with the maximum speed determination, that is, the point in which the engine produced a near black smoke.

Test Procedure Description

It was important to check that all the apparatus and equipment necessary for the experiment were in good running condition. To start each run of the test fuels, some of them such as the test engine and test load, were put in a proper location. Air mass flow meter was then connected to the test engine. Fuel supply from the fuel tank was also connected to the test engine passing through the fuel mass flow meter.

The test load was then connected to the test engine. Some other instruments used for the reading of data such as the tachometer, two multimeters, etc. were stationed in their respective strategic location. Tachometer was used for the readings of engine speed while the two multi-meters were used to read the voltage and current, respectively, of the electric generator. The procedure for the investigation of the performance and emissions characteristics of the test fuels for each run is described as follows:

1. Before conducting each test run, the fuel lines were freed from the previous fuel by draining them into a waste container.
2. Approximately twenty (20) litres of the test fuel was placed in the fuel tank.
3. The analyzer probe was then firmly placed inside the test engine's muffler.
4. The test engine was started and idled for approximately 10 minutes until it was sufficiently warmed up and stabilized before starting each test run.
5. The test engine was operated under the specified rpm and specified electrical load while the performance and emission data were being continuously recorded for approximately one minute.
6. After data was obtained, the test fuel was replaced by the new one making sure that the previous fuel was completely drained and the fuel line was completely cleaned and freed from the previous fuel used.

The full load was run first. The engine was run at the rated speed of 3600 rpm and loaded until black smoke was emitted while maintaining the engine speed. Data obtained from this procedure defined the full load performance of the engine.

The part-load tests were conducted after the full load test. The procedure followed was similar to the full load test except that the loads were set at a fixed percentage of the full load as the engine was varied. Part-load performance data for 75 %, 50 % and 25 % of full load were obtained using this procedure.

As a basis for comparison of the performance and emission characteristics of the blends of the ozonated coconut oil and diesel fuel to that of the neat diesel fuel, the test engine was first operated on a neat-petroleum diesel fuel. After which, the blends of the ozonated coconut oil and diesel fuel was used as fuel in the engine. Considering the quantity of the blended test fuels, each blend had two trials with each blend preceded by neat diesel fuel runs. There was a random order in the test run of the blended test fuel as follows: 1, 10, 5, 3 then 7.5 %. Finally, the recorded data were then sampled, analyzed and evaluated.

Results and Discussion

This study explored, investigated and compared the effects on the engine performance and exhaust gas emissions characteristics of a naturally-aspirated direct injection, single cylinder, four-stroke, air-cooled diesel engine using five (5) different blends of OCO with PBDF at variable engine speeds and loads. The baseline data was generated using neat PBDF. Two runs of tests were performed for each fuel blend under identical conditions to check for the repeatability of all results. The experimental data was averaged from each load condition of three engine speeds for all test fuels.

During the experiment conducted for the determination of maximum and minimum speed of the test engine, the following were obtained:

Maximum speed: 3600 rpm
Minimum Speed: 2945 rpm

The average of the two speeds is 3272.5 rpm, but in this experiment, the speed 3270 rpm was used for simplicity. These three speeds of 2945, 3270 and 3600 rpm were used in the experiment for all the test fuels at all test engine loads.

The experimental results are given in two sections. The first section compares the engine performance characteristics of the various blends of OCO with PBDF using a neat PBDF as baseline. The second section investigates the effects of various blends on the engine exhaust gas emissions. The experimental results are described and discussed in the following sections.

Performance Characteristics Analysis

Specific Fuel Consumption

The specific fuel consumption (SFC) is defined as the ratio of the fuel consumption rate to the engine power output. Figure 4 shows the SFC of each test fuel in terms of the test engine speed for its four different loads. The SFC used in the succeeding figures and charts are computed as follows:

$SFC = FC/PO$

where

SFC = specific fuel consumption, kg/kW-hr

FC = fuel consumption, kg/hr

P = power output, kW

Power is computed as follows,

$P = VA$

where

V = electric voltage, kV

A = electric current, A

The figure shows that for all test fuels there was an increase in the SFC as the test engine speed increased for almost all of its loads. It can also be observed from the figure that the 25 % load of the test engine gave the highest SFC for all the test fuels while the 75 % load gave the lowest.

It can also be observed from Figure 4 that the variations of the SFC in all blends for all loads except the 24 % are relatively small and can be attributed to instrumentation and procedural inaccuracies.

For 100 % load of the test engine, Figure 5 shows that almost all the test fuels exhibited an increase in SFC as the test engine speed was increased except for the neat diesel one. For all blends, B1 gave the highest SFC while the B3 gave the lowest. Comparing with the base diesel fuel, B1 produced an 18.57 % increase in the SFC at 3600 rpm.

For 75 % load, Figure 6 shows that for all the test fuels, B7.5 gave the highest SFC while the B1 gave the lowest. It also shows that considering all the engine speeds, all blends showed a significant decrease in the SFC as compared with that of neat diesel fuel. B1 exhibited a decrease of 12.04 %, but at speed of 3600 rpm, B7.5 demonstrated an increase of 7.82 %.

For the 50 % load of the test engine, Figure 7 shows that B7.5 again displayed the highest SFC, while B1 the lowest. Comparing with the neat diesel fuel, B5 and B7.5 showed an increase in the SFC considering the values for all engine speeds, while the other blends exhibited a decrease. B1 produced a decrease of 5.64 % compared with the neat diesel fuel.

For 25 % load, which gave the highest SFC for all four loads of the test engine, Figure 8 shows that for all the test fuels, B1 gave the lowest value and again B7.5 gave the highest SFC considering all the engine speeds, but at 3600 rpm, B3 exhibited a 13.64 % increase compared with that of the neat diesel fuel. At 2945 rpm, B1 produced an 8 % decrease.

Emission Characteristics Analysis

Carbon Dioxide (CO_2) Emissions

Figure 9 shows the carbon dioxide (CO_2) emission of each test fuel at four different engine loads. The figure shows that for all test fuels, 100 % load gave the highest amount of CO_2 emission, while the 25 % load the lowest. It is very obvious from the same figure that CO_2 emissions, are clearly load dependent, that is, the higher the load percentage, the higher the CO_2 emissions.

For 100 % engine load, Figure 10 shows that B5 gave the highest amount of CO_2 emission, while B3 gave the lowest value. B5 produced a more than 100 % increase in the CO_2 emission, which was a similar result obtained for all test loads of 25, 50 and 75 %.

Similarly, for 75 % engine load, Figure 11 shows that B5 gave the highest value of CO_2 emission while B3 gave the lowest value.

For 50 % of the engine load, Figure 12 shows that B5 gave the highest value of CO_2 emission, while B3 gave the lowest one.

Same thing happened at 25 % engine load (Figure 13) that B5 gave the highest amount of CO_2 emission, while B3 gave the lowest value.

From the five figures, Figures 9 – 13, it can be seen that the CO_2 emissions on B5 are relatively higher than the rest, this can be attributed to the instrumentation / procedural inaccuracies during the run of B5 during the conduct of the experiment.

Carbon Monoxide (CO) Emissions

Figure 14 shows the carbon monoxide (CO) emission of each test fuel at four different engine loads. It shows that the 100 % load gave the highest amount of CO emission, while all other loads have similar emissions except for the B0 in which 75 % load gave the lowest one.

For 100 % engine load (Figure 15), B1 gave the highest amount of CO emission, while B3 gave the lowest. Comparing with the base fuel, B3 and B7.5 gave an emission lower than the base fuel, while all other blends gave a higher value. At 3600 rpm, B1 produced an increase of 172 % CO emission compared with the neat diesel fuel and at lower speed of 2945, it exhibited an increase of 90.13 %, but at the same speed of 2945 rpm, B3 gave a decrease of 53.2 % CO emission.

For the 75 % engine load (Figure 16), B5 gave the highest value of CO emission while B3 again gave the lowest. Comparing with the base fuel, B5 gave an emission higher than the base fuel, while all other blends gave a lower value. B5 produced an increase of CO emission of 168 %.

For 50 % engine load, from Figure 17, it shows that all blends gave a lower value of CO emission compared with the neat diesel fuel at all speed engines with B3 again having the lowest amount of emission with a decrease of 71.12 % at 3270 rpm.

Similarly, from Figure 18, for 25 % engine load, all blends gave a lower value of CO emission compared with the neat diesel fuel with B3 again having the gave the lowest amount of emission with a 76.33 % decrease at 3270 rpm.

Nitrogen Oxides (NO_x) Emissions

Figure 19 shows the nitrogen oxides (NO_x) emission of each test fuel at four different engine loads. It shows that for all test fuels, the 75 % load gave the highest amount of NO_x emission while the 25 % load gave the lowest one.

For 100 % load, Figure 20 demonstrates that all blends have higher NO_x emission than the neat diesel fuel, the B5 the highest with an increase of 104.02 % at 2945 rpm compared with the neat diesel fuel, while all other blends have only slight amount of increase.

Figure 21 displays that for 75 % engine load, again B5 gave the highest amount of NO_x emission while all other blends have an insignificant increase of emission compared with the neat diesel fuel except for the lower engine speed where the B1 gave a lower amount of NO_x emission. B5 produced a 38.54 % increase at 2945 rpm compared with the base diesel fuel.

Similarly, for 50 % engine load, Figure 22 illustrates that all blended test fuels have a higher amount of NO_x emission compared with the neat diesel fuel. B5 has the highest emission followed by B7.5, while all other blends had a slight amount of increase than the base fuel. B5 exhibited an increase of 43.73 % at 2945 rpm compared with the base diesel fuel.

Furthermore, at 25 % engine load, Figure 23 shows a similar result, that is, all blended test fuels have higher NO_x emission as compared with the base neat diesel fuel with the B5 showing a significant increase than other blends. Similarly, B5 displayed a 54.24 % increase at 2945 rpm compared with the base diesel fuel.

Total Hydrocarbon (THC) Emissions

Figure 24 shows the total hydrocarbon (THC) emission of each test fuel at four different engine loads. It demonstrates that for all the test fuels, the 25 % engine load gave the highest amount of THC emissions, while the 100 % load gave the lowest value. It can also be observed that as the engine speed was increased, the emission decreased as the load was increased.

From Figure 25, for 100 % engine load, B5 gave the highest amount of THC emission, while B3 gave the lowest value, and comparing with the base diesel fuel, only the B3 gave the lower amount of THC emission; all other fuels had values greater than the base diesel fuel.

Moreover, from Figure 26, for 75 % engine load, B5 also gave the highest amount of THC emission while B3 gave the lowest value and comparing with the base diesel fuel, only the B3 gave the lower amount of THC emission while all other fuels had values greater than the base diesel fuel; a similar result as obtained with that at 100 % load.

Furthermore, Figure 27 shows that for 50 % engine load, B5 gave the highest amount of THC emission, while B3 gave the lowest value, and comparing with the base diesel fuel, only the B3 gave the lower amount of THC emission; all other fuels had values greater than the base diesel fuel. These results are similar with that at 100 and 75 % load.

Finally, from Figure 28, for 25 % engine load, the result was similar with that of other engine loads in which B5 gave the highest amount of THC emission, while B3 gave the lowest value and comparing with the base diesel fuel, only the B3 gave the lower amount of THC emission; all other fuels had values greater than the base diesel fuel.

Conclusion

From the figures acquired, based on the data obtained during the conduct of the experiment of this study, the following conclusions were drawn:

1 a. The test engine exhibited the highest specific fuel consumption (SFC) at lowest engine load of 25 % and lowest SFC at engine load of 75 % for all the test fuels (OCO-PBDF blends and neat PBDF).
   b. Comparing with the base neat diesel fuel, at higher loads, all blends exhibited an increase of SFC at higher speed, but showed an opposite result at lower speed, but not much of changes at the lower loads.

2 a. At all test engine speeds, B1 produced the lowest decrease of SFC especially at lower engine loads.

3. All the test fuels resulted to an increase in the CO_2 emission as the load is increased for all engine speeds.

4 a. CO_2 emission increased notably in B5 while it decreased in B3 at all engine loads and speeds.
   b. Considering all the test fuels, CO emission was notably higher at full engine load of 100 %, but a little difference at lower loads at all engine speeds.
   c. At lower loads, all blends showed a significant decrease of CO emission, especially at higher engine loads.
   d. For all engine speeds at all engine loads, B3 showed the lowest decrease of CO emission.
   e. NO_x emission was highest at 75 % engine load and lowest at 25 % load with the 50 and 100 % load almost with the same emission, especially at highest speed of 3600 rpm.

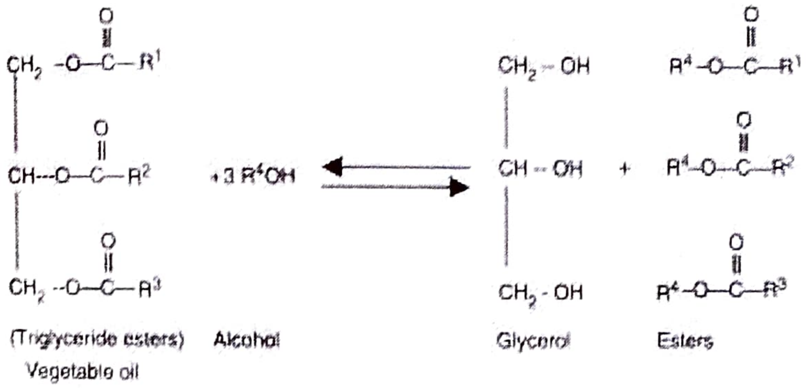
f. Almost all the blended test fuels have the same amount of NO_x emission except for the B5 where it showed a slightly higher increase, especially at lower loads.
g. Total hydrocarbon (THC) emission decreased as the engine load was increased for at all the tested fuels.
h. Almost all the tested blended fuels demonstrated an increase in THC with B5 being the highest except for B3 which exhibited the opposite result.

5. Finally, based on the performance and emission characteristics of all the blended test fuels, B3 gave the optimum blend, especially for its decrease in exhaust gas emissions.

Recommendations

In order to present a complete picture on the utilization of blends of ozonated coconut oil (OCO) and petroleum-based diesel fuel (PBDF) in diesel engines, the extension of this study on the following factors that may affect performance and emission must be investigated:

1. Further study must include higher blends of OCO with a neat PBDF.
2. More engine speed variation must be made.
3. More engine load variation must be made.



Adapted from [6]

Figure 1. Transesterification process.

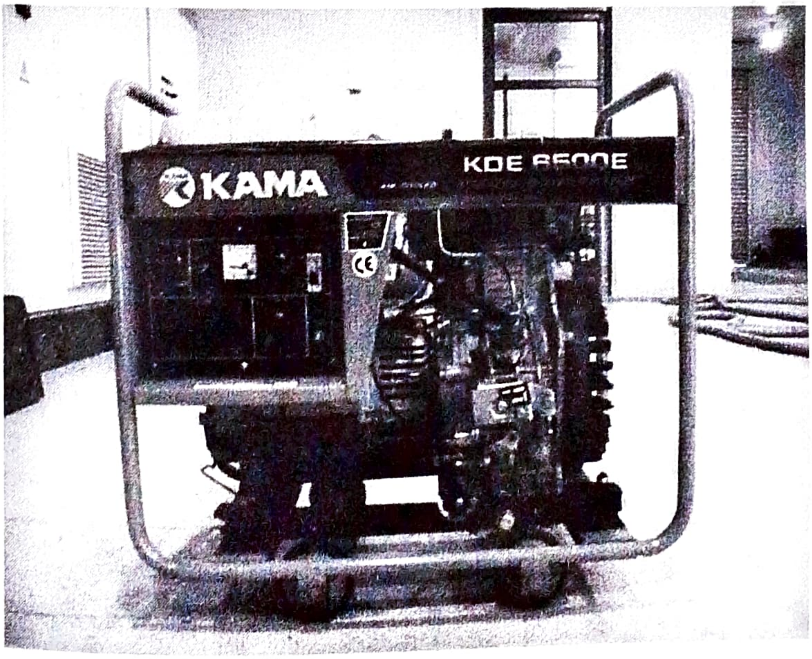


Figure 2. Naturally-aspirated, single cylinder, four-stroke, air-cooled, direct injection diesel engine used as test engine.

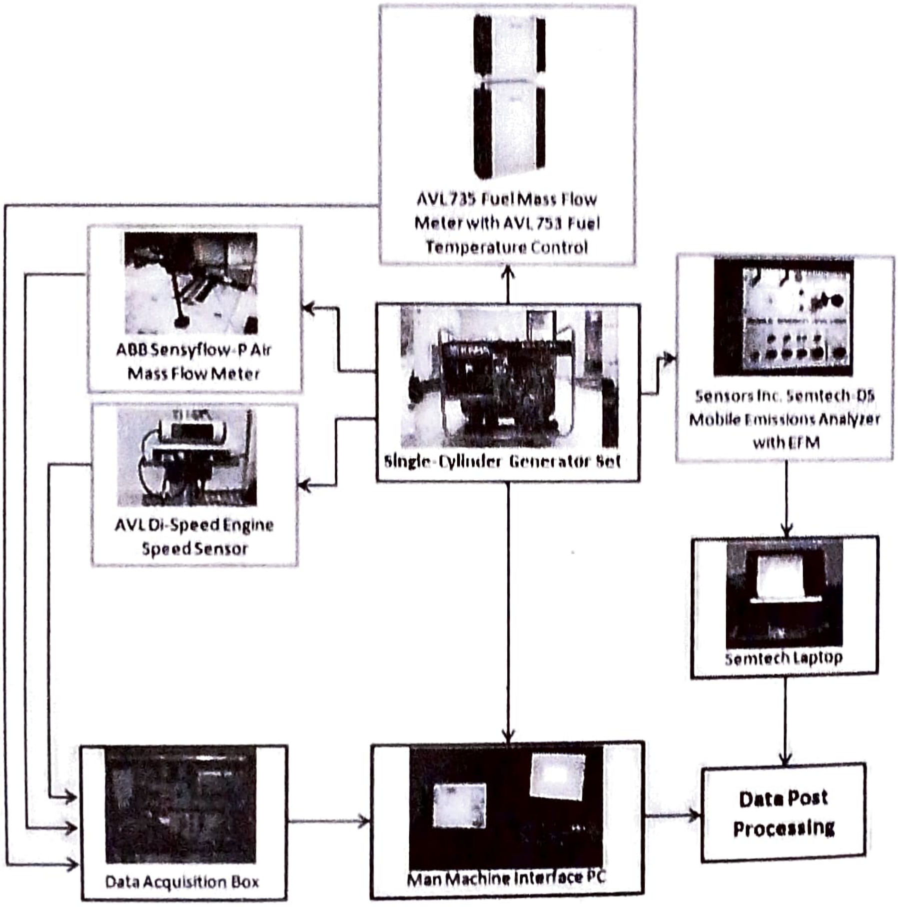


Figure 3. Diagram of the experimental setup.

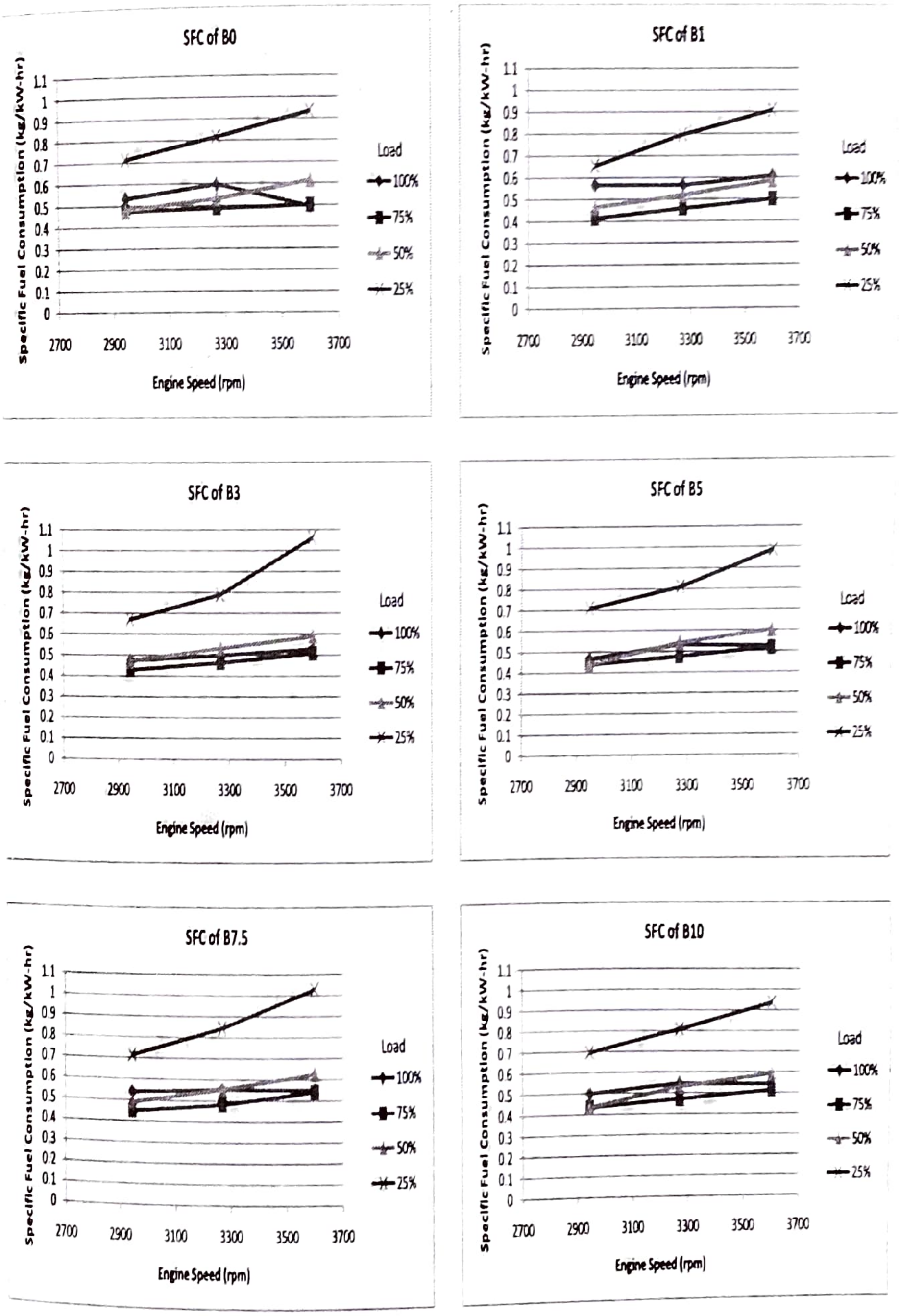


Figure 4. Specific fuel consumption (SFC) of each test fuel at four different engine loads.

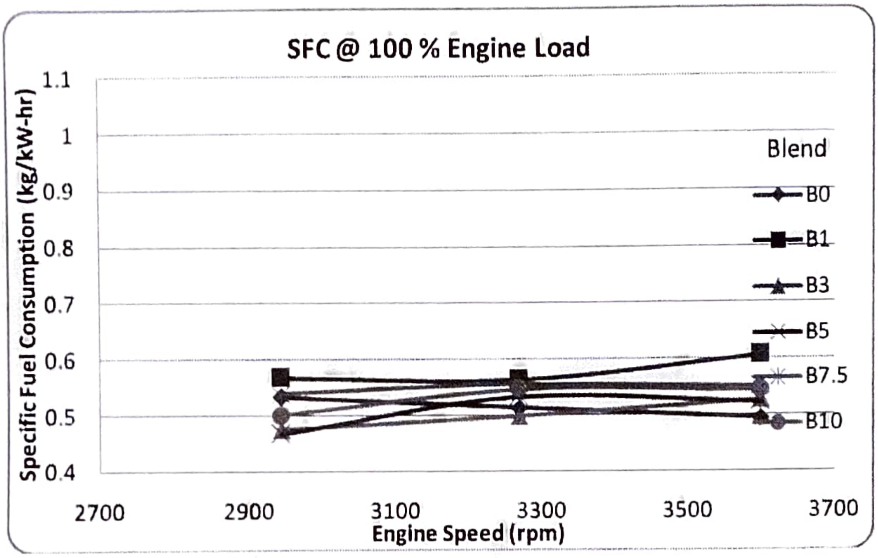


Figure 5. Specific fuel consumption (SFC) of the test fuels at 100 % engine load.

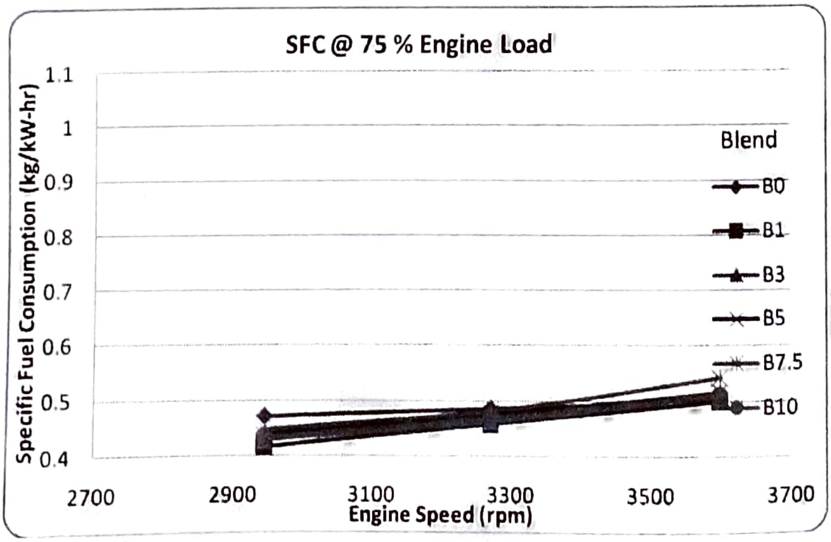


Figure 6. Specific fuel consumption (SFC) of the test fuels at 75 % engine load.

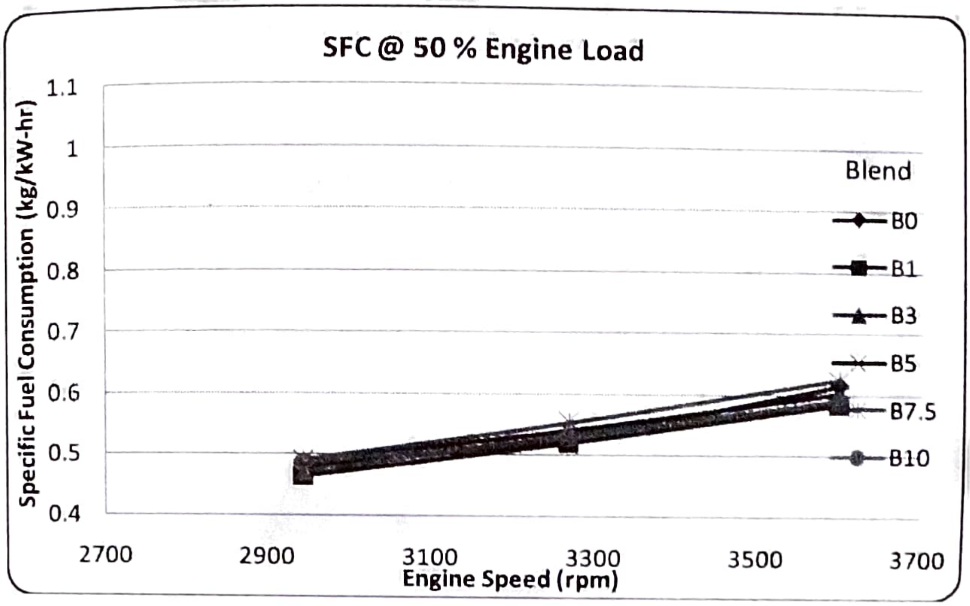


Figure 7. Specific fuel consumption (SFC) of the test fuels at 50 % engine load.

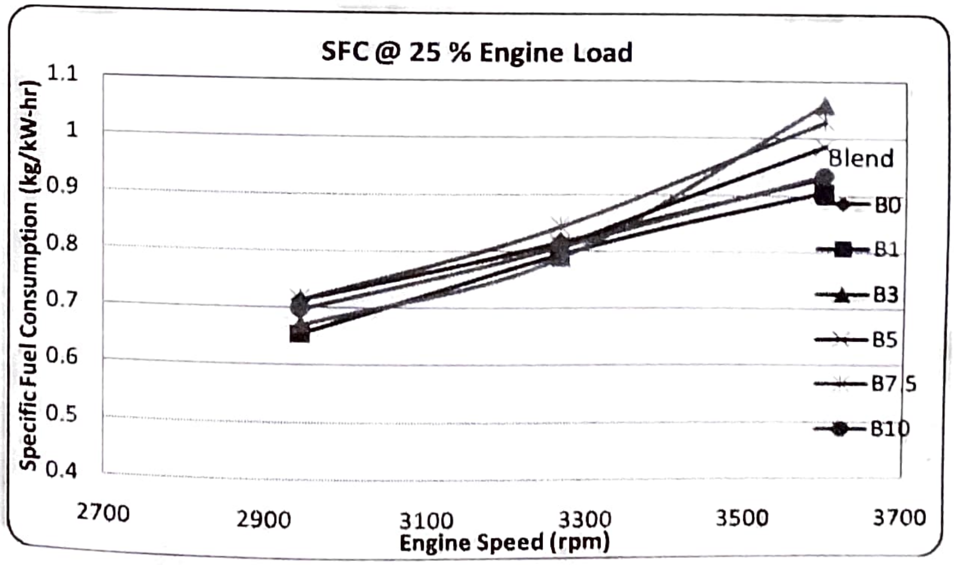
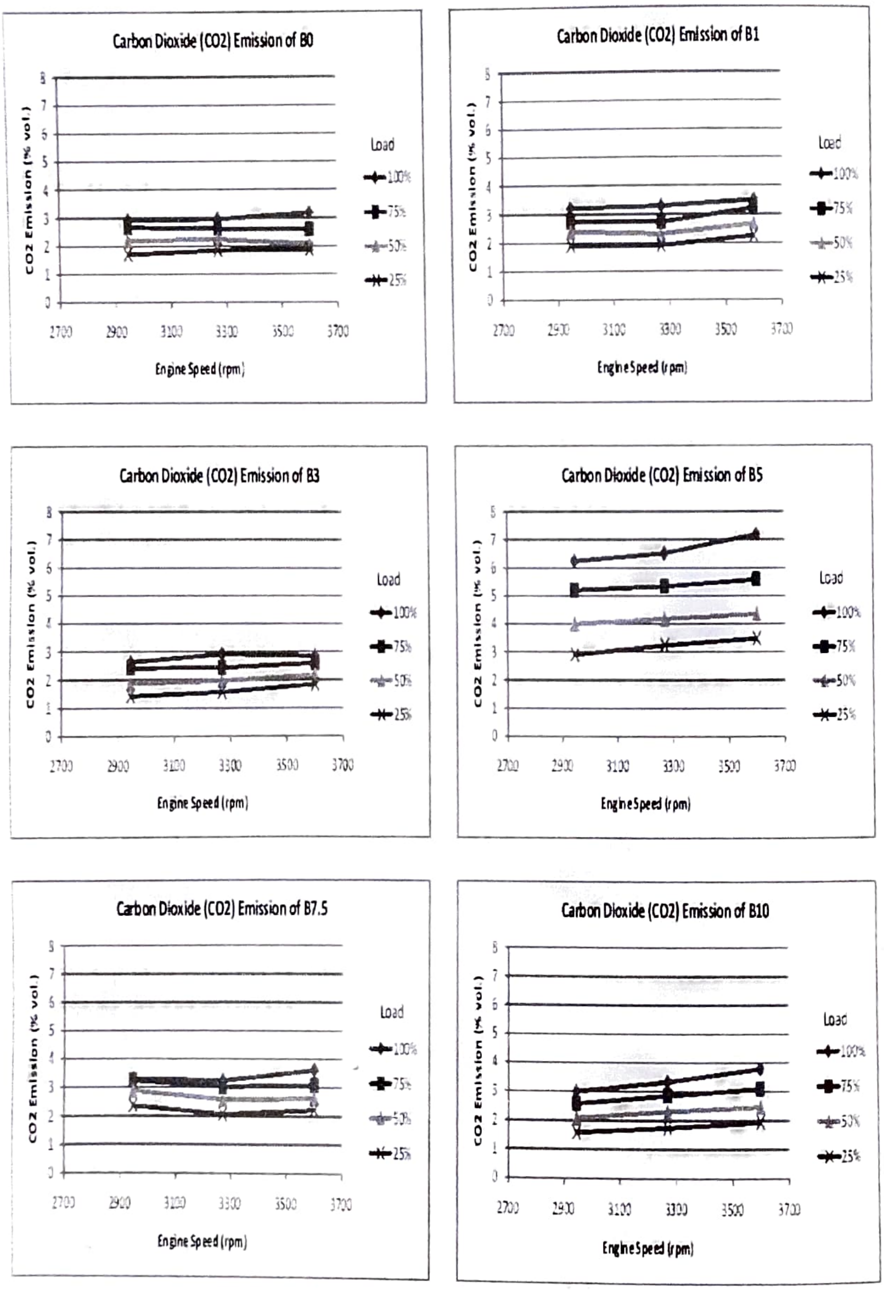


Figure 8. Specific fuel consumption (SFC) of the test fuels at 25 % engine load.


Carbon Dioxide (CO2) Emission of B0

Carbon Dioxide (CO2) Emission of B1

Carbon Dioxide (CO2) Emission of B3

Carbon Dioxide (CO2) Emission of B5

Carbon Dioxide (CO2) Emission of B7.5

Carbon Dioxide (CO2) Emission of B10

Figure 9. Carbon dioxide (CO_2) emission of each test fuel at four different engine loads.

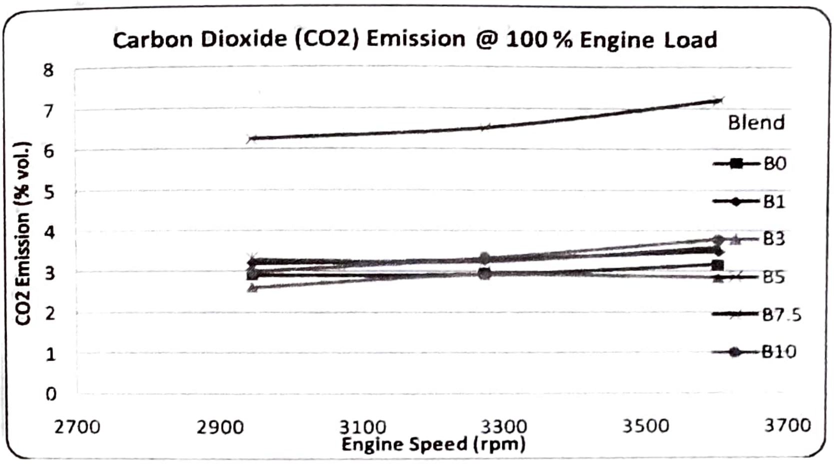


Figure 10. Carbon dioxide (CO_2) emission of the test fuels at 100 % engine load.

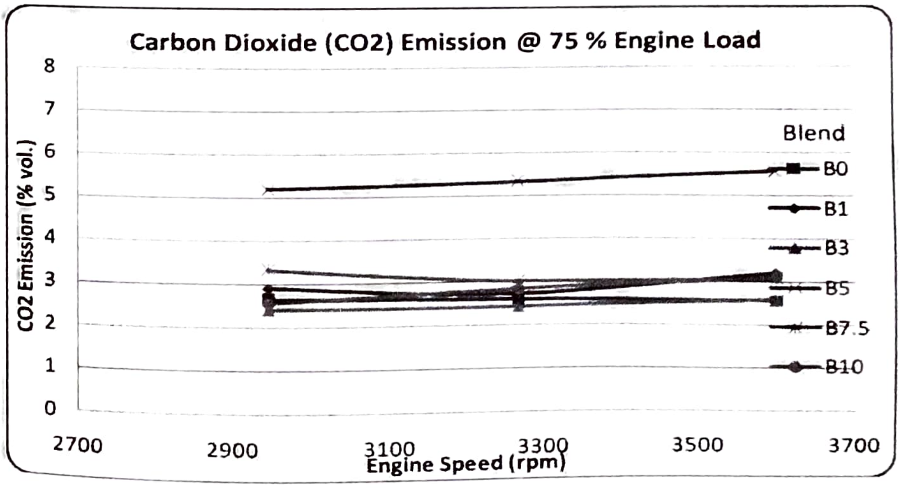


Figure 11. Carbon dioxide (CO_2) emission of the test fuels at 75 % engine load.

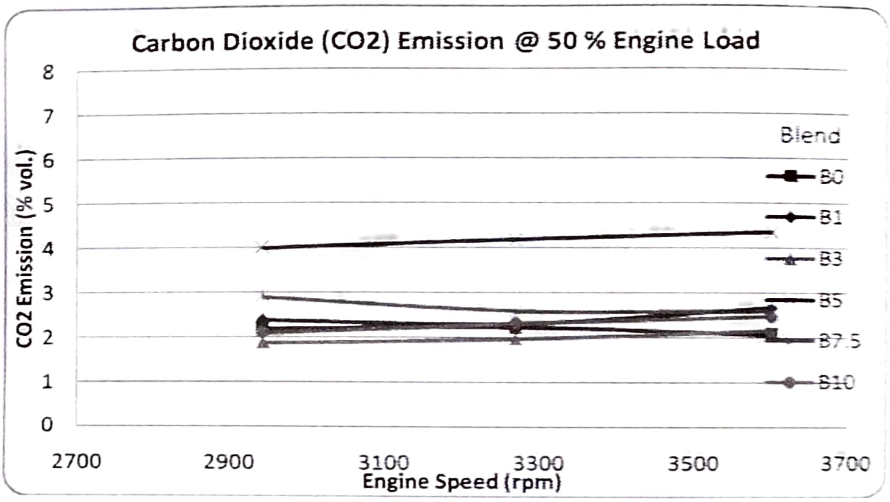


Figure 12. Carbon dioxide (CO_2) emission of the test fuels at 50 % engine load.

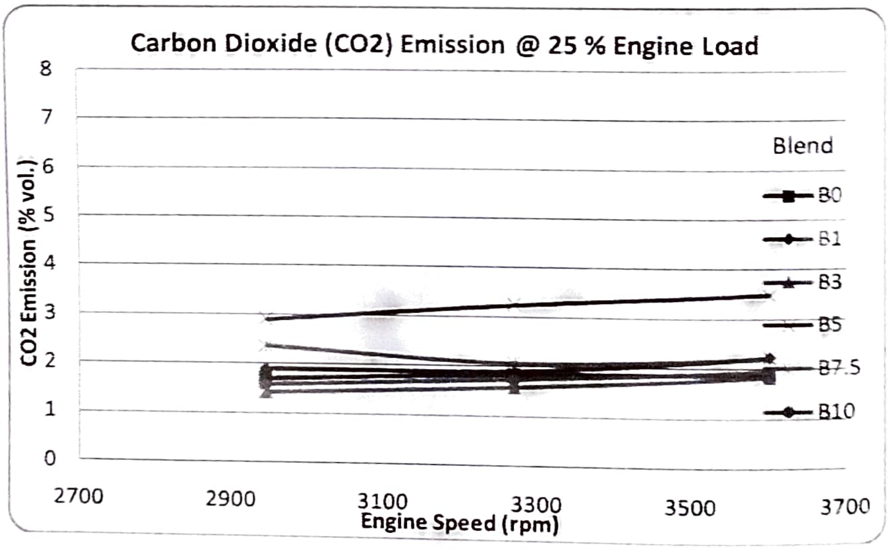


Figure 13. Carbon dioxide (CO_2) emission of the test fuels at 25 % engine load.

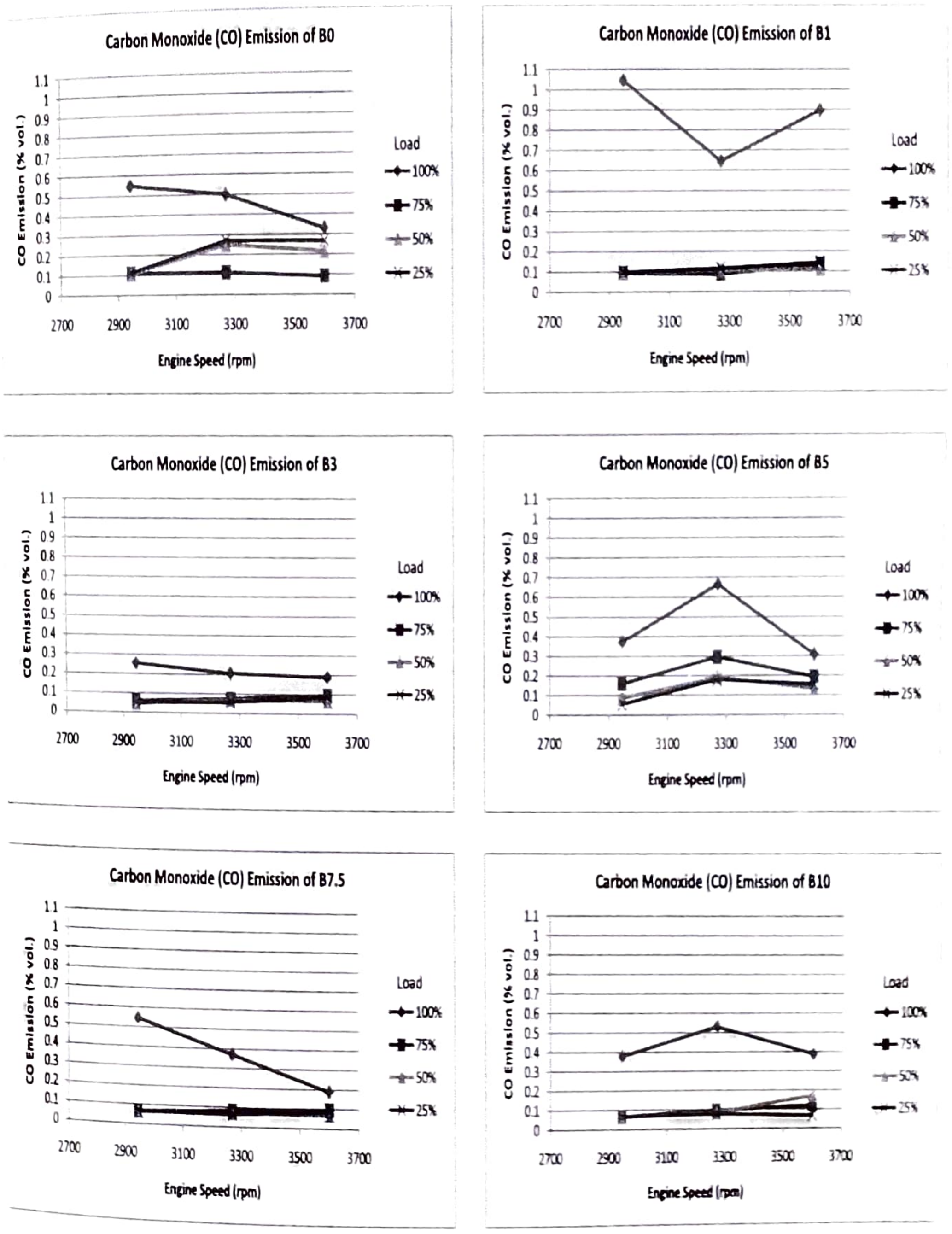


Figure 14. Carbon monoxide (CO) emission of each test fuel at four engine loads.

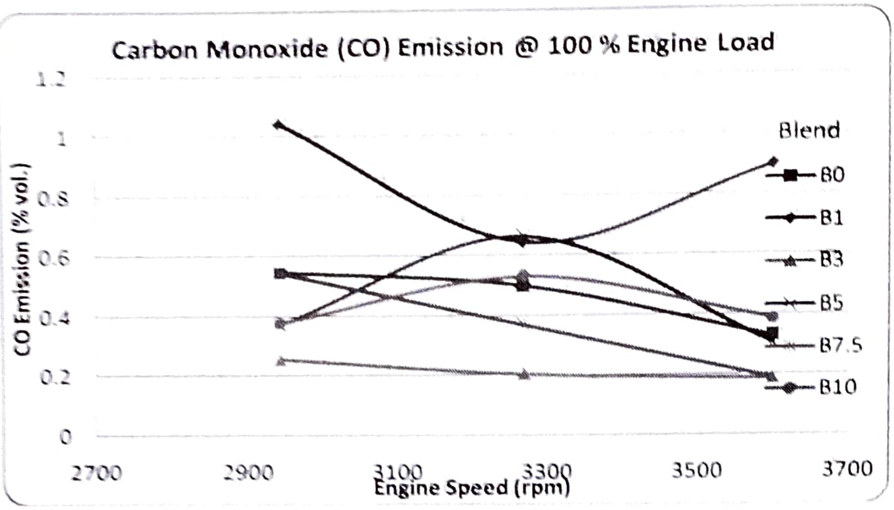


Figure 15. Carbon monoxide (CO) emission of the test fuels at 100 % engine load.

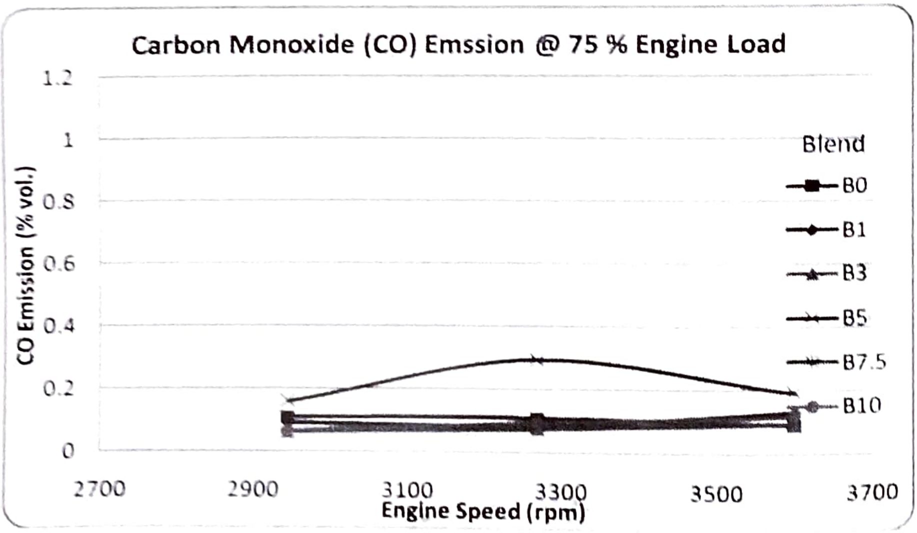


Figure 16. Carbon monoxide (CO) emission of the test fuels at 75 % engine load.

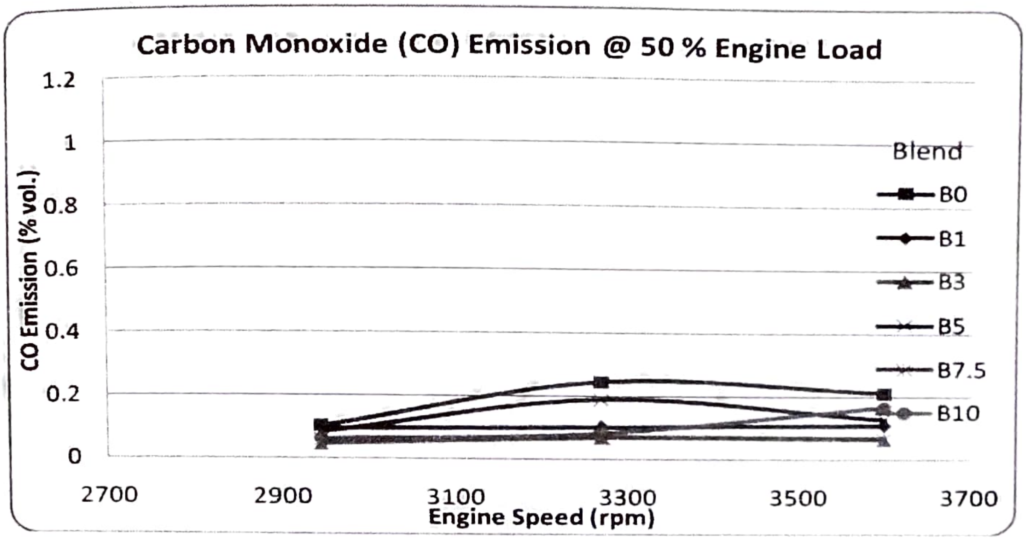


Figure 17. Carbon monoxide (CO) emission of the test fuels at 50 % engine load.

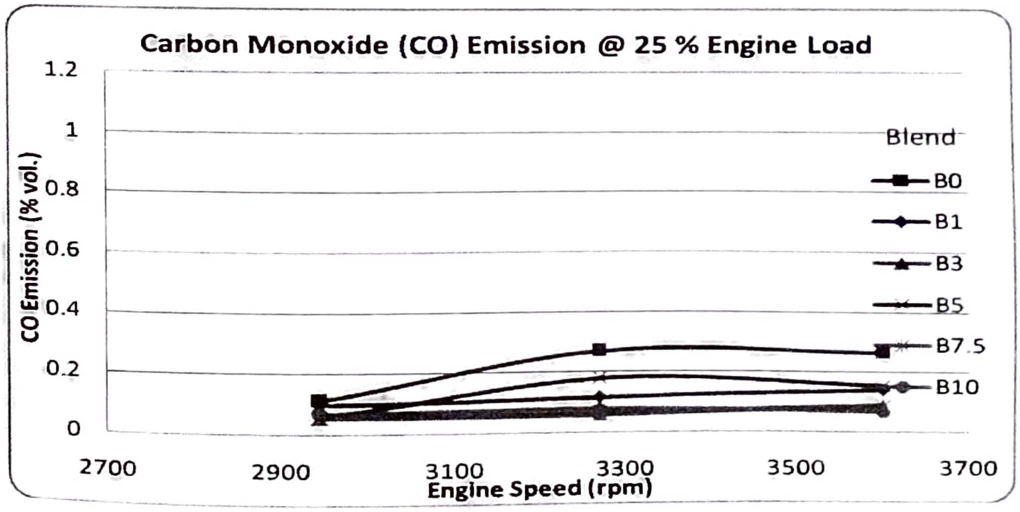
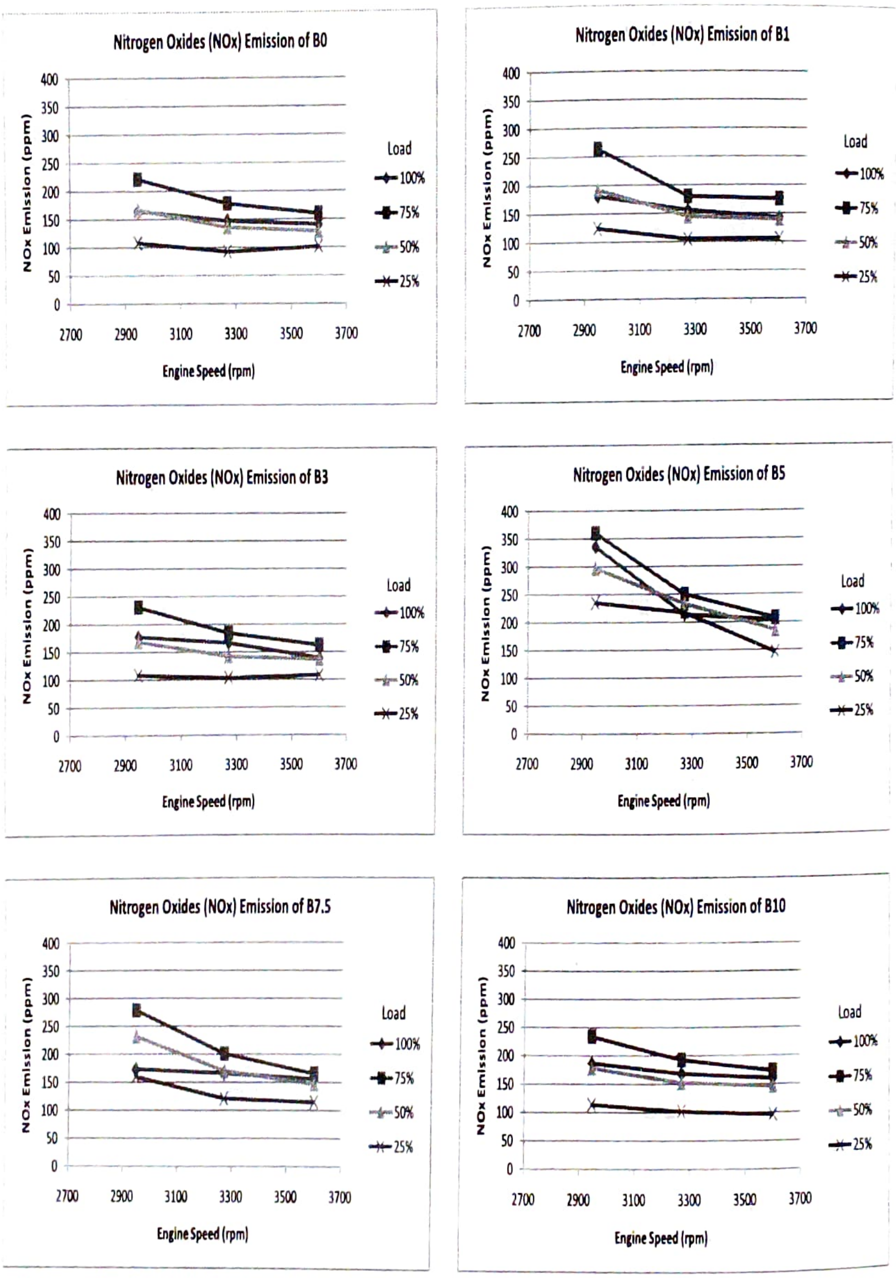


Figure 18. Carbon monoxide (CO) emission of the test fuels at 25 % engine load.



Nitrogen Oxides (NOx) Emission of B0

Nitrogen Oxides (NOx) Emission of B1

Nitrogen Oxides (NOx) Emission of B3

Nitrogen Oxides (NOx) Emission of B5

Nitrogen Oxides (NOx) Emission of B7.5

Nitrogen Oxides (NOx) Emission of B10

Figure 19. Nitrogen oxides (NO_x) emission of each test fuel at four different engine loads.

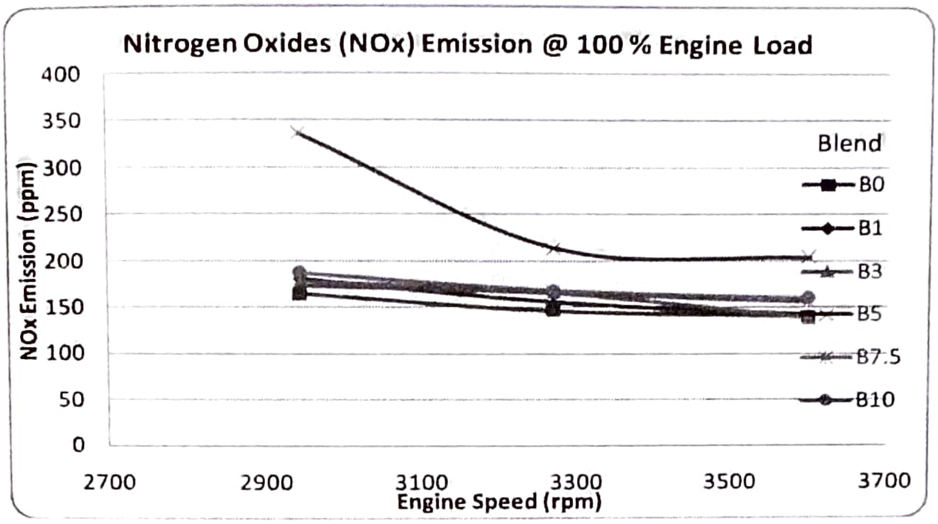


Figure 20. Nitrogen oxides (NO_x) emission of the test fuels at 100 % engine load.

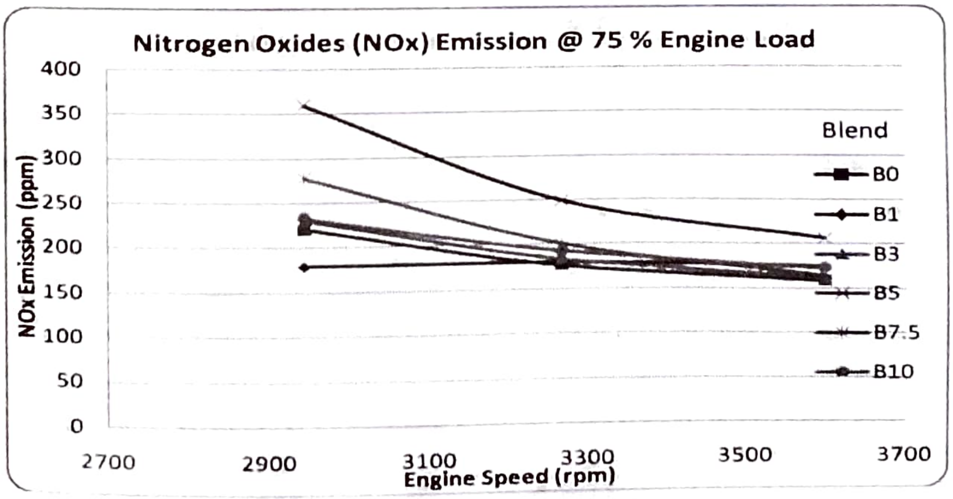


Figure 21. Nitrogen oxides (NO_x) emission of the test fuels at 50 % engine load.

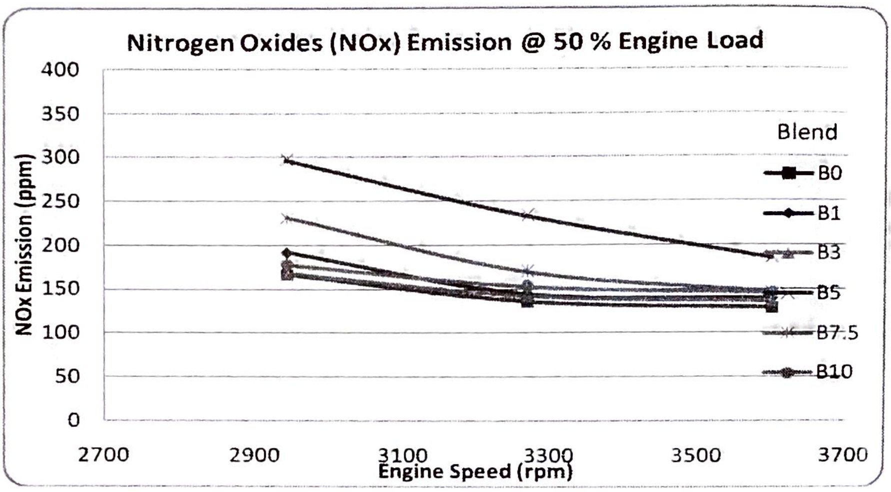


Figure 22. Nitrogen oxides (NO_x) emission of the test fuels at 50 % engine load.

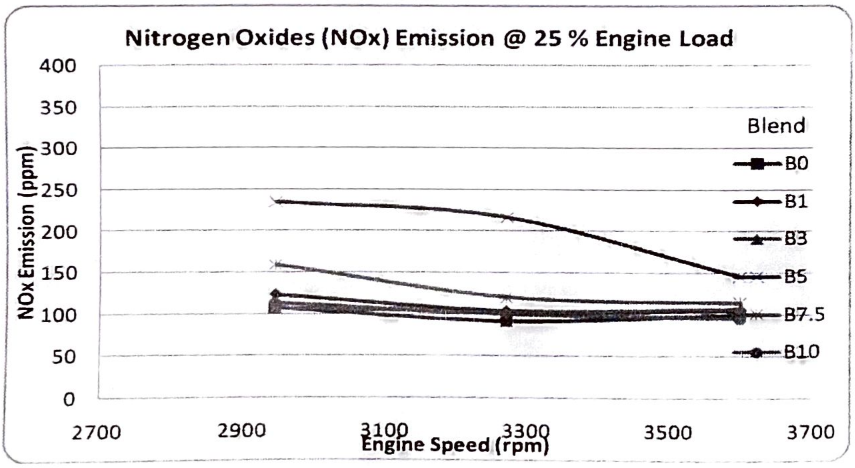


Figure 23. Nitrogen oxides (NO_x) emission of the test fuels at 25 % engine load.

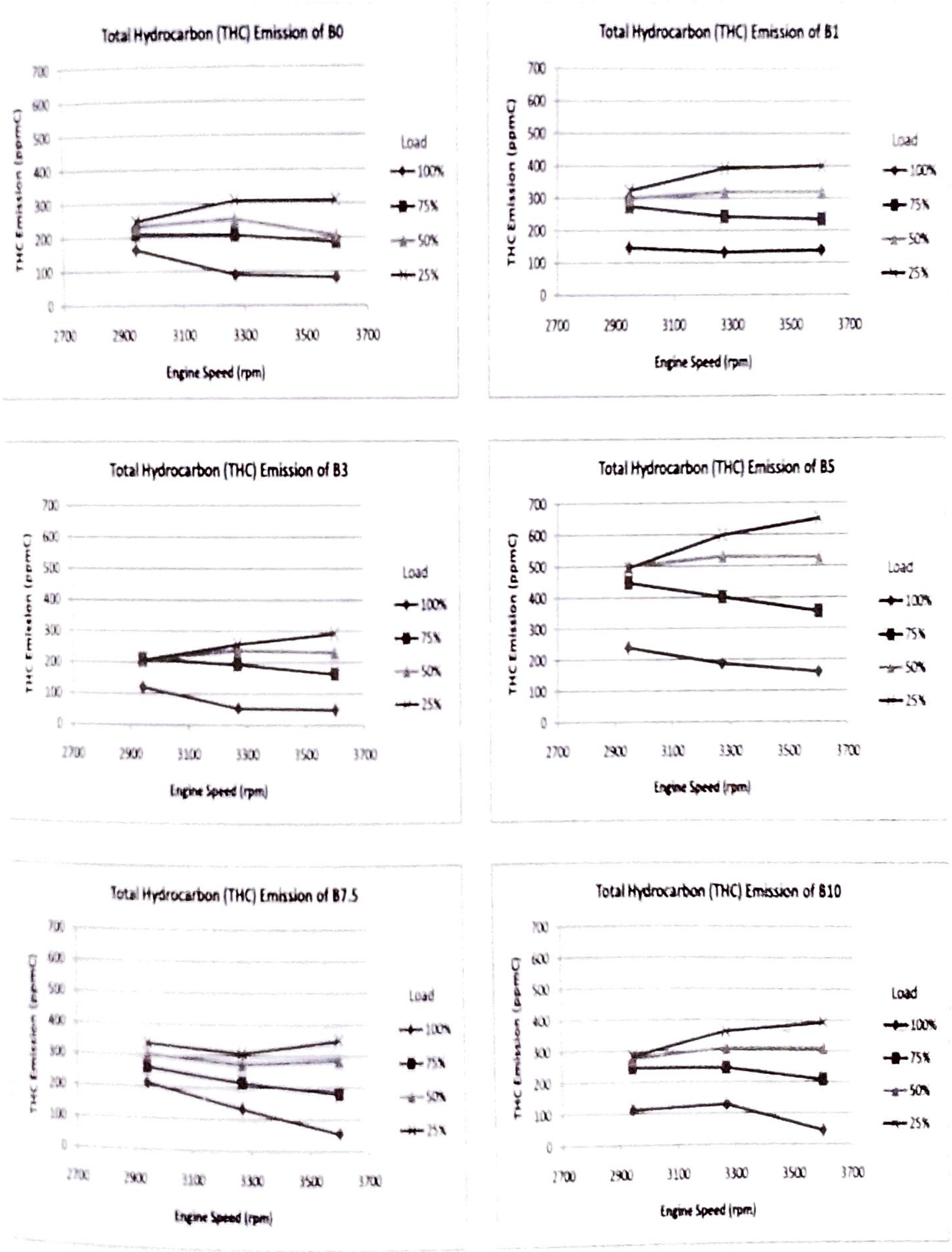


Figure 24. Total hydrocarbon (THC) emission of each test fuel at different engine loads.

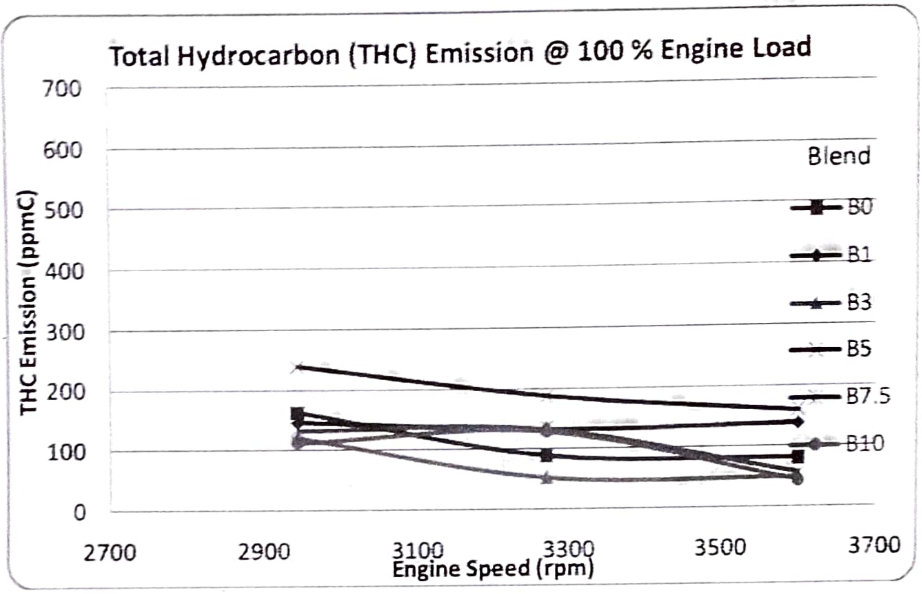


Figure 25. Total hydrocarbon (THC) emission of the test fuels at 100 % engine load.

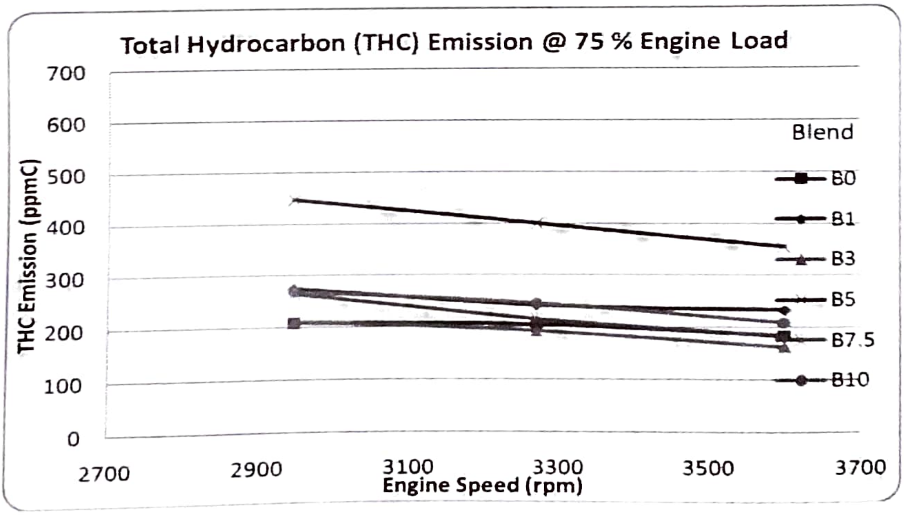


Figure 26. Total hydrocarbon (THC) emission of the test fuels at 75 % engine load.

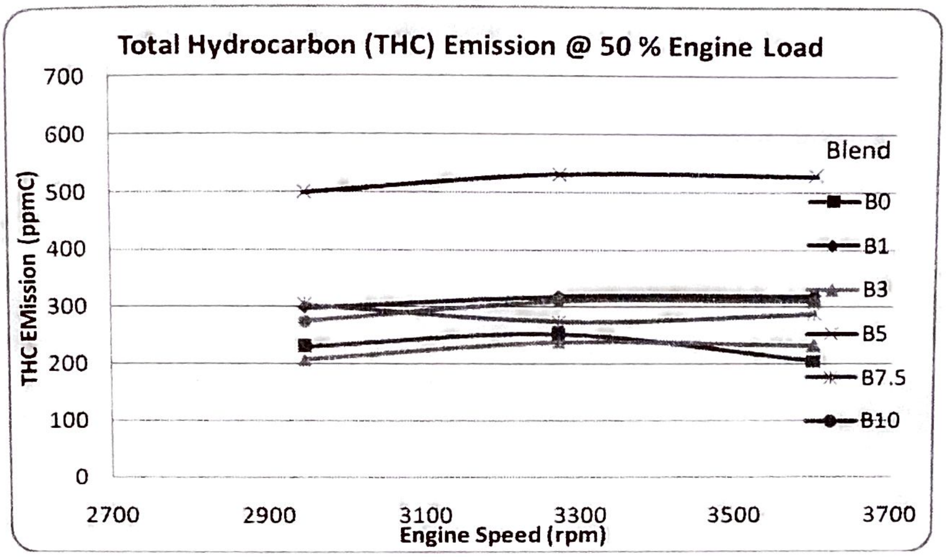


Figure 27. Total hydrocarbon (THC) emission of the test fuels at 50 % engine load.

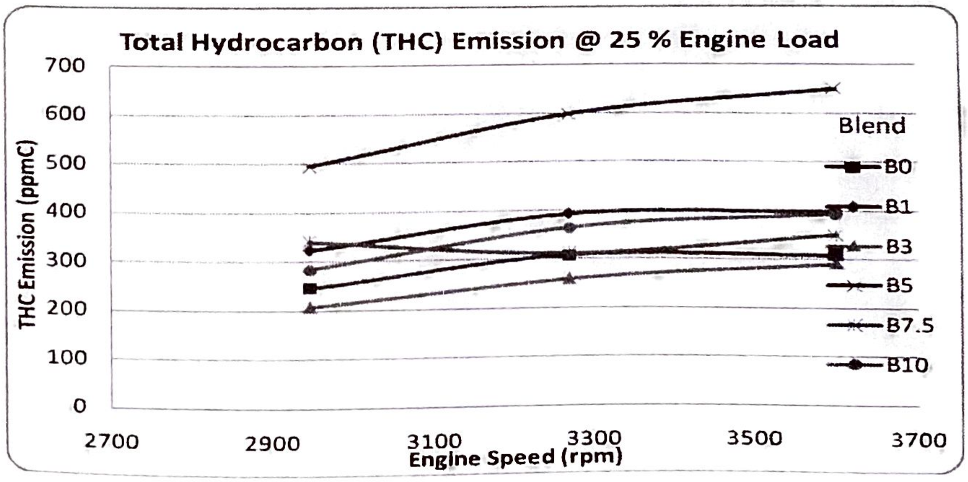


Figure 28. Total hydrocarbon (THC) emission of the test fuels at 25 % engine load.

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