Effect of Additives on Performance and Emission Characteristic of Diesel Engine Fuelled with Biodiesel

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Abstract. The depletion of fossil fuel resources and environmental pollution are two major crises that are currently faced by mankind. As the solution for the crises, an additive liquid like Tripmexx is introduced into automotive industries to increase performance of internal combustion engine, hence reducing bad emission to the environment. The objective of the study is to investigate the effect of various Tripmexx mixed into 80% diesel and 20% biodiesel (B20) with an amount of 0.1 ml (B20-0.1), 0.2ml (B20-0.2), and 0.3ml (B20-0.3) compared to conventional pure diesel. The experiment was carried out by using single cylinder, four-stroke diesel engine, and conducted with constant speed at range of 1000, 1500, and 2000 rpm with various load range from 2Nm to 6Nm. For constant speed 2000 rpm, the B20-0.3 is in lower brake specific fuel consumption value compared to the diesel fuel by 40% on average. The blend B20-0.3 produce higher brake thermal efficiency reading compared to diesel fuel by 5%. Besides, the carbon monoxide and hydrocarbon product of B20-0.3 is lower than diesel fuel by 92% and 0.002% respectively. However, the nitrogen oxide and carbon dioxide produced by B20-0.3 is higher than diesel fuel by 68% and 50% respectively. In overall, the B20-0.3 shows the best results for all measured parameters at all engine test due to consideration of green fuel.

1. Introduction
The continual use of fossil fuel resources by people in the world for transportation and industry which is involve in combustion process is a major contributor in air pollution. This may affect to unhealthy environment thus it may cause the global warming, ozone layer depletion, and jeopardize human respiratory system [1]. Moreover, air quality is a main concern to be improved to avoid air pollution to surrounding which may harmful to the human.

Alternative fuel such as biodiesel is receiving a lot of attention in the automotive industries due to the shortage in the hydrocarbon fuel source. The key issue in using vegetable oil-based fuels is oxidation stability, stoichiometric point, bio-fuel composition, antioxidants on the degradation, and much oxygen with comparing to diesel fuel [2]. So that the improvement of exhaust gas emission from biodiesel fuel engines is urgently required to meet the future stringent emission regulation. Biodiesel has higher cetane number than diesel fuel, no aromatic, almost no sulphur and contains 10-11% oxygen by weight. These
characteristics of the fuel reduce the emission of carbon monoxide (CO) and hydrocarbon (HC) in exhaust gas. In addition, higher viscosity and specific gravity are found to increase the fuel quantity, injection timing, and spray pattern will strongly influence the degree of initial premixing and combustion process [3]. Numerous emissions using biodiesel and its blends show emission concentration varies depend on source of biodiesel and engine combustion system.

Fuel additive is chemical that are used to enhance the properties of the fuel. Currently, numerous chemical additives is used in transportation to improve the quality of biodiesel fuel and diesel fuel in order to convene up the most wanted performance level [3]. Additives will help petroleum to recover its engine combustion, performance, and emission environmental standards. Various studies have proven that adding additives in biodiesel enhancing engine performance and reduce engine emissions. According to [4], the result of feasibility of pure biodiesel and blended fuel at high blending ratio using different chemical additives by different researchers which evaluated the fuel properties trend, and engine performance and emissions with different chemical additives varied of chemical additives can be utilised with biodiesel fuel to improve the fuel properties. [5] investigated on the butanol/acetane (BA)-diesel and showed that BA can improved energy efficiency and reduce emissions. Moreover, [6] studied the effect of adding graphene oxide (GO) nanoparticles into Jatropha Methyl Ester (JME) and the result showed that there are increment in brake thermal efficiency by 17% while reduction in carbon dioxide (CO), unburned hydrocarbon (UHC), and nitrogen oxide (NOx) by 60%, 50%, and 15% respectively for JME-Go blends compared to JME fuel. Furthermore, [7] analysed the effect of silver oxide (Ag2O) as an additive in various mass fractions, and the results are compared to conventional diesel. The investigation indicated that the addition of Ag2O nanoparticles into palm oil mill effluent (POME) resulted in enhancement in engine performance and reduce carbon emission [9].

The additives selection will be based upon the draw-backs of biodiesel fuel such as density, toxicity, viscosity, economic feasibility, additives solubility, auto ignition temperature, flash point, and cetane number for the fuel blending process. There are several types of additive which is mostly used in the ignition fuel which is metal based additive, oxygenated additive, cetane number improver, and antioxidant additive. Recently, [10] reported that the biodiesel stability can be obtained by using a reduced amount of additives, suggesting that biodiesel shelf life can be improved in association with a cost reduction when compared to the use of conventional antioxidants.

The objective of this study is to investigate the effect of fuel additive (Tripmexx) blended with B20 diesel-biodiesel fuel on engine performance and exhaust emission characteristics. Both were tested, evaluated, and compared with the diesel and bio-diesel fuel. In this study, Tripmexx is used as the fuel additive that acts as corrosion inhibitors or lubricant thus may create greater efficiency and power from the higher compression ratio. This additive is added into diesel-biodiesel blends in order to enhance engine performance, reduce emissions, and serve some other identified functional purpose beyond the basic fuel itself [11].

2. Methodology

In this study, the experiments were carried out using four-strokes, single-cylinder, and compression ignition (CI) diesel engine with specification as shown in Table 1. Single cylinder diesel engine test bench, Electric current dynamometer, Fuel estimation framework, voltage control and Gas Emission Analyzer mechanical assembly are utilized as shown in Figure 1. The engine type used is direct injection diesel engine with total displacement of 219cc. A 5 kW electric dynamometer is used to measure the revolution speed (rpm) and the torque from the engine.

Three phase power supply is plugged into the system. Next, the air ventilation for exhaust system, control panel and voltage control for dynamometer was set up. The engine was allowed to run about 10
minutes by using pure diesel fuel as a warm up. The exhaust port temperature was set to determine the exhaust temperature while gas analyser was set up on the exhaust tip. After exhaust temperature achieved 70℃, the gas analyser reading can be started and the data was taken after four minutes.

![Diagram of Experimental Test Rig](image)

**Figure 1.** Layout of Experimental Test Rig

**Table 1.** Test engine specifications

| Model                  | L48 Yanmar Italy            |
|------------------------|----------------------------|
| Engine type            | Air cooled, 4-cycle, vertical cylinder  |
| Fuel                   | Diesel                      |
| Combustion type        | Direct injection            |
| Engine cylinder        | 1                           |
| Total Displacement     | 219cc                       |
| BSFC at rated output   | 274gkW/hr                   |
| Max output             | 6.8kW                       |
| Engine rated speed     | 3600rpm                     |
| Bore x Stroke          | 70 x 57 (mm)                |
| Cooling system         | Forced air cooling by flywheel fan |

**Table 2.** Test Condition

| Engine Speed                        | 1000-2000 rpm (500 rpm increment) |
|-------------------------------------|-----------------------------------|
| Engine Load                         | 2, 4, 6 N.m                       |
| Time Measurement for exhaust emissions | 4 minute per testing              |
| Time for fuel consumption           | 4 minute per testing              |

The engine will be tested at constant low engine speed range of from 1000rpm, 1500rpm, and 2000rpm with variation load 2 Nm, 4 Nm and 6 Nm by using dynamometer control as shown in Table 2. Hence, exhaust gas emission for each load and fuel consumption at varied speed will be recorded after 4 minutes. Two-cylinder fuel system with valve system is used to change sample used. This procedure will be repeated by using each fuel sample.

The mass flow rate for fuel consumption, engine power and torque generated are needed for the engine performance verification. The calorific value of each sample fuel is needed for the Brake Thermal Efficiency (BTE). Calorific value of the sample fuel was determined by using bomb calorie.
BSFC implies the ratio of fuel consumption rate to the brake power output. BSFC can be used as a convenient parameter in order to assess the engine performance with varied fuel blends. To calculate BSFC, the following formula used is;

\[
BSFC = \frac{r}{P}
\]

where;

- BSFC is brake specific fuel consumption in (g/kW.h)
- \( r \) is the fuel consumption rate in kilograms per second (kg/s)
- \( P \) is the power produced in watts where \( P = \tau \omega \)
- \( \omega \) is the engine speed in radians per second (rad/s)
- \( \tau \) is engine torque in Newton meters (N.m)

BTE can be additionally used to show on how well a motor ready to change over the thermal energy to deliver a valuable mechanical work. To ascertain BTE, the formula is;

\[
\eta = \frac{BP \times 3600}{V \times cv} \times 100\%
\]

where;

- \( \eta \) is BTE in percentage (%)
- \( BP \) is the brake power
- \( V \) is the fuel’s volume flow rate (kg/s)
- \( cv \) is the calorific value (kJ/kg)

The exhaust gas analyzer, MRU Gas Analyser VARIOplus is employed to measure the percentage of gas emission from exhaust such as \( O_2, CO_2, CO, NO_x, \) and HC which give response time T90 at 30 seconds from analyser to inlet, 0.05% respectively 1ppm detection limit and both 1% FS for linearity error and repeatability. For data collection, the MRU gas analyser is allowed to run for 4 minutes for one data. The reading will be repeated for 3 times for the average value.

In this work, a fuel additive manufactured from Germany, Tripmexx is used. The additive is in a liquid form which is claimed to have oxygen rich molecule as fuel catalyst which works on the molecular level of fuel to enable better and more complete combustion to result in fuel saving, better engine performance with lesser emission of harmful gas to the environment.

3. Results and Discussion

BSFC implies the ratio of fuel consumption rate to the brake power output. BSFC can be used as a convenient parameter in order to assess the engine performance with varied fuel blends. Figure 2 shows the variations of the BSFC of different fuel blends against variation load condition at constant speed 2000 rpm which show the lowest BSFC. As shown in the graph, the BSFC of the modified blend decreased as the load condition increase from 2 Nm to 6Nm load condition. It can be clearly observed that all the diesel fuel and blend possessed lowest BSFC at the load of 6 Nm. At 6 Nm load, the diesel fuel possessed of BSFC of 396 g/kWh, while the B20-0.3 blend possessed BSFC of 264 g/kWh which is 40% lower than the diesel fuel. It showed that B20-0.3 modified blend has better BSFC than the diesel fuel at this load. The B20, B20-0.1 and B20-0.2 blends exhibited 18%, 27% and 34% respectively lower BSFC as compared with diesel fuel. B20-0.3 blend possessed the lowest BSFC at this condition at value of 264 g/kWh. Addition of Tripmexx fuel additive enriches the oxygen content in the fuel mixture, higher oxygen content will increase the compression ratio of the engine. Thus, thermal efficiency also will be increased [2]. It will result lower BSFC and meet fuel economy regulations [1].

BTE can be used to indicate on how well an engine able to convert the thermal energy to produce a useful mechanical work. Some of researches have concluded that the BTE for the biodiesel fuel was lesser than the diesel fuel characteristics. The BTE decreased as the shorter ignition delay of biodiesel and heat loss of diesel engine. BTE also will decrease with biodiesel blend because of low calorific value, higher viscosity, high volatility and poor spray properties. In this study, BTE of the biodiesel
increase as the fuel additive added into the fuel blend which promote to the increasing of engine heat due to complete combustion in the internal combustion chamber [12].

![Figure 2. BSFCs vs Loads for base fuel and its modified blends at constant speed 2000 rpm](image1)

![Figure 3. BTEs vs loads for base fuel and new formulated blends at constant speed 2000 rpm](image2)

Figure 3 shows the BTEs of the modified blends and diesel fuel against the load applied at constant speed of 2000 rpm. From the graph, the diesel fuel exhibited lowest BTE among the other blends on average 10% at 2 Nm load. This was 4% lower than the B20-0.3 blend at the same load. Moreover, the modified blends of B20, B20-0.1, and B20 0.2 improved BTE than diesel fuel on average 2%, 2.2%, and 3% at 2 Nm load. The reason behind this improvement is identical to the factors of reducing of the BSFCs. The higher compression ratio, the higher the thermal efficiency will be produced [8]. Combustion reactions will also be better due to the increases of BTE [13]. B20-0.3 blend at 6 Nm load condition gave the highest BTE in this condition which is 17%. It was 5% higher compared to the diesel fuel at the same load. Therefore, it can be concluded that the B20-0.3 give the higher BTE on average 13.2% compared with other fuel blend in all engine test.

CO is created because of incomplete combustion in the engine. CO is a colourless, odourless and poisonous gas that is promoted when the engine operates at fuel-rich equivalent ratio. It is produced when there is insufficient oxygen supply to convert all carbon to CO₂ resulting in some fuel does not get burned and some ends up as CO.
Figure 4. COs vs Loads for base fuel and its modified blends at constant speed 1500 rpm

Figure 4 exhibits the lowest CO of the tested fuel with respect to different loads at a constant speed of 1500 rpm. As shown in Figure 3.3, the CO of the tested fuels decreased as the load increased from 2Nm to 6Nm. The diesel fuels and formulated fuel possessed lowest CO at the load of 6Nm. From the graph, the diesel fuel exhibited highest CO among the other blends on average 110 ppm at 6Nm load. This was 92% higher than the B20-0.3 blends at the same load. Additionally, the modified blends of B20, B20-0.1, and B20-0.2 reduced CO than diesel fuel on average 26%, 43%, and 80% respectively at 6 Nm. The reason behind this enhancement is due to complete combustion is accomplished. The high content oxygen in the fuel helps the complete combustion reaction in the internal combustion chamber [3, 11, 13]. The CO formed is declined because CO is not product of complete combustion process. B20-0.3 produced lowest CO at constant speed 1500rpm for 6Nm of load with 9ppm. B20-0.3 possessed the lowest emission value of CO on also due to the good spray atomization and good air-fuel ratio in the internal combustion chamber [14]. In overall, B20-0.3 give the lowest value of CO on average 10% compared with other fuel blend in all engine tests.

Figure 5. CO₂s vs Loads for base fuel and its modified blends at constant speed 1500 rpm

Carbon dioxide, CO₂ is colourless and odourless gas. The natural chemical compound is consisting of a carbon atom covalently double bonded to two oxygen atoms. Figure 5 exhibits the lowest CO₂ at a constant high-speed of 1500rpm compared other speed of the tested fuels with respect to different loads. It can be clearly seen that the diesel fuel exhibited lowest CO₂ among the other fuel blends on average
0.2% at the lowest load applied. This was 68% lower than the all fuel blends at 2 Nm. As the load increased, the CO$_2$ produced is also increased. This change was due to the complete combustion in internal combustion chamber happened. Complete combustion achieved in internal combustion engine because of oxygen enrichment and lesser quantity of carbon in the fuel blends in the present of biodiesel and fuel additive [13]. CO$_2$ at the 2 Nm for diesel fuel possessed lowest value, 0.2% compared to other blends at the same load. B20-0.3 at 6Nm produced 1.0%, which is the highest percentage of this condition. Therefore, it can be concluded that B20-0.3 fuel shows the highest value of CO$_2$ emission by 0.96% on average value CO$_2$ gas emission increased as the B20 fuel mixture with Tripmex increase at every load applied.

Figure 6. HCs vs Loads for base fuel and its modified blends at constant h speed 1500 rpm

Hydrocarbons can be found in the diesel and biodiesel fuel, which are its primary source of energy. Any hydrocarbon emitted from vehicle indicates unused fuel which results from incomplete fuel combustion. Figure 6 exhibits the lowest HC at a constant speed of 1500 rpm emission of the tested fuels with respect to different loads. From the graph, the diesel fuel exhibited highest HC among the other blends on average 0.009% at 2Nm. This was 0.002% higher than the B20-0.3 and 0.003% higher than B20-0.1 and B20-0.2 blends at the same load. The B20-0.3 and B20-0.2 blends possessed lowest HC emission with 0.001% emission at 4Nm and 6Nm load applied.

The formulated fuel B20, B20-0.1, and B20-0.2 reduce HC emission than diesel fuel on average 0.005%, 0.002%, and 0.001% respectively at 6Nm load. This improvement is due to complete combustion in the internal combustion chamber. High oxygen content in the fuels helps to achieve complete combustion in the engine [3]. HC is not a product of complete combustion; thus, the emission is able to be reduced. B20-0.3 produced the lowest percentage of HC at 2Nm, 4Nm and 6Nm. Hydrocarbon emission from internal combustion engine is resulted from unburned fuel. Higher cetane number and higher oxygen quantity and can reduced the Hydrocarbon emission. The quantity of the oxygen present in the biodiesel leads to complete combustion and the higher cetane number reduces the ignition delay, as shorter the ignition delay decreases the unburned hydrocarbon [15]. Therefore, it can be concluded that the B20-0.3 give the best result with the lowest emission of HC gas which is 0.0012% on average compared with other fuel blend.
Figure 7. NOx vs loads for base fuel and new formulated blends at constant speed 1000 rpm

NOx is formed due to the engine highly rely on the temperature. The higher the combustion reaction temperature, the more diatomic nitrogen, N2 dissociates with monoatomic nitrogen, N and more NOx will be formed. Pressure, reaction temperature, residence time of combustion products, premixed portion of combustion, availabilities of oxygen, ignition delay period, heat removal rate and operational parameters of the engine is part of the NOx formation.

Figure 7 shows the lowest NOx of the tested fuels with respect to different engine loads at a constant speed of 1000rpm. The diesel fuel exhibited lowest NOx among other blends on average 6 ppm at 2Nm. This was lower than all blends at the same load. In addition, B20-0.3 blend at 6Nm produced 19ppm and increased NOx than diesel fuel on average 111%. The reason behind this improvement is due to complete combustion was achieved. The oxygen enrichment in the fuel aids the complete combustion reaction in the internal combustion chamber [3, 11, 13]. Complete combustion increasing the engine temperature and formed NOx. If the engine temperature is high, the emission of NOx will be increased. B20-0.3 at 6Nm for 1000rpm speed produced highest ppm value which is 19ppm compared to other blends for all speed. It can be concluded that fuel additive added significantly increase the formation of NOx gas. Therefore, B20-0.3 fuel blend show the higher formation of NOx which is 160ppm on average value compared with other fuel blend.

4. Conclusions and Recommendations

An inclusive study was performed to examine and understand the performance and exhaust emissions of diesel engine fuelled with diesel-biodiesel blends with different percentages of Tripmexx additives which were used on a single cylinder compression-ignition (CI) diesel engine. BSFC and BTE were measured and calculated to compare the performance characteristics of the engine. Exhaust emission such as NOx, CO, CO2, and HC were measured for each selected fuel. Below are the summarised conclusions from the findings:

- BTE was enhanced by 5% and the BSFC was decreased by 40% with the addition of Tripmexx at B20-0.3 blends. The addition of Tripmexx additive into the fuel blends showed lower BSFC and BTE than the base fuel because oxygen content for the test fuels with Tripmexx is higher than the base fuel.
- The fuel additive has been improved some of the exhaust emission characteristics where it reduced the CO and HC while the CO2 and NOx increase significantly compared with base fuel. B20-0.3 give the lowest value for both CO (10%) and HC (0.0012%) on average compared with other fuel blend in all engine tests.
- In overall, the B20-0.3 blend shows the best result for all measured parameters at all engine test compared with other blended fuel.
Moreover, some recommendation and future study that can be made which related to this research which by using other fuel additive which can be compared with this study. The advantageous and disadvantageous of two different fuels will be compared to observe the best result produced. Hence, the use of other biodiesel improved formulation of fuel blends using automatic stir system and using high calorific value, low viscosity and low volatility of biodiesel also will shows the different result to be compared with this study by using more advanced experimental apparatus which give more precise and accurate result. The experimental procedure also can be change by using high specification engine with more loads applied as a variable or at the constant load with various speed as a future study to investigate the effect of additive on its engine performance and emission characteristics.

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