Effect of Fuel Additives (Ethanol) on the Engine Performance Emissions of Single Cylinder Diesel Engine Fueled with Palm Oil Methyl Ester (PME) (B20)

Asiah Ab. Rahim1, Nik Rosli Abdullah2*, Mohamad Hafsham Mazlan2, Hazim Sharudin3 and Helmisyah Ahmad Jalaludin1

1Faculty of Mechanical Engineering, Universiti Teknologi MARA, 23200 Bukit Besi, Terengganu, Malaysia
2Faculty of Mechanical Engineering, Universiti Teknologi MARA, 40450 Shah Alam Selangor, Malaysia
3Faculty of Mechanical Engineering, Universiti Teknologi MARA, 13500 Permatang Pauh, Pulau Pinang, Malaysia

*Corresponding e-mail: nikrosli@uitm.edu.my

Abstract. Transport technology development is a major issue leading to increase the number of vehicles, hence increase emissions and contributing to global warming. In this work the effect of fuel additives (ethanol) on the engine performance and emissions of single cylinder diesel engine fueled with palm oil methyl ester (PME) (B20) were investigated. The tests were performed by varying the engine speed between 2700, 3100 and 3500 rpm with intervals 400 rpm while maintaining the engine load at 50% of rated load. In this study, different fuels which is B0 (100% Pure diesel), B20 (20% PME), E5 (20% PME + 5ml ethanol), E10 (20% PME + 10ml ethanol) and E15 (20% PME + 15ml ethanol) were used. The result indicated that, average brake specific fuel consumption (BSFC) and Brake thermal efficiency (BTE) for usage of E5, E10 and E15 were increased compare with B0 and B20. Meanwhile, average value results of Carbon Monoxide (CO) and Unburned Hydrocarbon (UHC) for E5 was lowered compare to PME (B20). The addition of ethanol with PME (B20) fuel in single cylinder diesel engine can help in controlling exhaust emission and significantly improve engine fuel consumption.

Keywords: fuel, additives, diesel engine, ethanol, palm oil

1. Introduction
Today, energy is one of the most important issues that need to resolve in order to save planet Earth because global energy demand has increased every single day. Currently, 85% of the world's energy consumption has been fueled by fossil fuels. Limited reserved of existing fossil fuels contribute to seek for alternative sources. [1]. Compression-ignition (CI) engines are widely used in the transportation, power generation, automotive, industrial and agriculture sectors due to their high energy conversion efficiency and ease of operation [2]. However, diesel engine produces high carbon emissions as diesel fuel was derived from crude oil, resulting in high carbon emissions and pollution whenever the incomplete combustion occurs during the combustion process [3]. These pollutants have tremendous effects on human, environment and ozone depletion caused to global warming. Previous studies have proven that emissions from diesel engine can cause respiratory and cardiovascular health problem [4].
In addition, a number of studies have shown that alternative fuel from renewable sources can improve engine performance and reduce exhaust emissions [5].

Biodiesel is an alternative diesel fuel consisting of an alkyl monoester of fatty acids derived from the first-generation feedstock such as vegetable oil or animal fats. Up to date, many studies have reported the use of the biodiesel on diesel engines due to its reproducibility, non-toxicity and Sulphur-free properties [6]. However, the main disadvantage of vegetable oil is its viscosity, which is considerably higher than that of conventional diesel oil. In order to overcome the problems associated with the blend of biodiesel diesel and the suitable alternative part of both diesel biodiesel, ethanol is added as the third liquid fuel along with the blend of diesel-biodiesel. Adding Ethanol into diesel-biodiesel blend can decrease the viscosity of the fuel and at the same time acts as the oxygenating mediator due to ethanol rich in oxygen content. Ethanol become the most encouraging substitute fuel because it can be produced from natural resources compared to fossil fuels produced from non-natural resources [7].

Furthermore, the use of alcohol-based fuels in petroleum fuels has increased due to benefits such as improved combustion and reduced exhaust emissions. Many researchers have researched the effect of mixing different oxygenates with diesel and biodiesel fuel since it was introduced [8]. Mixing oxygenated fuels such as ethanol with baseline fuel (diesel, biodiesel) is considered a potential solution for reducing harmful emissions worldwide as well as meeting the increasing global energy demand.

Therefore, the purpose of the current work is to study the effect of adding ethanol on engine performance and emissions of single-cylinder diesel engine fueled with Palm Oil Methyl Ester (PME) (B20). The research will focus on finding the impact of fuel additives (ethanol) on engine performance and emission of a single-cylinder diesel engine fueled with diesel-palm oil methyl ester (PME) (B20) in response to this issue.

2. Research Method

2.1. Test Fuel

Diesel fuel was supplied by a commercial fuel manufacture. Palm oil methyl ester and ethanol was supplied by local company. The five fuel samples adopted in this study are B0 (pure diesel fuel 100%), B20 [80% diesel + 20% Palm oil methyl ester (PME)], E5 (80% diesel + 20% Palm oil methyl ester (PME) + 5ml ethanol), E10 (80% diesel + 20% Palm oil methyl ester (PME) + 10ml ethanol) and E15 (80% diesel + 20% Palm oil methyl ester (PME) + 15ml ethanol). The fuel properties such as calorific value, viscosity and density were quantified. The calorific values and viscosity values were determined by using Bomb Calorimeter and Viscometer respectively.

2.2. Diesel Test Engine

For the experimental study, the Compression Ignition (CI) diesel engine setup consists of 1.5L engine powered diesel generator was used. The specifications of the engine are shown in Table 1. The engine will be coupled to industrial fan to provide load as shown in Figure 1. Test fuels were tested at 50% of rated constant load condition and with various engine speed condition between 2700 rpm, 3100 rpm and 3500 rpm with 400 rpm intervals. The test bench comprises of a diesel engine, measuring system, an industrial fan as constant load, tachometer for measuring engine speed, and gas analyzer to evaluate the exhaust emissions. Before the test, the engine was warm up with diesel fuel for about 30 minutes until the engine temperature are stabilized.

| Table 1. 1.5L Diesel engine specification. |
|-------------------------------------------|
| Item                                     | Specification                                      |
| Engine Series                            | BENMA 5GF-M Diesel Generator                       |
| Engine model                             | 5GF-M                                              |
| Engine type                              | 4 stroke, single cylinder, air-cooled diesel engine |
| Frequency (Hz)                            | 50                                                 |
2.3. **Performance and Exhaust Emission Measurement**

The most important input parameter in this study is load and speed. The data from the measuring cylinder taken to obtained fuel consumption volume for every 2 minutes for each tested fuel. The performance parameter which are brake specific fuel consumption and brake thermal efficiency calculated.

The output parameters for this experiment include exhaust emission analysis. The exhaust emission that involve in this study is Carbon Dioxide (CO2), Carbon Monoxide (CO), Unburned Hydrocarbon (UHC) and Nitrogen Oxide (NOx). For this experiment, gas analyzer (Portable Kane Automotive gas model 5-1) will be place near to the exhaust system with a nozzle placed in the exhaust. One of the ways to ensure the good data is by running the engine with applying the gas analyzer in 2 minutes and above for every run. Each experiment is run 3 times to obtain an average value of output parameters.

3. **Result and Discussion**

3.1. **Engine Performance**

3.1.1. **Brake Specific Fuel Consumptions (BSFC).** Figure 2 shows the variation of brake specific fuel consumption (BSFC) for all fuel samples with respect to the engine speed. It is seen that the BSFC for fuels with ethanol blend are higher compared to neat diesel fuel for same power output and it is steadily increasing with increase in amount of ethanol in blends. It reveals that the engine uses more ethanol blended fuel than pure diesel fuel due to an improvement in the combustion process by increasing the efficiency of the combustion chamber [4], [5], [9], [10]. The finding shows that BSFC increase is reported due to the ability of the additive as a lubricant to reduce friction in the combustion chamber [7], [11]. Average brake specific fuel consumption for usage of B20, E5, E10, and E15 was 13.86%, 24.61%, 44.61%, and 53.84% respectively higher than that of diesel fuel (B0).

Other than that, the increase in BSFC is primarily attributed to the lower calorific value of biodiesel and ethanol compared to that of pure diesel fuel [7], [12], [10]. Some researchers also have a similar view that higher BSFC for biodiesel blends are due to high viscosity and density values, respectively [3], [13], [14].

Therefore, it can be concluded that ethanol-palm oil methyl ester (E15) produce higher BSFC throughout all engine test conditions as compared with fossil diesel and palm oil methyl ester (PME) (B20). This is because of additive act as lubricant to improve the combustion process in combustion chamber [6], [10], [15].
3.1.2. Brake Thermal Efficiency (BTE). Figure 3 shows the comparison of the BTE with engine speed for the tested fuels. The average of BTE for B0, B20, E5, E10, and E15 is 25.33%, 20 %, 30.33 %, 27.33 %, and 25.33 % respectively. The BTE decrease with an increase in engine speed due to the engine exhibits high friction and heat losses as the engine speed increases [9], [16], [17], [18]. At the lower engine speed 2700 rpm, the BTE value is higher due to the improvement of the combustion process on account of increased oxygen content in the fuels [3], [12]. As a result, the combustion process is improved and thermal efficiency is improved when fuel additive is added [19]. Despite the higher BSFC of ethanol-blends, the higher BTE of the blended fuel is noticed. The justification for BTE improvement is an increase in the compression ratio due to its higher octane number in the case of ethanol blended fuel [5].

Therefore, it can be concluded that ethanol-palm oil methyl ester (E5) will increase the BTE due to the presence of more oxygen and higher latent heat of vaporization as compared to B0 and B20 without additive. It can be said that the most excellent volume of additive is 5ml blended with ethanol-palm oil methyl ester (E5) content in the fuel blends, the higher the value of BTE.
3.2. Emission Parameters

3.2.1. Carbon Monoxide (CO). Figure 4 illustrates that the variation in CO emission of the test fuel with diverse engine speed. In general, by increasing the engine speed, the percentage of CO emissions of all tested fuels is increased. As a result, all fuel additive ethanol blended with palm oil methyl ester (B20) at different volumes (5ml, 10ml and 15ml) and palm oil methyl ester (B20) of fuel provide a lower percentage of CO emissions compared to pure diesel. This can be explained by the enrichment of oxygen due to the introduction of ethanol and biodiesel, in which an increase in the proportion of oxygen would facilitate further oxidation of CO during the exhaust cycle of the engine [20], [21]. The significant reduction of CO emissions in biodiesel-ethanol blends is mainly due to the addition of ethanol, a type of oxygenated additives that promotes more complete combustion [22], [17].

Therefore, it can be concluded that CO emissions decreased with increase the fuel additive on ethanol-palm oil methyl ester (5ml, 10ml and 15ml) content. Ethanol-palm oil methyl ester blended with 5 ml (E5) additive emitted the lowest emission of CO compared to other blends. Reduction in CO contributed to lowering the harmful gases be release to the atmosphere.

![Figure 4. Graph of CO (%) against Engine Speed (rpm).](image)

3.2.2 Carbon Dioxide (CO₂). The Figure 5 shows the trend of CO₂ percentage against various engine speed for various fuel blends B0, B20, E5, E10, and E15 at constant load. As a result, the output of CO₂ for all test blends increases when the engine speed has increased from 2700 rpm to 3500 rpm. It was also shown that Ethanol-palm oil methyl ester blended 5ml (E5) fuel additive demonstrates the most reduced percentage of carbon dioxide emission over engine speed whereas ethanol-palm oil methyl ester blended 15ml (E15) appeared the highest percentage of CO₂ emission if compared with E5 and E10. It is clear that the concentration of CO₂ emission increase as the fuel additive blended on ethanol-palm oil methyl ester substance increase [14], [23]. The higher CO₂ emission of the fuel blend (E10 and E15) with the additive compared to B20 without the additive due to the presence of oxygen content in the biofuel structure. However, the presence of oxygen in fuel improves the process of combustion [13], [19], [16]. In the other hand, high CO₂ formation is due to the complete combustion of the fuel and some previous researchers agreed on these reasons [11], [21], [17].

In conclusion, the result proves that by adding the right amount of fuel additive on palm oil methyl ester and pure diesel fuel content in the fuel blends tends to reduce the percentage of carbon dioxide (CO₂) emission.
3.2.3 Unburned Hydrocarbon (UHC). Figure 6 shows the variation of unburned HC (UHC) emissions. In general, UHC emissions increase with an increase in the engine speed. Compared with Pure diesel fuel (B0), biodiesel-palm oil methyl ester (B20) and the Ethanol-palm oil methyl ester (E5, E10, E15) blends give lower UHC emissions. The UHC emissions of biodiesel decrease 50%, 35.71%, and 33.33% at the engine speed of 2700 rpm, 3100 rpm, and 3500 rpm, respectively, in comparison with pure diesel fuel (B0). The higher oxygen content of biodiesel leads to better combustion, resulting in lower UHC emissions [12], [24]. Therefore, decreased UHC emissions in the biodiesel blends are also attributed to their shorter ignition delay [6], [14]. In other words, higher cetane number and oxygen content will reduce the UHC emissions significantly as agreed by many past researchers [21].

In conclusion, ethanol-palm oil methyl ester blended with 5 ml (E5) additive emitted the lowest emission of UHC compared to other blends. Therefore, the result proves that by adding fuel additive content in the fuel blends, it tends to decrease the percentage of unburned hydrocarbon (UHC) emissions.

3.2.4 Nitrogen Oxide (NO\textsubscript{x}). The variation of oxides of nitrogen at different engine speeds is shown in Figure 7. The emissions of NO\textsubscript{x} are rising with an increase in engine speed. The NO\textsubscript{x} emissions were found to be high, 170 ppm and 250 ppm at 3500 rpm and 3100 engine speeds, respectively, for the B0
operated engine. A variety of fuel properties have been shown to have an effect on NO\textsubscript{x} emissions. This is because more fuel was injected and combusted in the cylinder as the engine speed increased, which caused higher gas temperatures and resulted in more NO\textsubscript{x} formation in the engine cylinder and higher NO\textsubscript{x} emissions from the engine [1], [22], [16]. It also shows that one of the most important reasons for NO\textsubscript{x} emissions is the combustion temperature of the engine cylinder [3]. Moreover, compared with pure diesel fuel (B0) and biodiesel-palm oil methyl ester (B20), ethanol-palm oil methyl ester (E5, E10, E15) blends give lower NO\textsubscript{x} emissions at lower engine speed 2700 rpm. Therefore, adding ethanol to biodiesel as oxygenates can enhance combustion efficiency of the fuel [22], [20].

Figure 7. Graph of NO\textsubscript{x} (ppm) against Engine Speed (rpm).

4. Conclusions

As a conclusion, the effects of various volume of fuel additive (Ethanol) (5ml, 10ml and 15 ml) on the engine performance emissions of single cylinder diesel engine fueled with Palm Oil Methyl Ester (PME) (B20) were investigated at various engine speed (2700, 3100, 3500) rpm with constant engine load (50% of rated load). Results can draw the following conclusions:

- E5 blends with 5 ml of additive showed increased value of BSFC which is 3.13% than B20 without additive at (3500 rpm, 50% of rated load) due to the properties of additive as a lubricant. E15 blended with 15 ml of additive showed the highest BSFC at all test conditions.
- This study has shown that E5 blended with 5 ml of additive indicates improvement in BTE which is 20% and 30%, B0 and B20 respectively, without additive due to the enrichment of oxygen in the blends. Thus, it promotes better combustion process.
- It was also shown that E5 blended with 5 ml additive shown the lowest emission of CO compare to others blended fuel at all test condition while B0 and B20 blended without additive resulted highest CO and UHC by 35 % and 45% respectively, compared with B0 and B20 without additive.
- The increasing fuel additive volume blended with ethanol showed lower CO, and UHC emissions than the B0 and B20 without additive.

The overall result show engine operates with fuel additive blended with E5 showed promising result in controlling exhaust gas emission and improved BSFC. Therefore, it can be considered that adding the fuel additive will improve combustion behavior inside the combustion. This will be considered as an enhanced strategy in order to improved fuel consumption and diminish exhaust emission. The objectives of this experiment are accomplished, and the ideal volume of additives is found. Hence, the aim for this project is achieved.
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