Emission characteristics of biodiesel ratios of 10%, 20%, and 30% in a single-cylinder diesel engine

Helmisyah Ahmad Jalaludin¹, Nik Rosli Abdullah², Hazim Sharudin³, A R Asiah¹, Muhammad Firdaus Jumali²

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.

*nikrosli@salam.uitm.edu.my

Abstract. This research is devoted to investigate the effects of biodiesel ratios of 10%, 20%, and 30% to the emission of single cylinder diesel engine. Fuel blends comprise of 10% (B10), 20% (B20), and 30% (B30) with adding 0.1 ml of additives to each litre of fuel blend volume are put to the test on a diesel engine, comparing each aspect to differentiate the best fuel blend. A reference experiment with 100% diesel (D100) had been done to have a clear view of the working diesel engine emissions. These blends were used for testing in a four stroke, vertical single-cylinder, air-cooled diesel engine at a constant speed of 1500 rpm as with varying engine load of 2, 4, and 6 Nm. Exhaust emissions of nitrogen oxide (NOx), carbon monoxide (CO), carbon dioxide (CO₂), and unburned hydrocarbon (HC) are taken into account. The results show that the increase biodiesel blend in fuels does increase the NOx and CO₂ emission with steady increase of load. This is because these emissions relate to the complete combustion, high post-combustion and high oxygen content increase the amount of emission. Besides, the results prove that the higher percentage of biodiesel in the blends provide lower emission of CO and HC. Lower CO and HC emission due to better combustion efficiency as it reaches better overall combustion, producing higher energy output and better emissions. Thus, the findings provide helpful information for researchers to understand the technology of biodiesel and a possible substitute for the current diesel for a better fuel source.

1. Introduction
The global energy consumption has duplicated during the recent two decades. According to the Environment Information Assessment (EIA), fossil fuels has represent over 80% of the total energy supplies in the world and it is also known as the dominant in the global energy mix [1]. Due to rapid economic development, a further increase in the utilization of energy is being expected which will resulted in the fast depletion of fossil fuel reservoirs. Within a century, oil fossil fuel storage is eventually going to run out mainly because of an ever-growing industry with the constant need of fuel. Together with the increase in fuel prices per barrel has made people trying to find cheaper and possibly cheaper alternatives from the conventional fuel. Besides, the world today also faced with a serious environment pollution and global warming. The major gas that contributes to the greenhouse phenomenon are nitrogen oxide (NOₓ) and carbon dioxide (CO₂) which is mainly emitted from the
combustion of fossil fuel. This twin crisis on the depletion of fossil fuel and environment pollution that has been an issue in the last decades leads to the search of the alternative sources of liquid fuel energy. Therefore, there is an urgent to find alternative energy fuel that is clean, renewable, and reliable.

Biodiesel is one of the environmentally and renewable friendly alternative fuels that can be used in a diesel engine with little or no modifications to the engine. The term biodiesel refers to a non-petroleum-based diesel fuel which consists of the mono-alkyl esters of long chain fatty acids. Biodiesel commonly extracted from the reaction of vegetable oil or animal fat with methanol in the presence of a catalyst. Biodiesel are expected to lower the dependency on imported petroleum that correlates to economic vulnerability, reduce greenhouse gas emissions and other pollutants, and recuperate the economy by increasing demand and prices of agricultural products [2]. Thus, biodiesel is one of the best ways to replace current fuel source that has a good potential to perform up to par and fill in the demands in case of fuel depletion. Biodiesel can effectively reduce engine-out emissions, particularly unburned HC, CO, and NOx in a typical four-stroke compression-ignition engine. This is crucial in developing an innovative way to substitute or even better, upgrade the current fuel market to be greener without sacrificing performance too much. Higher oxygen content in biodiesel will increase the overall complete combustion in the engine hence higher value of Brake Thermal Efficiency (BTE). This will also help to ensure lower Brake Specific Fuel Consumption (BSFC) which is ideal in finding an alternative fuel. Diesel-biodiesel blends significantly reduce harmful emissions and increase performance of diesel engine, so that these studies should be researched even further to help in resolving current fuel problem.

A study by Nabi et al. [3] shows that biodiesel play an important role in overall emission of diesel engines. According to the study, CO emissions with biodiesel were found to be 11-51% lower relative to the reference diesel. The difference of particulate matter (PM) and particle number (PN) between biodiesels and conventional diesels are also being observed in the study. The result reported that there are reductions in PM and PN emissions with biodiesel blend relative to those of the reference diesel. Another study by Bueno et al. [4] states that both soybean and castor biodiesel increase the CO emissions caused by the biodiesel iodine value. Castor bean or castor oil plant is one of the promising non-edible oil crops since it has low implementation and production costs and relative resistance to hydric stress. However, the result of the study shows that castor oil biodiesel blending into diesel fuel did not advance fuel injection for the engine in use and continuously increased the NOx emissions. Other authors concluded that the effect of biodiesel on NOx emissions depends on the type of engine and its operating conditions. It will be easier to analyse the engine performance results by increasing the biodiesel ratio in the blended fuel because the measurement and evaluation of blended fuel property is an important indicator [5].

However, these studies differ from the origin of the biodiesel as well as the percentage of biodiesel-diesel blend. In this research, it will particularly focus on B10, B20, and B30 from palm oil-based biodiesel-diesel blend to standardize the results later. Some researchers [3, 6-8] suggested that B20 has a better density, viscosity, flash point, and calorific value similar to conventional diesel which makes it an ideal blend ratio for this research. Therefore, this research is carried out to compare the significance between the optimum biodiesel blend and the conventional diesel in current market. Indirectly, the study wants to help users to choose their fuels wisely since it will also affect environment and health despite of nowadays economic problems.

2. Methodologies

2.1. Sample Preparation
Sample of Palm Oil Methyl Ester (POME) biodiesel fuel blends were prepared through mechanical mixing and blending (based on volume). Briefly, each biodiesel blends are added with 0.1ml additives as a wet lubricant during combustion process. A 100% diesel (D100) will be a baseline reference for this research to compare later. The test fuels were 0.9 L diesel + 0.1 L palm oil + 0.1 mL additives (B10), 0.8 L diesel + 0.2 L palm oil + 0.1 mL additives (B20), and 0.7 L diesel + 0.3 L palm oil + 0.1 mL additives (B30). Each of the mixture was stirred continuously for 30 minutes by using an electric magnetic stirrer and left for 30 minutes to reach an equilibrium at room temperature before they were subjected to any test as recommended by previous research [9].
2.2. **Measurement of Fuel Properties**

The fuel properties play a big role in analyzing the results of its performance. For this research specifically, the density, calorific value, and viscosity are needed in the explanation of the results. It aims to provide a clear understanding of the characteristics of blended biodiesel fuel with its additives. All the fuel properties of the samples as shown in Table 1 are tested out in Tribology Lab in the Faculty of Chemical Engineering, at Universiti Teknologi MARA Shah Alam.

### Table 1. Measured properties of D100, B10, B20 and B30.

| Fuel  | Density @ 15°C g/ml | Calorific value (J/kg) | Kinematic viscosity @ 40 °C mm²/s |
|-------|---------------------|------------------------|-----------------------------------|
| D100  | 0.8270              | 45500                  | 2.28                              |
| B10   | 0.8330              | 43825                  | 2.49                              |
| B20   | 0.8350              | 43375                  | 2.82                              |
| B30   | 0.8410              | 42925                  | 2.85                              |

2.3. **Engine Setup and Specification**

The engine used in this study is a natural aspirated, air cooled single cylinder diesel engine, namely the Yanmar TF-M by Yanmar Co. Ltd where Table 2 shows the specifications of the engine. An eddy dynamometer with a maximum power input of 20 kW at 2,450 rpm to 10,000 rpm will be attached to the engine. For further understandings, a schematic experimental setup of the main components in detail is presented in Figure 1. The experimental procedures in this study were conducted in the Faculty of Mechanical Engineering, at Universiti Teknologi MARA Shah Alam.

### Table 2: The Yanmar TF-M diesel engine specifications

| Descriptions                  | Specifications |
|-------------------------------|----------------|
| No. of Cylinder               | 1              |
| Bore x Stroke (mm)            | 70x57          |
| Displacement (liter)          | 0.219          |
| Fuel Tank Capacity (liter)    | 2.4            |
| Continuous Rated Output       |                |
| Engine Speed rpm (min⁻¹)      | 3600           |
| Output kW(hp)                 | 3.1 (4.2)      |
| Maximum Rated Output          |                |
| Engine Speed rpm (min⁻¹)      | 3600           |
| Output kW(hp)                 | 3.5 (4.7)      |

The analysis of exhaust emission is carried out by using a BOSH BEA-350 exhaust gas analyser to detect output of CO, CO2, HC, and NOx. The gas analyser is calibrated by the supplier company to assure the accuracy of the data collection. For the engine test operation conditions, the speed of the engine will be at a constant speed of 1500rpm with variation of engine load range of from 2, 4, and 6Nm. The engine is ran approximately for ten minutes with diesel fuel before the test, and the fuel is changed for the next test to ensure no traces of remaining previous fuel blend in the system, so that accuracy and consistency of measurement data could be achieved. Furthermore, the engine fuel tests were repeated three times for each fuel at the specified test conditions in order to have a reliable measurement.
3. Results and Discussion

3.1. Nitrogen Oxide Emission, NOx
The generation of nitrogen oxide (NOx) emissions is directly dependent on the temperature in the combustion chamber, lower enthalpy of vaporization and oxygen concentration [10]. Figure 2 shows the comparative results of NOx emission between base diesel (D100), 10% biodiesel blend (B10), 20% biodiesel blend (B20), and 30% biodiesel blend (B30). All biodiesel fuel blends with additive generally produce higher emissions of NOx as the higher of the engine load is applied. The results obtained shows that B10 at 2 Nm results in the increase of 55% (62 ppm), B20 an increase of 115% (86 ppm) and B30 an increase of 140% (96 ppm) as compared to D100 (40 ppm). A maximum of NOx emission by D100 at 6Nm was 112 ppm, compared to the others blends, there is an increment of 11.6% (125 ppm) using B10, increase of 16.1% (125 ppm) on B20, and 25% increase on B30 (140 ppm). Many studies suggested the cause of higher NOx emission in biodiesel blends than normal diesel fuels are due to high burned gas temperature, concentration of oxygen, and equivalence ratio.

Based on a study by Agarwal et al. [11], the increase of NOx emission over base diesel and biodiesel blends is mainly due to the high concentration of oxygen in biodiesel and blends used. According to Bueno et al. [4], cetane number is a major parameter for nitrogen oxide formation. The study also said that in low temperature such as in 2 Nm load, carbon double bonds lowers in rate of reaction that reduces the cetane number in unsaturated biodiesel, while higher temperature condition as in 6 Nm, load increase the rate of reaction and provide higher cetane number, and overall NOx emission [4]. In this study, it proves that the increment of biodiesel blend percentage in fuel does increase the NOx emission with steady increase of load.
3.2. Carbon Monoxide Emission, CO
Carbon monoxide (CO) is colorless, odorless and considered as an intermediate product of hydrocarbon combustion. CO is a gas result from insufficient amount of oxygen reacting with all the fuel’s carbon to produce CO₂, the unburned fuel is the cause of production of carbon monoxide [12]. Figure 3 shows the CO emissions for base diesel and blended biodiesel (10%, 20%, and 30%) at a constant engine speed of 1500 rpm and various engine loads. The results show that there is a slight decrement in CO emissions from using D100 to the other biodiesel blend fuels. At 2 Nm, a slight decrease has been recorded by using B10 of 11.6% (221 ppm) from using D100 (250 ppm). Furthermore, B20 gives a reduction of 12% (222 ppm) and B30 reduces for 20.8% (198 ppm) in comparison with the baseline diesel (250 ppm).

There is a slight decrease of CO emission from 4 Nm from using diesel fuel (182 ppm) to 3.8% (175 ppm) using B10, 7.1% (169 ppm) using B20, and a drop of 14.3% (156 ppm) using B30. At 6 Nm, the results show that the CO emission of D100 is at 110 ppm. Upon further experimentation and observation, B20 shows a decrement of 8.2% (101 ppm), B20 decreases by 14.5% (94 ppm), and B30 decreases as much as 45.5% (60 ppm) from using diesel fuel.

Figure 3. CO emission vs engine load at constant engine speed of 1500 rpm

All results obtained can be explained because of oxygen concentration in the biodiesel which leads to more complete combustion and results in conversion of CO to CO₂. This result is in agreement with the previous study by Nabi et al. [3], which has found that the higher the engine speed, the lower the production of CO emission due to the increase in excess air as CO formed are factored by insufficient air supply. Other researches also reported that higher percentage of biofuel in the blends can decrease the amount of CO emission. This is because oxygen is inherently present in biofuels making them easier to be burnt at higher temperature in the chambers [13]. Thus, the results prove that the higher percentage of biofuel in the blends provide lower emission of carbon monoxide.

3.3. Carbon Dioxide, CO₂
Generally, the ideal output of any combustion product of a hydrocarbon should be water and carbon dioxide (CO₂) emissions [14]. In that sense, between all the emissions, CO₂ emission should be the least concern as it contributes to less harm and can be counter-act with the increase of biodiesel crops. Figure 4 shows the variations of CO₂ emissions for base diesel and blended biodiesel (10%, 20%, and 30%) at a constant engine speed of 1500 rpm and various engine loads. The results show that biodiesel contents give higher CO₂ emissions compared to the base diesel at all engine loads. At 2 Nm, there is an increment to 0.54%, 0.82%, and 0.91% for B10, B20, and B30 respectively. The same trend of increment of CO₂ emission can be seen at all of the biodiesel fuel at every load. The maximum CO₂ emission is with B30 at all 2, 4, and 6Nm load with 0.91%, 0.97%, and 1.21% respectively.
This is mainly due to the present of oxygen content in the blended biodiesel fuels which interact with unburned carbon atoms during the combustion process, and produce greater amounts of CO$_2$. This result is in agreement with previous study which shows that the increase of biodiesel content gradually increases the percentage of CO$_2$ emission. It is due that CO$_2$ emission relates to the complete combustion, high post-combustion, and high oxygen content increases the amount of emission [15, 16].

3.4. Hydrocarbon Emission, HC

In general, unburned hydrocarbon emissions (HC) are hydrogen-carbon compound results from incomplete combustion. Combustion chamber geometry, deposits on walls, crevice volume, and engine operating parameters are also influence the HC emissions [17]. Figure 5 shows the variations of HC emissions with various engine loads at constant engine speed of 1500 rpm. The results show that D100 produces 0.009% at 2 Nm, 0.006% at 4 Nm, and 0.006% at 6 Nm of HC percentages from its emission. As seen in the Figure 5, there is a distinct decrement in comparison where B10 drops to 0.007% at 2 Nm, difference of 0.002%. Furthermore, B10 shows the same emission of 0.006%, same as the D100 results at 4 Nm but eventually drops to 0.005% at 6 Nm, a difference of 0.001% from the D100 results. B20 slightly decrease to 0.007% at 2 Nm, difference of 0.002%.

However, B20 shows the same results with base diesel and B10 at 4Nm, and base diesel at 6 Nm at 0.006%. On the other hand, B30 shows HC emission of 0.007% at 2 Nm, a difference of 0.002% with base diesel, and it expelled 0.005% at 4 Nm, a difference of 0.001 % from D100 at 4 Nm. At 6 Nm, B30 drops even lower to 0.004%, a difference of 0.002% compared to using D100. All the results obtained is in agreement with other researchers which proves that fuel blends that contain higher percentage of biodiesel would have lower HC emissions [18, 19]. Lower HC emission also suggests better combustion
efficiency as it reaches better overall combustion, producing higher energy output and better emissions. Although the numbers are small but comparing using D100 fuel and other biodiesel blends proves that the HC emissions are lower using higher percentage of biodiesel.

From these experimental investigations, it demonstrates as well that methyl ester blends biodiesel can be used as a fuel in a diesel engine without any major change in the engine [20].

4. Conclusions
This work experimentally assessed the effects of biodiesel ratios of B10, B20, and B30 to the exhaust emission in a four-stroke, vertical single-cylinder, air-cooled diesel engine at a constant engine speed of 1500 rpm and various engine loads of 2 Nm, 4 Nm, and 6 Nm. Based on the results, the following are the conclusions that can be made:

1. Increase of palm oil methyl ester biodiesel content shows a higher nitrogen oxide (NOx) and carbon dioxide (CO2) emission in comparison with diesel fuel because of its higher cylinder temperature and high concentration of oxygen.
2. Carbon monoxide (CO) emission decreases with the increment in percentage of biodiesel blends. This is due to better combustion in the chambers caused by the higher presence of oxygen in biodiesel blends.
3. The emission of unburned hydrocarbon (HC) shows a slight decrement using biodiesel blends compared to diesel fuel caused by the higher cetane numbers and better overall combustion.

References
[1] A. Sieminski, "World energy consumption 1990-2040," 2013.
[2] M. Hasan and M. Rahman, "Performance and emission characteristics of biodiesel–diesel blend and environmental and economic impacts of biodiesel production: A review," Renewable and Sustainable Energy Reviews, vol. 74, pp. 938-948, 2017.
[3] M. N. Nabi, A. Zare, F. M. Hossain, Z. D. Ristovski, and R. J. Brown, "Reductions in diesel emissions including PM and PN emissions with diesel-biodiesel blends," Journal of Cleaner Production, vol. 166, pp. 860-868, 2017.
[4] A. V. Bueno, M. P. B. Pereira, J. V. de Oliveira Pontes, F. M. T. de Luna, and C. L. Cavalcante Jr, "Performance and emissions characteristics of castor oil biodiesel fuel blends," Applied Thermal Engineering, vol. 125, pp. 559-566, 2017.
[5] M. Zaharin, N. Abdullah, G. Najafi, H. Sharudin, and T. Yusaf, "Effects of physicochemical properties of biodiesel fuel blends with alcohol on diesel engine performance and exhaust emissions: A review," Renewable and Sustainable energy reviews, vol. 79, pp. 475-493, 2017.
[6] D. N. Thoai, S. Photaworn, A. Kumar, K. Prasertsit, and C. Tongurai, "A novel chemical method for determining ester content in biodiesel," Energy Procedia, vol. 138, pp. 536-543, 2017.
[7] M. Ventura, W. Deus, J. Silva, L. Andrade, T. Catunda, and S. Lima, "Determination of the biodiesel content in diesel/biodiesel blends by using the near-near-infrared thermal lens spectroscopy," Fuel, vol. 212, pp. 309-314, 2018.
[8] J. Xue, T. E. Grift, and A. C. Hansen, "Effect of biodiesel on engine performances and emissions," Renewable and Sustainable Energy Reviews, vol. 15, pp. 1098-1116, 2011.
[9] W. Lim, T. Ooi, and H. Hong, "Study On Low Temperature Properties Of Palm Oil Methyl Esters-Petrodiesel Blends," Journal of Oil Palm Research, vol. 21, pp. 683-692, 2009.
[10] H. Sharudin, N. R. Abdullah, G. Najafi, R. Mamat, and H. Masjuki, "Investigation of the effects of iso-butanol additives on spark ignition engine fuelled with methanol-gasoline blends," Applied Thermal Engineering, vol. 114, pp. 593-600, 2017.
[11] A. K. Agarwal, J. G. Gupta, and A. Dhar, "Potential and challenges for large-scale application of biodiesel in automotive sector," Progress in Energy and Combustion Science, vol. 61, pp. 113-149, 2017.
[12] E. Jiaqiang, M. Pham, D. Zhao, Y. Deng, D. Le, W. Zuo, et al., "Effect of different technologies on combustion and emissions of the diesel engine fueled with biodiesel: A review," Renewable and Sustainable Energy Reviews, vol. 80, pp. 620-647, 2017.
[13] E. Buyukkaya, "Effects of biodiesel on a DI diesel engine performance, emission and combustion characteristics," *Fuel*, vol. 89, pp. 3099-3105, 2010.

[14] G. Knothe and L. F. Razon, "Biodiesel fuels," *Progress in Energy and Combustion Science*, vol. 58, pp. 36-59, 2017.

[15] H. Bayındır, M. Z. Işık, Z. Argunhan, H. L. Yücel, and H. Aydin, "Combustion, performance and emissions of a diesel power generator fueled with biodiesel-kerosene and biodiesel-kerosene-diesel blends," *Energy*, vol. 123, pp. 241-251, 2017.

[16] G. Najafi, "Diesel engine combustion characteristics using nano-particles in biodiesel-diesel blends," *Fuel*, vol. 212, pp. 668-678, 2018.

[17] V. Ganesan, *Internal Combustion Engines*: McGraw-Hill Education, 2012.

[18] H. Sharudin, N. R. Abdullah, A. Mamat, M. Zaharin, S. Alam, and M. A. Asiah, "Experimental Investigation on Physicochemical Properties of Iso-Butanol Additive in Methanol-Gasoline Blends," 2017.

[19] N.R. Abdullah, Z. Michael, AR Asiah, AJ Helmisyah, S. Buang, Effects of Palm Oil Methyl Ester (POME) on fuel consumption and exhaust emissions of diesel engine operating with blended fuel (fossil fuel+ Jatropha oil methyl ester (JOME)), Jurnal Teknologi, vol. 76(5), 2015.

[20] G. Goga, B.S. Chauhan, S.K. Mahla, H.M. Cho, Performance and Emission Characteristics of Diesel Engine Fueled with Rice Bran Biodiesel and n-butanol, Energy Reports 5 (2019), p78-83.