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Engine Emissions Analysis of Emulsified Fuel of Different Blend Ratios

To cite this article: Hazman Abu Hassan *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1062** 012016

Engine Emissions Analysis of Emulsified Fuel of Different Blend Ratios

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Abstract. Diesel engines are widely used because of their fuel efficiency in producing a higher mechanical energy ratio compared to gasoline engines. The current study is an extension of these efforts where diesel and biodiesel blend are modified to emulsify and oxygenate through water and alcohol to reduce NO_x emissions from the exhaust. Biodiesel on the other hand, has the advantage of being sulfur-free, which reduces the emission of smoke and particulate matters but unfortunately increases NO_x emissions. Meanwhile, emulsion fuel is found to lower the temperature of the cylinder during combustion and thus, reduce the release of NO_x gas. The oxygenated fuels are tested for their emission behaviors in a four-stroke, single cylinder, water cooled, and direct fuel injection engine evaluated at a speed of 1200 rpm until 2400 rpm with the engine load varied at 0%, 50% and 100%. The method of fuel oxygenation and their effect on the concentration of NO_x are discussed. The results have demonstrated a significant reduction in the NO_x emission with an increase in the fraction ratio of palm oil biodiesel. The competition to produce high-performance and environmentally friendly fuels has made emulsion fuel and biodiesel renewable fuels believed to be new alternative fuels that emit very little NO_x emissions into the atmosphere.

Keywords: diesel engine, emissions, biodiesel, emulsion fuel,

1. Introduction

Over the years, the diesel engine has undergone many evolutions leading to a more superior engine performance. Despite the simplicity of the diesel engine design, the problem of NO_x can cause health problems especially to large−scale residents of industries and vehicles using diesel engines. Diesel engine is a notably important contributor to the advancement of the global economy and wellbeing of society while not neglecting its impact on pollutants consequent from the combustion of diesel fuel [1]. The emissions by the fossil-based fuels have shown to damage all the treasures of nature. Naturally, the diesel fuel emits PM (particulate matter), THC (total gaseous hydrocarbon), SO_x (sulphur oxides), CO_2 (carbon dioxides), NO_x (nitrogen dioxide) and CO (carbon monoxide). Moreover, the diesel also emits smoke that harms the air by turning into acid rain and global warming [2]. The cause for the major emissions mainly NO_x, PM and THC are the deficiency of oxygen in the combustion process and the presence of aromatics in diesel fuel [3]. Besides, the combustion process in diesel engine which is best represented as heterogenous where the fuel reaches the oxidizer by diffusion. This causes the flame to travel slowly unlike to the premixed combustion.

Numerous studies have focused on solving issues related to pollution through producing various alternative fuels, engine design modifiers and treatment after engine combustion by applying technological advancements [4, 5]. In recent years, there has been increased attention on the oxygenated fuels because oxygen helps in deep burning and reduces NO_x emissions [6]. The method based on fuel study containing oxygen has become popular because it does not require a change in the diesel engine hardware. Challenges and pollution threats caused by diesel fuels are anticipated to be handled by producing alternative fuels that contain oxygen and that can facilitate the diffusion process [7-9]. As such, oxygenated fuel is a fuel that contains oxygen in its chemical structure [10, 11], where it can reduce carbon monoxide and soot due to complete combustion [12, 13]. Mostly, oxygenated fuels have positive effects on properties such as viscosity, density and cetane number by stabilizing temperature and reducing NO_x product [14, 15].

Fuel modification through blending has been subject to research since the time researchers found the limitation with biofuels to serve as standalone energy source in diesel engine. Blending of two or more fuels is the process of mixing diesel fuel with other naturally miscible liquid fuels to produce new fuel with a different fuel property to its parent fuels and that can provide better engine performance, reduce pollution and cost-efficient effect [16-19]. The method based on fuel study containing oxygen has become popular because it does not require a change in the diesel engine hardware. The demand for biodiesel and biofuels has been growing rapidly since the year 2000. There have been many researches on the blend of diesel with biodiesel [16-18], diesel with alcohols [8, 20-22] and three blends of diesel, biodiesel and alcohols [23, 24]. Biodiesel has many advantages in which the plant does not contain sulphur and the presence of high oxygen content [25]. The oxygen content in biodiesel promotes combustion, and this will further enhance the efficiency of the engine. Biodiesel also has higher cetane number than diesel, which causes the biodiesel to be more combustible and reduce the ignition delay time. Biodiesel is also readily available in Asian countries, especially in Malaysia and Indonesia. Similarly, alcohols are known with their higher oxygen content originally bio-based fuels. Besides, alcohols are known with their higher latent heat of vaporization. However, attaining a stable blend is the challenge.

Several researchers have demonstrated that the experiments on the blended fuel for investigating the characteristics of fuel extraction obtained from ethanol-aviation kerosene revealed the positive outcome. Mainly spray tip penetration, spray cone angle and spray area injection increased the extra performance [22]. Another study has shown that the blended fuel had better performance compared to a triple mixture of diesel/butanol/biodiesel blend, where there was an improvement in a flame tube boiler [26]. On the other hand, Ali Keskin et al. have indicated that mixing of diesel fuel-biodiesel blends with palladium and acetylferrocene has resulted in the reduction of pollution such as particulate matter [27]. Physical properties of fuel are crucial in influencing the combustion, performance and emissions of the engine. It is essential to look into the physical properties of different fuel blends and their impacts on the behavior of engine combustion. Despite the improvement on the performance and emissions of CO and PM, biodiesel have negative impact on the NO_x emissions due to an increase in the combustion temperature in the combustion chamber. Similarly, alcohols have specific only improving NO_x emission by reducing the combustion temperature. This is at the expense of the performance of the engine.

There have been recent efforts to extend the intervention of fuel blends in tackling all the emissions while not affecting the performance of the engine. This was further intensified through the recent discovery of micro−explosion phenomenon in the combustion chamber through the emulsification of different boiling temperature liquid fuels [28, 29]. An addition of alcohols or water into diesel and biodiesel blends has shown through an emulsification technique has shown improvements on emissions of NO_x while improving the performance of the engine [30-32]. Despite the availability of research findings on the double impact of the emulsified fuels, there is limited research on the effect of the emulsified fuel mainly on the NO_x reduction in quantity and its effect on the environmental pollution. Therefore, the primary aim of this study is to investigate the NO_x of diesel, biodiesel and water in biodiesel. The goal is to investigate four new alternative fuels that can produce the minimum hazardous smoke.

2. Experimental Detail

2.1. Material and Method of Blend Preparation

A single cylinder diesel engine is utilized in this investigation. The engine test rig platform and sampling system of this four-stroke engine with water−cooled and direct fuel injection is illustrated in Figure 1. An eddy current dynamometer with a power of 15 kW is used in this study. Meanwhile, a dynamometer controller is used to control engine speed and torque. Table 1 shows the specifications for the diesel engine that was used. The operating temperature of the air intake is at 2.5± 0.5 °C with the temperature of the lab controlled by the fan. There are two main types of fuel used in the study, namely diesel and biodiesel. Diesel fuel is obtained from Universiti Malaysia Pahang's lab and biodiesel fuel obtained from Mission Biotechnologies Sdn. Bhd. All fuels have been certified to comply with EN 14214 standards. The engine oil lubricant used is the Delta Super HD40 German Technology.

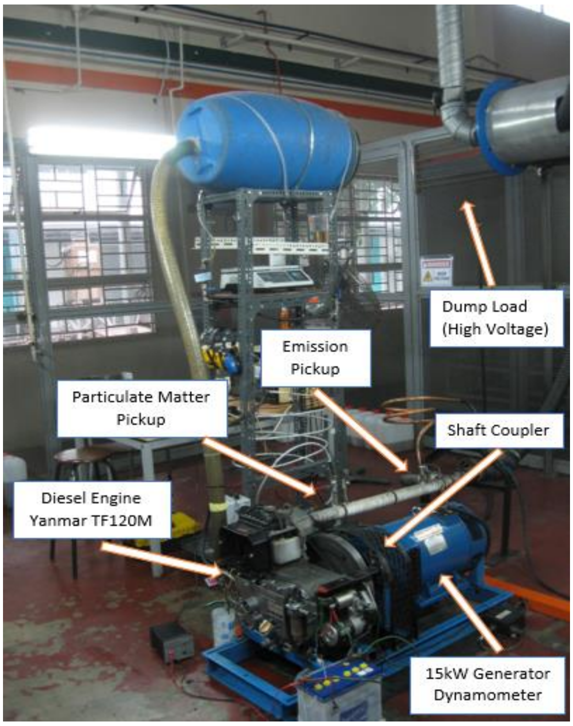

Figure 1. Engine test rig

Table 1. Specification of YANMAR TF120M.

Engine parameters	Specifications
Engine type	Diesel 1-cylinder
Stroke type	Four – stroke
Cylinder bore x stroke (mm)	92 x 96
Injection timing (deg.)	btdc 17°
Compression ratio	17.7
Displacement (L)	0.638
Maximum torque (kgf.m / rpm)	4.42 / 1800
Specific fuel consumption (g /kWh)	169
Fuel injection pump	Bosch Type
Injection pressure (Nm)	200

IOP Conf. Series: Materials Science and Engineering 1062 (2021) 012016 doi:10.1088/1757-899X/1062/1/012016

2.2. *Test Fuels and Experimental Procedures*

The preparation of fuel requires carefulness and sensitivity as it can affect the new fuel properties. The right tools are used to mix fuel and test the properties of diesel-based fuels comprising B5M10, B10M10, B5M10E3 and B10M10E3. Fuel test is performed to determine the following properties such as: cetane number, density, viscosity, boiling point calorific value, flash point and moisture content. All test equipment and methods of property analysis will be explained in this section.

The biodiesel used in the current study is palm oil-based biodiesel also known as POME, supplied by a local industrial supplier from Selangor, Malaysia. A commercial fuel supplier provided the diesel fuel which is 100% pure diesel unlike the 7% biodiesel blended fuels available in stations. Methanol, Span 80 and Tween 80 were obtained from the chemistry laboratory of Universiti Malaysia Pahang. Biodiesel blends can be produced by mixing diesel fuel and biodiesel fuel with the help of a magnetic stirrer. The mix was done in a closed beaker for 20 minutes at speed of 600−620 rpm and left at room temperature for 30 minutes. The emulsification process was conducted by an ultrasonic emulsifier in the presence of a surfactant. In addition to the diesel fuel (DIESEL), a methanol emulsion of 10% by volume was added into both palm oil biodiesel and mineral diesel fuel, which correspond to B5M10 and B10M10 fuels, respectively.

Besides that, two emulsions of water were prepared which corresponded to B5M10E3 and B10M10E3 fuels. The emulsion mixtures require the use of a mechanical stirrer and ultrasonic horn agitators to obtain the naturally immiscible liquid by using a surfactant. This method produces stable fuel and micro−emulsion. When a micro-emulsion mixture is formed, it is expected that a micro−explosion phenomenon will occur in the combustion. Consequently, there will be an increase in the performance and reduction in emission. [33]. Figure 2 exhibits the contents of five bottles containing five types of fuels to be tested.

Figure 2. Five bottles containing five types of fuel to be tested.

B5M10E3 is also known as an emulsion fuel as it contains 5% biodiesel oil, 10% methanol, 3% water, 80% diesel and 2% surfactant. The involvement of surfactants is intended to help weaken the liquid surface tension, so that the liquid that attenuates the surface allows other liquids to enter its molecule [34]. The surfactants are required to undergo HLB balance processing (hydrophilic−lipophilic balance) before the use. There were non-ionic surfactants for Tween 80 with HLB 15 and Span 80 with HLB 4.3 being the most suitable option for this study. American Society Testing Material (ASTM) suggests that HLB 0.5%−16% is suitable for fuel, hence 2% of surfactant is considered as an option [17, 35]. The direct mixing of oil and water will deteriorate the function of the engine. This is due to the nature of the water that interacts with the iron, which will cause rust on the engine portion of the iron component [17]. This problem can be solved by ensuring the water is encapsulated in the oil employing an emulsification process called water in oil known as W/O and oil in water and water in oil called O/W/O. Oil in water and water in oil (O/W/O) has shown to be a more stable emulsion and suitable for micro−explosion phenomenon in the diesel engine. The first stage of oil in water (O/W) is a process where oil is blended into the water with a surfactant of HLB 13 to stabilise the emulsion as expressed in Equation (1) and (2) as follows:

$$\% (A) = \frac{100(x - HLB_{(B)})}{HLB_{(A)} - HLB_{(B)}} \quad (1)$$

$$\% (B) = 100 - \% (A) \quad (2)$$

Based on Equations (1) and (2), the percentage of mixtures of Tween 80 and Span 80 surfactant were included in B5M10E3 fuel and mixed with a mechanical stirrer for 20 minutes at 25 °C. The time interval for mixing was between 25 to 30 minutes. According to the ASTM standard, the ideal room temperature for the coolant material is at 25 °C. To ensure that all data obtained is true and can be taken into account, control over pressure, temperature and relative humidity is always given attention to in all the experiments that are carried out, in order to minimize the impact of environmental error. The mechanical stirrer with a power of 80 to 100 hertz and with speed of 600 to 620 rpm was employed for the first stage surfactant to produce O/W. The power of 80 hertz is essential for creating a strong force for the molecular mixture, while 600 rpm was ideal to cause the stirring of the water in a simple state according to the size and volume of the 500 ml jar. The second stage process involved using HLB 6 O/W, which was formed to be used with O/W/O to obtain better fuel emulsion stability.

The mixture of the surfactant percentage was added into B5M10E3 fuel gradually during the fuel recovery process using an ultrasonic emulsifier machine. It should be noted that the ultrasonic emulsifier machine had a power of up to 24 kHz to break the surface tension molecules to ensure optimum mixing of water and fuel. Cycle 0.6 was selected as it provides the appropriate mix of impact. Moreover, amplitude of 70 was selected due to the medium strength of the medium−sized power 500 ml jar, which incorporated O/W into O/W/O with 10 minutes of operation time. The temperature of the fuel sample increases with the increase in the duration of the ultrasonic emulsification process. Furthermore, the recommended loading time was between 5−20 minutes depending on the size of the jar and the requirements for the sample rate. After the emulsification process, the fuel was processed slowly under the stirrer mechanical gauze for 10 minutes for gentle mixing of the molecular composition. It should be noted that B10M10E3 emulsion fuel requires similar processing to B5M10E3.

3. Result and Discussion

3.1. Properties of the test fuels

It has been noted from different research that the performance and emissions improvement with different alternative fuels is directly linked to the change on the physicochemical properties of the modified fuels [36, 37]. Table 2 demonstrates the results of fuel properties obtained from different experiments. The properties considered in the current study are cetane number, calorific value, the density at 25ºC, kinematic viscosity at 40ºC, flashpoint and boiling point. There are five fuels as a test sample and diesel is taken to be as reference base fuel. The experiment was conducted three times on average, and the tabulated result is the average. Each fuel characteristic affects the combustion behaviour in the combustion chamber, which consequently influences NO_xemission and performance.

Table 2. The fuel properties of five different fuels

Properties		Fuel				
	Unit	Diesel	B5M10	B10M10	B5M10E3	B10M10E3
Cetane Number	-	50	51.6	51.9	52.3	53.9
Calorific Value	MJ/kg	42.7	34.22	35.27	41.69	42.74
Density at 25°C	g/cm³	0.84	0.86	0.84	0.92	0.83

Kinematic Viscosity at 40°C	mm²/s	5	5.69	5.71	5.25	5.25
Flashpoint	°C	80	100-105	95-100	90-95	105-110
Boiling Point	°C	149	208.2	191.7	105.2	73

3.2. Analysis of the NO_x Concentration

NO_x is composed of Nitric oxide (NO) and nitrogen dioxide (NO_2), and its formation mainly depends on the peak temperature, engine design, stoichiometry, ignition delay and operating conditions. The trend for NO_x is low at 1200 rpm followed by a dramatic increase until it reached 1800 rpm due to an increase in thermal efficiency in the combustion chamber. After that, NO_x decreased steadily from 1800 rpm to 2400 rpm due to incomplete combustion which lowers the temperature in the combustion chamber. Figure 3 shows that at 2400 rpm and low load condition, NO_x for B5M10, B10M10, B5M10E3 and B10M10E3 fuels is low compared to diesel with percentages of 7%, 3%, 12.28% and 8.77% respectively. NO_x range varied between 42 ppm and 73 ppm with B5M10E3 being the lowest due to low biodegradability. B5M10E3 and B10M10E3 have lower NO_x emissions compared to B5M10 and B10M10 due to micro-explosion phenomenon which helps burn fuel perfectly and reduce the temperature in the combustion chamber. Similarly, evaporation of droplets will also reduce the temperature in the combustion chamber and assist in the reduction of NO_x emissions [38, 39]. The presence of many oxygen molecules in the combustion chamber will help increase combustion activity and increase temperature thereby causing high NO_x formation [40]. NO_x is largely formed in palm oil biodiesel compared to diesel at constant speeds and different loads.

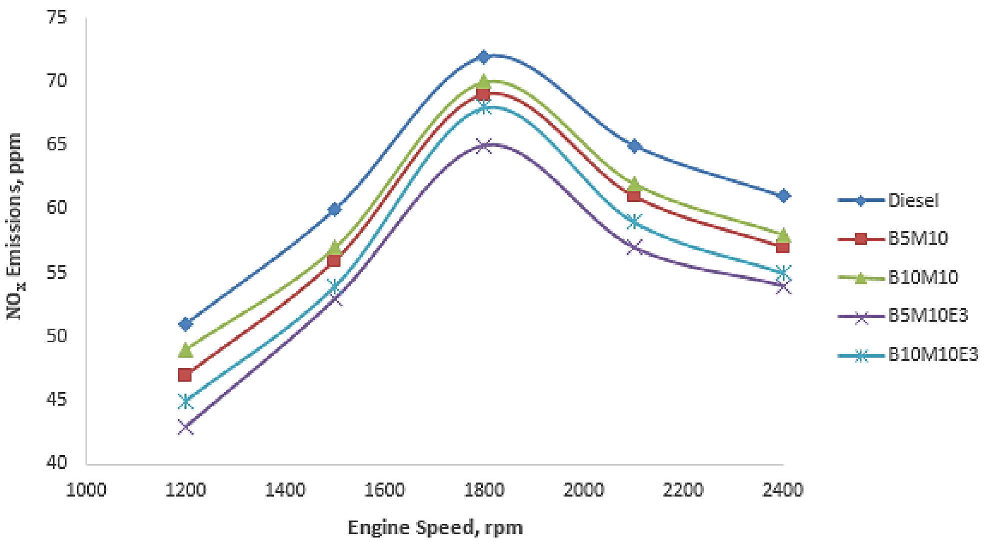

Figure 3. Measured NO_x emissions at low load and various engine speeds using diesel, B5M10, B10M10, B5M10E3 and B10M10E3 and the deviations in NO_x emissions compared to the diesel engine data

At partial load condition and engine speed at 1200 rpm, NO_x slightly increased until it reached 1800 rpm due to increased combustion efficiency. Then NO_x emissions slightly decreased from 1800 rpm to 2400 rpm due to incomplete combustion. Figure 4 shows that emissions for B5M10, B10M10, B5M10E3 and B10M10E3 fuels are low compared to diesel with percentages of 8%, 5.33%, 13.33% and 10.67% respectively. The range for NO_x varied between 57 ppm and 88 ppm with B5M10E3 being the lowest. B5M10 and B10M10 have lower NO_x emissions compared to diesel due to the addition of 10% methanol, which reduces the temperature. It has also been proven by many researchers developing biodiesel alternative fuels that NO_x emissions increase with the increase in biodiesel use [39, 41, 42]. B5M10E3 and B10M10E3 have lower NO_x compared to diesel, B5M10 and B10M10 due to the effect of water evaporation in the cylinder which helps to reduce the temperature in the combustion chamber.

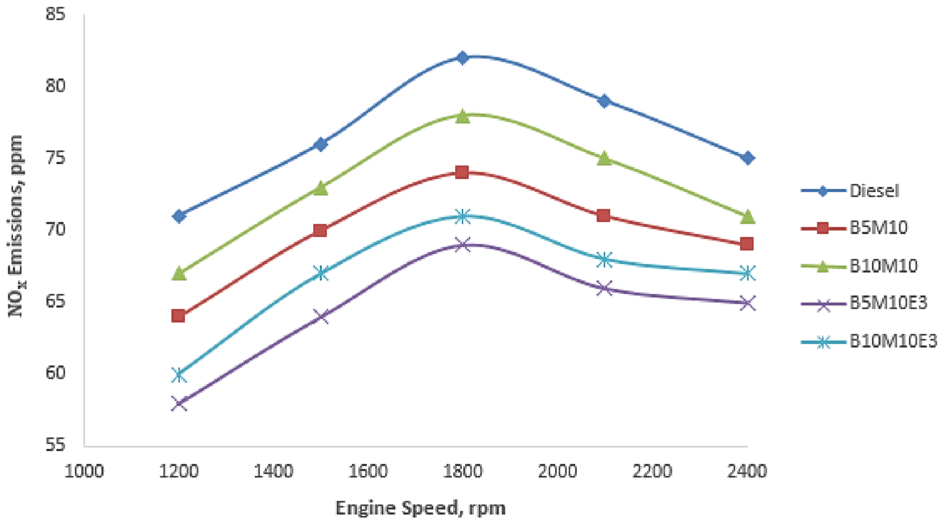

Figure 4. Measured NO_x emissions at partial load and various engine speeds using diesel, B5M10, B10M10, B5M10E3 and B10M10E3 and the deviations in NO_x emissions compared to the diesel engine data

Trend at high load found that NO_x emissions followed a steep upward trajectory from 1200 rpm until it reached 1800 rpm which is the ideal speed for maximum engine efficiency. Then NO_x emissions slowed down noticeably from 1800 rpm to 2400 rpm due to incomplete combustion. Figure 5 shows that at full load and engine speed of 1800 rpm, NO_x emissions for B5M10, B10M10, B5M10E3 and B10M10E3 are lower compared to diesel with percentages of 5.49%, 4.27%, 12.80% and 9.15% respectively. B5M10E3 and B10M10E3 fuels were found to be more able to reduce NO_x emissions compared to B5M10 and B10M 10, approximately 5.4−15% reduction. Reduction of NO_x emissions by B5M10E3 and B10M10E3 fuels is influenced by the temperature factor in the engine combustion chamber. If the temperature in the cylinder increases, NO_x emissions will also increase. Likewise, if the temperature in the cylinder decreases, NO_x emissions also decreases. B10M10 biodiesel blends produced higher NO_x emissions than the B5M10 biodiesel blends due to the fact that B10M10 has a higher oxygen content which enables a more complete combustion. To counteract high NO_x emissions, emulsion fuel is used to compensate for engine performance and lower NO_x emissions due to its 3% water content in disperse phase. Thus, there is a potential for emulsion fuels to compensate for combustion cylinder temperature and at the same time reduce the emission of NO_x [43].

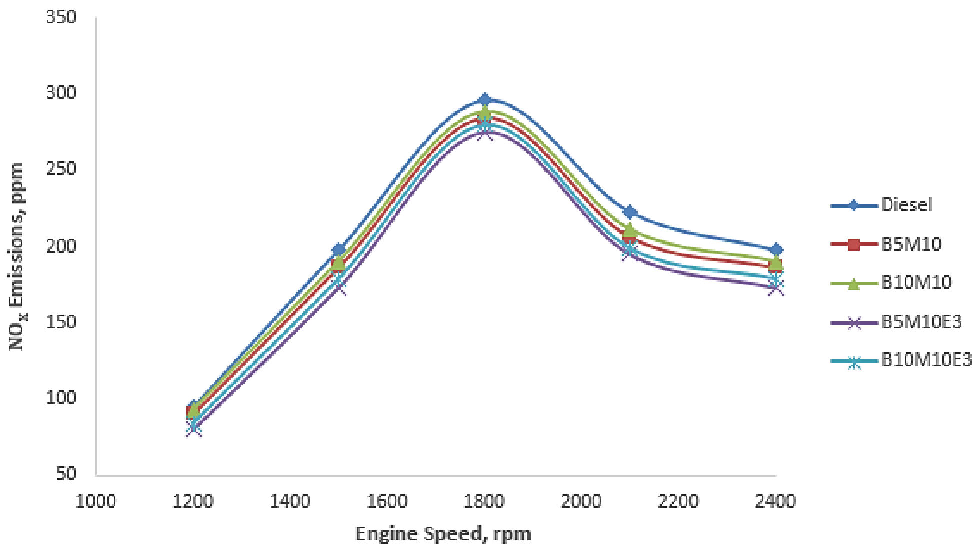

Figure 5. Measured NO_x emissions at full load and various engine speeds using diesel, B5M10, B10M10, B5M10E3 and B10M10E3 and the deviations in NO_x emissions compared to the diesel engine data.

4. Conclusions

Many countries are scrutinizing the use of the diesel engines in the transportation sector due to their negative impact in the environment. Fuel borne emissions from diesel engine which are severely compromising the environment are nitrogen oxide (NO_x). Emulsion fuel derived from palm oil showed superior engine performance and emitted low NO_xat all engine operating condition, compared to biodiesel blends and baseline mineral diesel. The water function caused B5M10E3 and B10M10E3 of collected NO_xlower than diesel, B5M10 and B10M10 at low load conditions, partial load and high load. The B5M10E3 and B10M10E3 as emulsion fuel promote to achieve an optimal temperature of the engine performance with better fuel properties which reduce NO_x.

Acknowledgments

The author would like to acknowledge the financial support by Universiti Malaysia Pahang through grant number RDU1803164 and RDU172204.

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