

Fuel Heating for Reduce Emission of Diesel Engine

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(Received: 17 April 2026 / Revised: 19 April 2026 / Accepted: 13 June 2026 / Available Online: 28 September 2026)

Abstract— Diesel engines offer the highest efficiency compared to other internal combustion engines, and are therefore widely used in industry and transport. However, exhaust emissions from the combustion of diesel fuel pose a threat to the environment and human health. As a preventive measure, research has been conducted with the aim of modifying the fuel system or combustion system to reduce exhaust emissions. The research employed an experimental approach, involving the preheating of fuel using a recovery jacket cooler before it entered the combustion chamber of a 70 kW Mitsubishi 4D30 diesel engine, which was connected to a Hofman Test Stand Type Afa 19 water brake dynamometer. Data were collected under 100% engine load conditions, with temperatures set at 30°C, 40°C, 50°C, 60°C, and 70°C, and at different speeds of 1800 rpm, 2000 rpm, and 2200 rpm. The results demonstrate that fuel preheating can reduce exhaust emissions from diesel engines.

Keywords—Fuel Heating, Emission, Diesel Engine

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I. INTRODUCTION

An internal combustion engine is a machine that generates mechanical energy from the chemical energy contained in fuel. Fuel is injected into the cylinder, where it mixes with oxygen that has been compressed by the piston, causing the pressure to rise, after which combustion takes place [1][2][3].

A diesel engine is an internal combustion engine, it is An engine that generates mechanical energy from the chemical energy contained in the fuel. The fuel is injected into the cylinder, where it mixes with oxygen that has been compressed by the piston, causing the pressure to rise and ignition to occur [1]. Diesel engines have the highest thermal efficiency compared to other internal combustion engines and other external combustion engines, as they have a very high compression ratio. Low-speed diesel engines (such as those found in ships) can achieve a thermal efficiency of over 50% [4].

Diesel engines have had a significant impact on the

transport sector; demand for diesel engines continues to rise worldwide, as they are used not only to power vehicles but also to drive industrial machinery [3][5]. Some of the advantages of diesel engines are their high efficiency and power, fuel economy, and widespread use in vehicles and heavy machinery [6].

Diesel engines produce exhaust emissions during operation, which is also a serious problem because diesel exhaust has high emission levels [7][8][9]. Exhaust emissions are harmful to the environment and human health; whilst they originate from land-based industries, they also come from the maritime sector. This issue is not merely a national concern but a global one [10][11][12].

As part of various pollution prevention measures, the IMO has set emission limits for sulphur oxides (SOx) and nitrogen oxides (NOx) from ship exhaust gases and requires the implementation of energy-efficiency measures to reduce emissions from ships [13]. Meanwhile, the World Bank sets the limit for nitrogen oxide (NOx) emissions at 940 ppm [14]. In addition, various technical approaches—such as information systems, estimation, and detection—are employed to reduce engine exhaust emissions [15][16][17][18].

Various measures have been taken, such as modifications to the fuel system, the air intake system, the combustion system, the drivetrain components (transmission), and many others, all aimed at reducing exhaust emissions [19][20][21][22]. Efforts to address this issue have led to innovations in the use of conventional fuels. One such example is the use of vegetable oil as a feedstock for diesel fuel [23].

B20 biodiesel is a blend of 20% vegetable oil and 80% diesel fuel [24]. The vegetable oil in question is a Fatty Acid Methyl Ester (FAME) product, which serves as a feedstock for biodiesel. B20 biodiesel can be used in diesel engines as a substitute for fossil fuels without the need for engine modifications. The use of B20 biodiesel as a solution helps to conserve fossil fuel reserves, improve combustion quality, and reduce environmental

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pollution [25].

Based on several existing fuel heaters, heating is carried out using a shell-and-tube heat exchanger-type fuel heater, with the innovative addition of fins to the baffle section, known as a fin baffle. The presence of the fin baffle causes the fuel flow on the shell side to slow down and undergo turbulence, thereby achieving more optimal heating.

The development of the baffle fin for a shell-and-tube heat exchanger was carried out by creating models and simulations using SolidWorks 2018 engineering software, a CAD programme developed by Dassault Systèmes. This software is used to design machined parts or assemblies of machined parts, utilising 3D visualisations to represent the parts prior to their physical manufacture, or 2D drawings to illustrate the machining process. Based on the results of the modelling and simulation, a prototype is then produced.

The prototype is fitted to a fuel heating system that operates using a heat recovery jacket cooler, whereby heat is absorbed whilst the engine is running, resulting in the engine outlet water reaching a temperature of 70°C–90°C [26]. It is estimated that around 15% of the engine's energy is lost due to the cooling process [27][28]. The hot coolant leaving the engine, before being cooled by the radiator, is used to heat the fuel via a heat exchanger.

The development of the fin baffle in the shell-and-tube heat exchanger results in higher temperatures compared to before the development. The prototype resulting from this development, when installed in a heat recovery jacket cooler, can increase the temperature of B20 biodiesel. This increase in temperature affects emission quality.

Several studies have indicated that fuel preheating also affects diesel engines, particularly in terms of exhaust gases, as it can reduce emissions such as NO_x, CO, hydrocarbons, particulates and others. One such study, conducted by [29] involved the preheating of biodiesel fuels, namely CPO, jatropha and WCO. The results obtained from this study included changes in NO_x, CO, CO₂ and HC levels. Fuel preheating was found to reduce the levels of NO_x and CO by approximately 5% during the mixing process. Fuel preheating demonstrated a reduction in emissions of carbon monoxide and hydrocarbons.[30].

Research into fuel treated with magnetic preheating has resulted in changes in exhaust emission levels. A comparison between preheated and untreated fuel shows

lower levels of CO, HC, and CO₂ [31]. Similar results were reported in a study by [32], jatropha fuel oil that had undergone preheating produced lower emission levels than jatropha fuel oil that had not undergone preheating. The test parameters were CO₂, smoke opacity, CO, and HC. Heaters or heat exchangers are generally used to heat the fuel.

Heating PO20 (B20) with a Butylated Hydroxyl Toluene (BHT) additive (2000 ppm) and butanol (20% by volume) resulted in brake specific fuel consumption 11.4% and brake thermal efficiency 5.1% higher than diesel fuel. Mixed CO emissions showed a 37.5% reduction, whilst NO_x emissions were 1.9% higher than those of diesel. Furthermore, smoke and EGT were found to be 13% and 3.1% lower, respectively, compared to diesel fuel. Furthermore [33] states that a diesel fuel heating system utilising engine coolant demonstrates energy efficiency and represents a long-term solution for energy savings. The schematic is shown in Figure 2.21.

The research findings indicate that a preheated E20 blend (20% ethanol and 80% diesel) achieves a higher thermal efficiency of 36.28% and results in a significant reduction in specific fuel consumption, as well as reducing emissions of carbon monoxide, unburned hydrocarbons, and smoke by 49%, 48% and 10% respectively, whilst NO_x emissions increased by 6%. Furthermore, preheating the fuel resulted in improved combustion, namely a significant reduction in the ignition delay period.

II. METHOD

Equipment and materials

a. Specification of Diesel Engine

Merk MITSUBISHI, Power 90-95 (PS) / 66-70 (kW), Speed 3500 rpm, Type 4D30, Displacement 3298 cc, Bore x stroke 100 x 105 mm, Injection System In-direct Injection (Swirl Chamber).

b. Dynamometer

Merk HOFMAN TEST STAND, Sries 50 19670-4K9-99, System Water Brake, Type AFA 19, No. Order 24150022, Year 1982.

c. Heater

Length 270 cm, Diameter of tube out/in 0.95 cm/0.81 cm, Diameter shell out/in 5.715 cm, No. baffle 3, Model of baffle Fin, Type of flow - Contra flow

a. Gas Analyser

Merk ECOM, type J2KN, Parameter: NO, NO₂, NO_x CO₂.

valve no. 2 by 100%, and stop valve no. 3 by 100%. The solenoid valve (Normally Closed) on the water inlet line

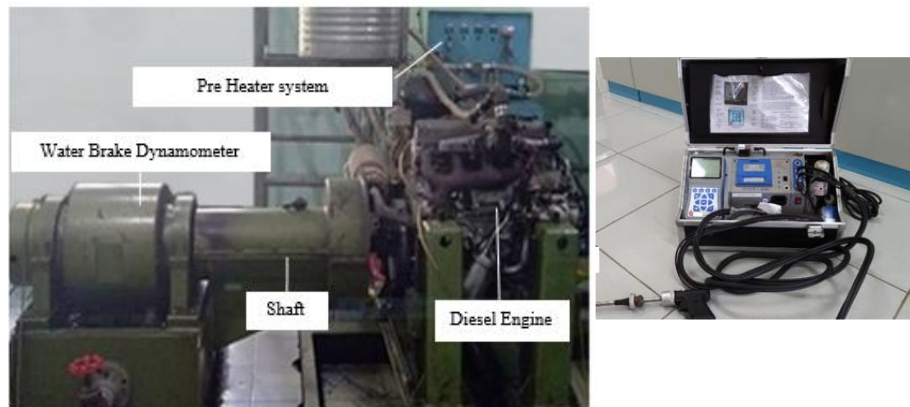


Figure 1. Sett Up Engine and Equipment

Research Procedure

Emissions testing was carried out to assess several emission characteristics, including: Nitrogen Monoxide (NO), Nitrogen Dioxide (NO₂), Nitrogen Oxides (NO_x), and Carbon Dioxide (CO₂). The diesel engine operates at varying fuel temperatures (30°C, 40°C, 50°C, 60°C, 70°C), engine speeds (1800 rpm, 2000 rpm, 2200 rpm) and a load of 100%.

Several steps were carried out during the collection of emission characteristic data, including the following:

- Step one: Before collecting emission data, the diesel engine connected to the dynamometer (Figure 1) is run for 10 minutes at 800 rpm to warm up before being loaded. During the warm-up, checks are carried out on

to the heat exchanger operates automatically in response to the fuel temperature (fuel outlet sensor). The solenoid opens when the fuel temperature is below the set point and closes once the set point is reached. The fuel heating system is shown in Figure 2.

-Step three: Once the machine is operating normally and there are no faults, proceed by gradually applying the load up to 100%. Next, set the fuel temperature to 30°C using the thermostat on the heat exchanger panel (Figure 3.19) and set the engine speed to 1800 rpm. Then, insert the gas analyzer sensor, as shown in Figure 3.23, into the designated exhaust gas port, as shown in Figure 3.24. The data collected comprises Nitrogen Monoxide (NO), Nitrogen Dioxide

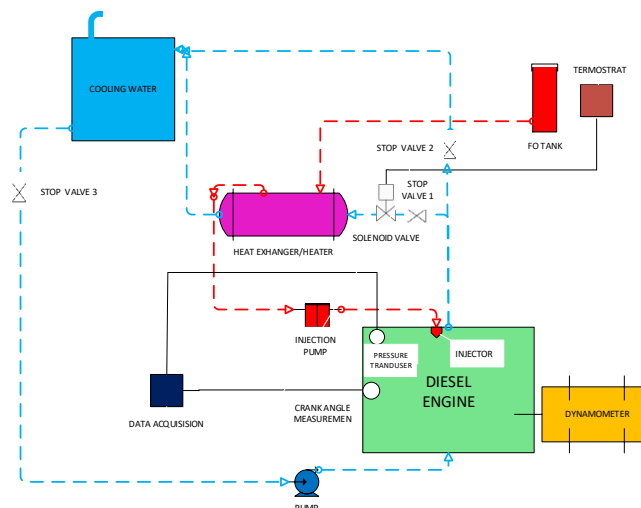


Figure 2. Scematic of Research

the engine's operating conditions, such as vibration, exhaust gas temperature, the fuel system, the engine coolant circulation, and the water brake dynamometer's water circulation. All are ensured to be in good working order so that the testing process runs smoothly.

- Step two: Adjust the circulation of the jacket cooler to supply water as the heating medium for the heat exchanger by opening stop valve no. 1 by 50%, stop

(NO₂), Nitrogen Oxides (NO_x), and Carbon Dioxide (CO₂). At the same time, emission dust samples were taken by inserting a sensor into the end of the exhaust pipe, as shown in Figure 2, using an emission dust testing device as shown in Figure 1.

After completing the data collection at 1800 rpm, the process continued with data collection at 2000 rpm and 2200 rpm. Exhaust gas emission data were collected

using an ECOM J2KN gas analyzer at temperatures of 40°C, 50°C, 60°C, and 70°C, following the same procedure as in the third step—namely, the test conducted at 30°C. At 100% load, with engine speeds of 1800 rpm, 2000 rpm, and 2200 rpm. The correction factor limits for the exhaust gas emission test are as follows: Gas volume is measured under standard conditions (25°C and 1 atmosphere pressure), and all parameters are corrected for an O₂ content of 13%. Meanwhile, for particulate emissions, SNI 19-7177.12-2005 is used, whereby the mass of particles contained in 1 m³ of dry exhaust gas is corrected to standard conditions (25°C, 760 mmHg), in units of g/Nm³

III. RESULTS AND DISCUSSION

The emission data were obtained by conducting experiments on a Mitsubishi 4D30 diesel engine with four cylinders, operating at 100% load and at engine speeds of 1800, 2000, and 2200 rpm, using B20 biodiesel. Data was collected using an ECOM J2KN gas analyser. The exhaust emission tests yielded several parameters, including:

a. Nitric Monoxide (NO) Levels

At a temperature of 40°C, the nitrogen monoxide (NO) concentration at 1800 RPM is 42 ppm; at 2000 RPM, it drops to 22 ppm; and at 2200 RPM, it further decreases to 16 ppm. At a temperature of 50°C, the nitrogen monoxide (NO) concentration at 1800 RPM was 16.5 ppm; at 2000 RPM, it fell to 10 ppm; and at 2200 RPM, it increased to 11.5 ppm. At a temperature of 60°C, the nitrogen monoxide (NO) concentration at 1800 RPM is 24 ppm; at 2000 RPM, it rises to 48 ppm; and at 2200 RPM, it decreases to 24 ppm. At a temperature of 70°C, the nitrogen monoxide (NO) concentration at 1800 RPM is 14 ppm; at 2000 RPM, it increases to 16.5 ppm; and at 2200 RPM, it decreases to 16 ppm.

From the above analysis, it can be concluded that the highest nitrogen monoxide (NO) level of 48 ppm occurred at 2000 rpm at a temperature of 40°C, whilst the lowest level of 10 ppm occurred at 2000 rpm at a temperature of 50°C.

Nitrogen oxide (NO) plays a role in atmospheric chemistry, influencing the ozone cycle and the troposphere's oxidising capacity. At high concentrations (> 50 ppbv; ppbv = parts per billion by volume) or > 0.05 ppm, nitrogen oxide causes ozone in the atmospheric boundary layer to become a toxic pollutant [34]. The heating effect of the fuel results in a minimum NO concentration of 10 ppm, which is still highly likely to cause toxic pollutants.

b. Nitrogen Dioxide (NO₂) Levels

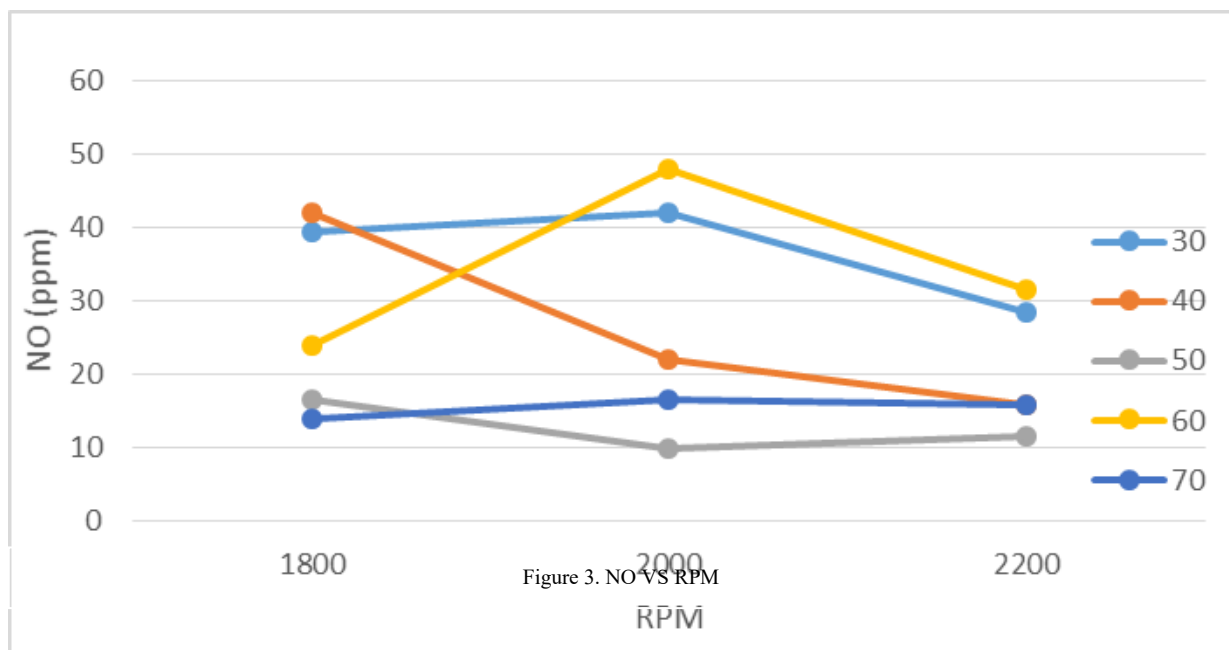


Figure 3. NO vs RPM

NO molecules are produced by pollutants resulting from the combustion of fuel; they are toxic and highly reactive. The graph in Figure 3 shows that at a temperature of 30°C, the nitrogen monoxide (NO) concentration at 1800 RPM is 39.5 ppm; at 2000 RPM, it rises to 42 ppm; and at 2200 RPM, it drops to 28.5 ppm.

Nitrogen dioxide is a chemical compound with the formula NO₂. This gas is reddish-brown in colour with a pungent odour and is a major toxic air pollutant. Nitrogen dioxide is formed and emitted from the combustion of fuels.

The graph in Figure 4 shows that at a temperature of 30°C, the nitrogen dioxide (NO₂) concentration at 1800 RPM is 11.85 ppm; at 2000 RPM, it rises to 12.6 ppm; and at 2200 RPM, it drops to 8.55 ppm. At a temperature of 40°C, the nitrogen dioxide (NO₂) concentration at 1800 RPM is 12.6 ppm; at 2000 RPM, it drops to 6.6 ppm; and at 2200 RPM, it further decreases to 4.8 ppm.

At a temperature of 50°C, the nitrogen dioxide (NO₂) concentration at 1800 RPM was 4.95 ppm; at 2000 RPM it fell to 3 ppm; and at 2200 RPM it increased to 3.45 ppm.

showed that the highest NO₂ concentration was 24.24 mg/m³, which is still below the maximum limit and can therefore be classified as good.

c. Nitrogen Oxide

NO_x is a general term for nitrogen monoxide (NO) and nitrogen dioxide (NO₂). These gases are produced by the reaction between nitrogen and oxygen in the air during combustion, particularly at high temperatures. NO_x gases are formed wherever combustion occurs, for example, in engines.

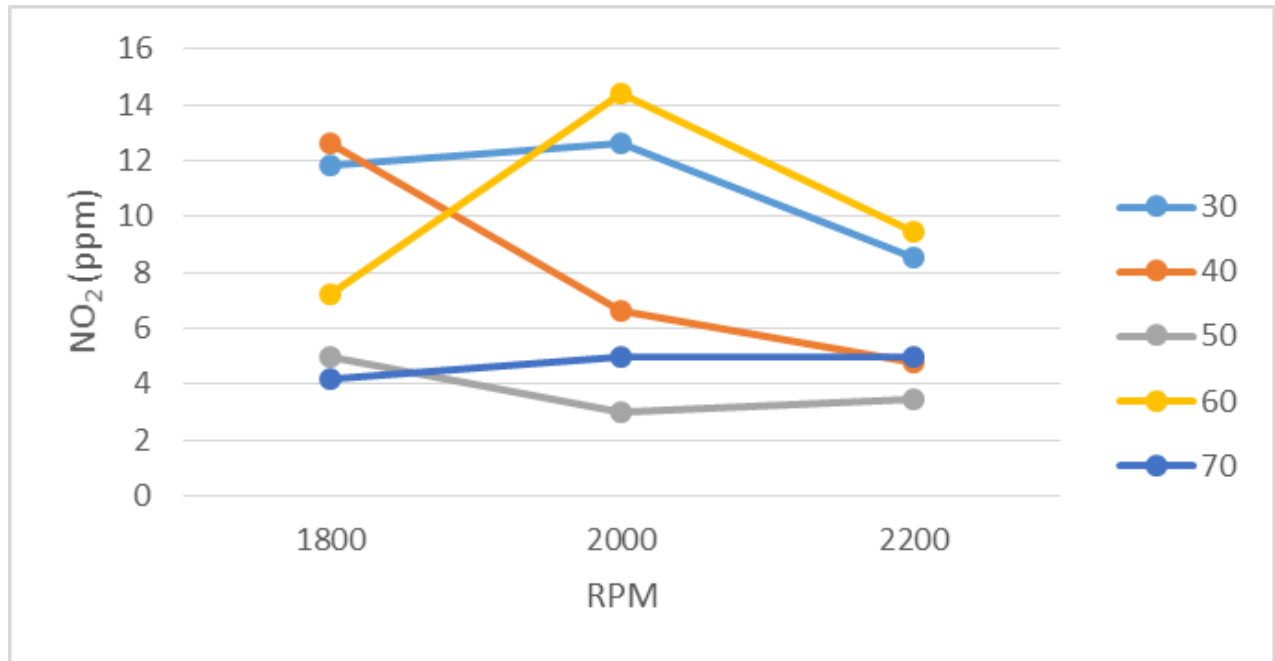


Figure 4. NO₂ VS RPM

ppm. At 60°C, the nitrogen dioxide (NO₂) concentration at 1800 RPM was 7.2 ppm; at 2000 RPM it increased to 14.4 ppm; and at 2200 RPM it decreased to 9.45 ppm. At a temperature of 70°C, the nitrogen dioxide (NO₂) concentration at 1800 RPM was 4.2 ppm; at 2000 RPM, it increased to 4.95 ppm; and at 2200 RPM, it remained unchanged at 4.95 ppm.

From the above analysis, it can be concluded that the highest nitrogen dioxide (NO₂) concentration of 14.4 ppm occurred at 2000 rpm at a temperature of 60°C, whilst the lowest nitrogen dioxide (NO₂) concentration of 3 ppm occurred at 2000 rpm at a temperature of 50°C. Referring to the maximum standard for NO₂ of 1000 mg/m³, as the test results are in ppm, they need to be converted. The test results indicate that the highest NO₂ concentration was 14.4 ppm at 60°C, with a molecular weight of 46.01, at a pressure of 1013.25 mbar; this is equivalent to 24.24 mg/m³ [35]. The test results for various combinations of fuel temperature and rpm

The graph in Figure 5 shows that at a temperature of 30°C, the nitrogen dioxide (NO_x) concentration at 1800 RPM is 51.35 ppm; at 2000 RPM, it rises to 54.6 ppm; and at 2200 RPM, it decreases to 37.05 ppm. At a temperature of 40°C, the nitrogen dioxide (NO_x) concentration at 1800 RPM is 54.6 ppm; at 2000 RPM, it drops to 28.6 ppm; and at 2200 RPM, it further decreases to 20.8 ppm.

At a temperature of 50°C, the nitrogen dioxide (NO_x) concentration at 1800 RPM was 21.45 ppm; at 2000 RPM it fell to 13 ppm; and at 2200 RPM it increased to 14.95 ppm. At a temperature of 60°C, the nitrogen dioxide (NO_x) level at 1800 RPM was 31.2 ppm; at 2000 RPM it rose to 62.4 ppm; and at 2200 RPM it fell to 40.95 ppm. At a temperature of 70°C, the nitrogen dioxide (NO_x) concentration at 1800 rpm is 18.2 ppm; at 2000 rpm, it rises to 21.45 ppm; and at 2200 rpm, it decreases to 20.95 ppm.

From the above analysis, it can be concluded that the highest nitrogen dioxide (NOx) concentration of 62.4 ppm was recorded at 2000 rpm at a temperature of 60°C,

The graph in Figure 7 shows that at a temperature of 30°C, the carbon dioxide (CO₂) concentration at 1800 RPM is 2.4%, then at 2000 RPM it drops to 1.7%, and at

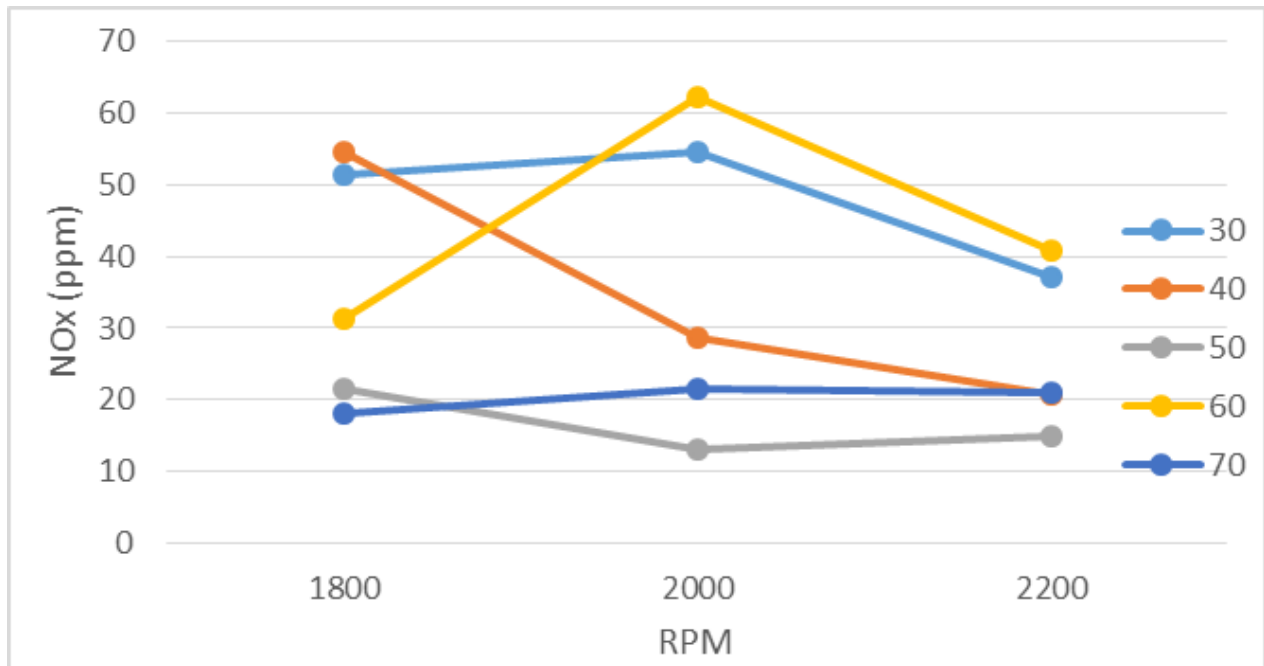


Figure 5. NOx VS RPM

whilst the lowest nitrogen dioxide (NOx) concentration of 13 ppm was recorded at 2000 rpm at a temperature of 50°C. Referring to the maximum NOx standard of 1000 mg/m³, as the test results are in ppm, they need to be converted. The test results indicate that the highest NOx concentration was 62.4 ppm at 60°C with a molecular weight of 46.006, at a pressure of 1013.25 mbar, which is equivalent to 105.01 mg/m³ [36]. Thus, it is found that the test results across various variations in fuel temperature and rpm show the highest NOx concentration of 105.01 mg/m³ remains below the maximum threshold, which can be considered satisfactory.

d. Carbon dioxide (CO₂)

Carbon dioxide, with the chemical formula CO₂ or carbonic acid, is a chemical compound consisting of two oxygen atoms covalently bonded to a carbon atom. CO₂ exists as a gas under standard temperature and pressure conditions. The results of the carbon dioxide (CO₂) test are shown in Figure 7.

2200 RPM it decreases further to 0.9%. At a temperature of 40°C, the carbon dioxide (CO₂) concentration at 1800 RPM is 1.55%, then at 2000 RPM it drops to 0.6%, and at 2200 RPM it continues to decrease to 0.35%. At a temperature of 50°C, the carbon dioxide (CO₂) concentration at 1800 RPM is 0.3%, then at 2000 RPM it remains the same at 0.3%, and at 2200 RPM it also remains the same at 0.3%. At a temperature of 60°C, the carbon dioxide (CO₂) concentration at 1800 RPM is 0.7%, then at 2000 RPM it increases to 1.4%, and at 2200 RPM it decreases to 0.8%.

At a temperature of 70°C, the carbon dioxide (CO₂) concentration at 1800 rpm is 0.3%; at 2000 rpm, it rises to 0.4%; and at 2200 rpm, it rises to 0.35%. From the above analysis, it can be concluded that the highest carbon dioxide (CO₂) concentration of 2.4% occurred at 1800 rpm at a temperature of 30°C, whilst the lowest concentration of 0.3% occurred at all rotational speeds—namely 1800 rpm, 2000 rpm, and 2200 rpm—at a temperature of 50°C.

The heating effect of B20 biodiesel can reduce emissions by up to 0.3% or 3,000 ppm. According to [37] CO₂ level > 5,000 ppm indicates unusual or

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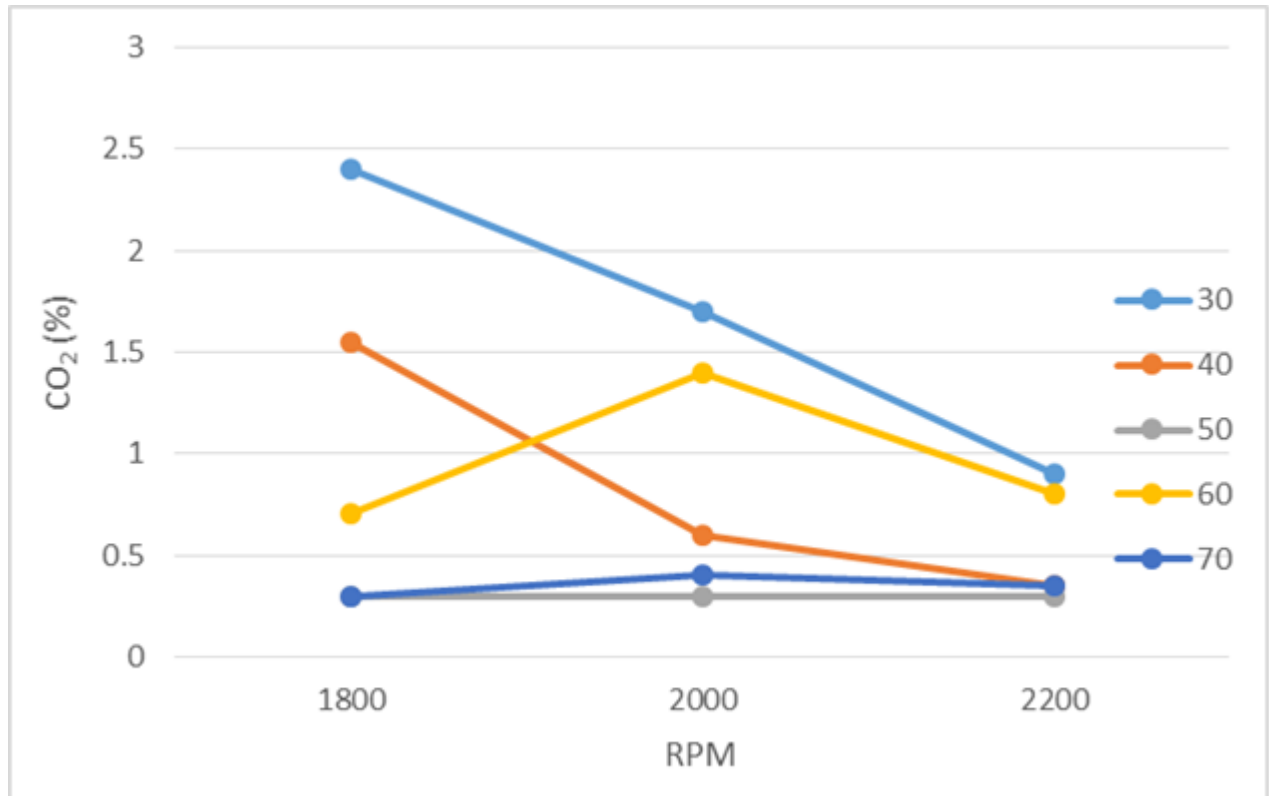


Figure 7. CO₂ VS RPM

abnormal air conditions, potentially indicating the presence of other gaseous contaminants. The risks of poisoning and oxygen deficiency may arise during this phase. A reduction in CO₂ levels to 3,000 ppm or below 5,000 ppm can mitigate the risks of poisoning and oxygen deficiency.

IV. CONCLUSION

Nitrogen monoxide, nitrogen dioxide, nitrogen oxides, and carbon dioxide emissions reach their lowest levels at a temperature of 50°C.

ACKNOWLEDGEMENTS

Our gratitude goes to the Ministry of Marine Affairs and Fisheries for providing research funding assistance. In addition, we also thank Institut Teknologi Sepuluh Nopember (ITS) Surabaya as a facility provider in carrying out testing and data collection.

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