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Analysis of Performance, Emission, Noise & Vibration on Single Cylinder Diesel Engine After Installing Dual Fuel Converter-Kit Based on ECU

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Abstract

To reduce the use of fuel oil and reduce emissions, alternative energy is needed. This is following the regulation of Marpol 73/78 Annex VI regarding air pollution due to engine exhaust gas. One alternative energy that can be used to reduce fuel oil consumption is LPG (Liquid Petroleum Gas). The use of alternative fuels for LPG in diesel engines is done by converting diesel engines into dual fuels. This research aims to determine the effect of using dual fuels that are LPG-Diesel fuel on engine performance including power, torque, fuel consumption, emissions, vibration, and noise. The research was conducted using a diesel engine at 2000 RPM engine speed with variations in loading of 1000, 1500, 2000, 2500, and 3000 watts electrical generator, and dual fuel with variations in injector openings of 3ms, 4ms, and 5ms. Based on results, the use of LPG in a dual fuel system with installing an ECU (Electronic Control Unit) converter-kit, can replace diesel fuel oil consumption up to 93%. The average power and torque was decrease up to 1.95% if using only diesel fuel have average power up to 2.32 kW and torque up to 11.09 Nm. When using dual-fuel there is a decrease in specific fuel oil consumption by up to 44% when using only diesel fuel has average fuel oil consumption up to 414.15 g/kWh. The maximum NOx emission produced is 1.83 g/kWh for a 3ms gas injector opening, 1.48 g/kWh for a 4ms gas injector opening, and 1.81 g/kWh for a 5ms injector opening. The maximum vibration generated is 33.2 m/s² for a 3ms injector opening, 31.4 m/s² for a 4ms injector opening, 27.46 m/s² for a 5ms injector opening, and when used only Diesel Fuel is 32.8 m/s2. The maximum noise generated is 92.33 dBA for 3ms injector opening, 92.43 dBA for 4ms injector aperture, 93.20 dBa for 5ms injector aperture, and 91.73 dBa when using diesel oil only.

1. Introduction

The diesel engine is an internal combustion engine that uses high compressed heat to create ignition and burns the fuel that has been injected into the combustion chamber. This engine does not use spark plugs like a gasoline engine. Diesel engines work using the working principle of Charles's law, namely, when air is compressed, its temperature will increase. The compression ratio of a diesel engine is between 15:1 and 22:1 so that it produces a pressure of 40 bar, while a gasoline engine is only 8-14 bar. This high pressure will raise the air temperature to 550° C. Diesel engines burn less fuel than gasoline engines to perform the same work because of their higher combustion temperature and compression ratio. Diesel engines generally have an efficiency level of converting fuel energy into mechanical energy reaching 45% [1].

In recent years the demand for fossil fuels has increased, this can cause fossil fuel reserves to decline, and also the increasing use of fossil fuels has also led to emissions such as Sulphur Oxide (SOx), Nitrogen Oxide (NOx), Hydroxide (HC), Carbon Monoxide (CO) and Carbon Dioxide (CO2). However, until now, the use of diesel engines and fossil fuels has remained an idol in the world of transportation and industry. To reduce these emissions, there are several solutions, including technological innovation, the use of fuel, and others [2].

Petroleum gas is an alternative fuel that can be used for diesel engines. Petroleum gas produces lower emissions than using fossil fuels so it can reduce air pollution. One of the petroleum gases that can be used to replace diesel fuel in diesel engines is LPG (Liquified Petroleum Gas) [3,4].

LPG (Liquified Petroleum Gas) is one of the fuels derived from liquefied petroleum. By increasing the pressure and lowering the temperature, the gas will turn into a liquid. The LPG component is predominantly propane (C3H8) and butane (C4H10). LPG can be combined with diesel fuel oil by modifying a diesel engine to become a dual-fuel engine to reduce fossil fuel oil consumption and reduce emissions resulting from the combustion process [5].

Diesel Dual Fuel (DDF) is a diesel engine that is slightly modified in the intake manifold by making an additional hole for the LPG inlet to the engine. To apply this dual-fuel method requires the addition of a device called a converter kit. Converter kits are all equipment used in gas fuel consumption systems in diesel engines consisting of a tank and binder, distribution pipes, regulators, mixers, and other equipment [5].

Diesel engines have high compression, this engine has high pressure and temperature to burn the fuel perfectly. Diesel Dual Fuel LPG-Diesel Fuel is suspected to have high performance and high power, but with high performance and power sometimes it causes high vibration and noise as well as explosions and pressure in the engine combustion chamber. Therefore, this research also examines the impact of the performance of Diesel Dual Fuel LPG-Diesel Fuel on the noise and vibration produced [6].

This research aims to analyze the performance, emissions, vibration, and noise generated by diesel engine single fuel (only diesel fuel) and diesel engine dual fuel using LPG-diesel fuel, after installing the ECU converter kit. So the results can be compared with the engine performance, emissions, vibration, and noise produced by diesel engines with single fuel and dual fuel. The engine performance analysis includes the calculation of power, torque, and specific fuel consumption. And another observation is emissions, vibration, and noise. The results of this research in the future can be used as a basis for the feasibility of using an ECU converter-kit on diesel engine dual fuel LPG-diesel fuel [7-9].

To determine engine performance, several parameters such as torque, power, and fuel consumption are needed. Here are the calculations to find torque, power, and fuel consumption:

a. Power

$$P = \left(\frac{V\ x\ A\ x\ 0{,}9}{0{,}85\ x\ Belt\ eff}\right) / \ 1000 \quad (1)$$

Where P is power (kW). V is voltage. A is current.

b. Torque

$$= \frac{P\ x\ 60000}{2\ x\ phi\ x\ RPM} \quad (2)$$

Where T is torque (Nm). P is power (kW). Phi is 3,14. RPM is rotation per minute from the engine.

c. Specific Fuel Consumption (SFC)

$$SFC = \frac{M_f}{P} \quad (3)$$

$$M_f = \frac{v\ x\ \rho}{t} \quad (4)$$

Where SFC is Specific Fuel Consumption (g/kWh). Mf is the amount of fuel per unit time (g/h). P is power (kW). v is the volume of fuel used.

2. Methodology

2.1. The object of research.

The main objective of this research is to analyze the differences in engine performance, emissions, vibration, and noise between a single-cylinder diesel engine with diesel fuel and a single-cylinder diesel engine with dual fuel, LPG-diesel fuel. So the results can be compared with the engine performance, emissions, vibration, and noise produced by diesel engines. Engine performance analysis includes the calculation of power, torque, and specific fuel consumption.

2.2. Treatment of research objects.

This research was conducted using a Yanmar TF 85 MH engine at 2000 RPM engine speed with variations in loading of 1000, 1500, 2000, 2500, and 3000 watts, and when dual fuel mode, LPG was delivered to the engine with variations in injector opening of 3ms, 4ms, and 5ms.

2.3. Methods.

The method that we used to do this research is the first research conducted on an experimental basis. Then literature research was conducted to research the theories needed to carry out this research, then designing a converter kit that will be used in this research, then performance, emission, vibration, and noise testing on diesel engines, then retrieval of necessary data such as voltage, current, fuel consumption time, NOx content, vibration level, and noise level, then data analysis was carried out to answer the purpose of this research, namely to find out the comparison of performance, emissions, vibration, and noise between diesel engines that only use diesel and diesel engines that use dual-fuel LPG-diesel, and the last is take conclusions and suggestions for further research. Fig. 1 below shows the engine set-up diagram for the experiment.

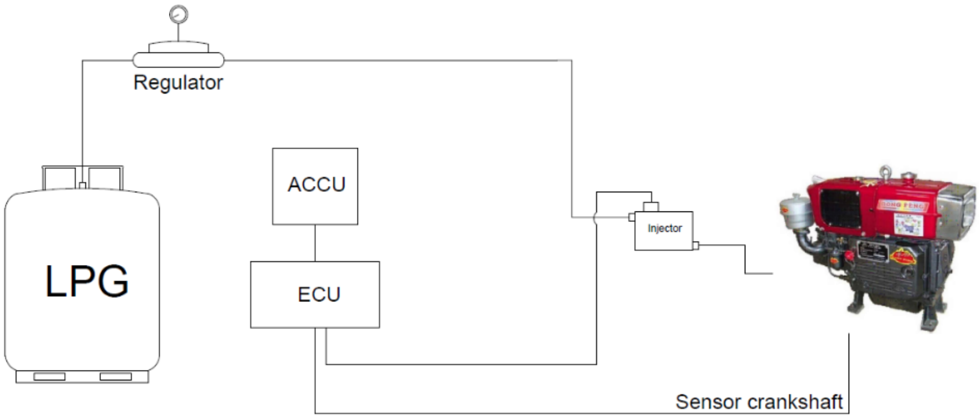

Figure 1. Engine set-up diagram

2.4. Tools and materials used in research.

In this research before the experiment, all the equipment was calibrated. The equipment used is a measuring instrument for fuel consumption, a measuring instrument for power, a measuring instrument for measuring torque, and a measuring instrument for vibration and noise. the equipment, tools, and materials used are described below.

1. Diesel Engine

The diesel engine is one type of internal combustion engine because the conversion of chemical energy into mechanical energy is carried out in the engine itself. In a diesel engine, there is a cylinder in which there is a piston that moves back and forth (translation). In the cylinder, combustion occurs between diesel fuel and oxygen from the air. From the combustion process, it is able to move the piston which is connected to the crankshaft by the connecting rod. The translational motion that occurs in the piston causes rotational motion on the crankshaft and vice versa, the rotational motion causes the piston to move back and forth. The engine that we used in this research is Yanmar TF 85 MH with an engine power of 8.5 HP and a maximum rotation of 2200 RPM.

2. Converter Kit

Converter kits are all equipment used in the use of Gas Fuel systems in motorized vehicles consisting of tanks and binders, distribution pipes, regulators, mixers, and other equipment [10]. The working principle of a converter kit, in general, is to channel natural gas into the engine. Gaseous fuel is stored in gas fuel cylinders at high pressure. Before entering the converter kit, the fuel gas pressure is too high. This pressure is then lowered by the regulator which is part of the converter kit. Next, the gaseous fuel is mixed with air by a mixer. Furthermore, the mixture of fuel gas and air enters the combustion chamber. The type of converter kit that we used in this research is a converter kit based on ECU so it can be set by software how much gas enters the engine.

3. Electronic Control Unit (ECU)

The Electronic Control Unit is a type of control unit that controls a series of actuators in an internal combustion engine to ensure optimal engine performance. The ECU in the injection engine is a core component that determines the amount of fuel that must be supplied to the engine. The computer program will receive some data and move the engine according to the required amount. The ECU also determines the duration of fuel injection into the injectors, by determining the right time to deliver the air and fuel mixture to the engine.

4. Emissions Data Collection Method

To find out the NOx emissions produced by diesel engines, a NOx emission tester is needed. The tool that is used is the BOSCH NOx emission sensor and it is placed at the end of the diesel engine exhaust. The data that comes out is in the form of NOx levels with PPM (particle per million) units which are then converted to g/kWh units.

5. Vibration Data Collection Method

To determine the level of vibration produced by a diesel engine, a tool called a "Vibration Meter" is needed. In this research, the type of vibration meter is Lutron VB-8200. The tool has a magnetic sensor which is then placed on the crankshaft housing of the diesel engine. The data that comes out is the vibration level with units of m/s^2.

6. Noise Data Collection Method

To determine the level of noise produced by a diesel engine, a tool called "Sound Level Meter" is needed. In this research the type of sound level meter is "Smart Sensor AS804" Data retrieval is done by measuring the specified distance from the source, which is using a distance of 1 (one) meter from the diesel engine and at the height of an adult's chest.

3. Results and Discussion

3.1. Making Electronic Control Unit

In making the ECU for this converter kit, Arduino is used as the core of the ECU. The components contained in this ECU include Arduino and relays. Arduino here functions to regulate how long the opening of the injector is by sending input to the relay, while the relay serves to provide voltage to the injector so that the injector opens and gas can enter the engine. In this experiment, the injector opening duration is set at 3 ms, 4 ms, and 5 ms. The created ECU is shown in Fig. 2.

Figure 2. Electronic Control Unit.

3.2. Engine Power

Based on the experiments, the engine power value was obtained. Furthermore, a comparison chart is made between the power when using diesel entirely and the power when using dual fuel. Fig. 3 is a power comparison chart between the use of single fuel and dual fuel

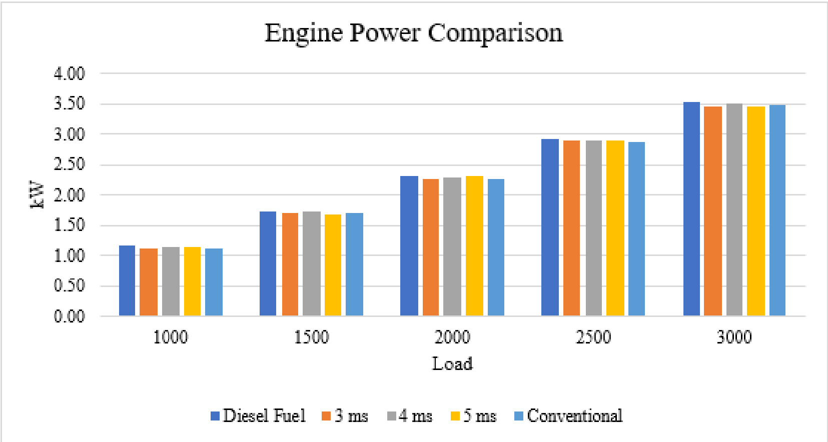

Figure 3. Electronic Control Unit.

In Figure 3 it can be concluded that the use of diesel fuel entirely has a greater engine power than the use of dual-fuel at each loading and variations in the use of dual fuel. At a load of 1000 Watt, the average power usage of dual-fuel decreased by 0.025 kW, at a load of 1500 Watt the average power decreased by 0.027 kW, at a load of 2000 Watt the average power decreased by 0.024 kW, at a load of 2500 Watt the average power decreased by 0.027 kW, at 3000 Watt load the average power decreased by 0.055 kW. The average difference in power when using diesel entirely compared to dual fuel is 0.031 kW. If as a percentage the average difference in power produced by dual-fuel at 1000 Watt, 1500 Watt, 2000 Watt, 2500 Watt, and 3000 Watt loads, respectively, is 2.18%, 1.56%, 1.02%, 0.94%, and 1.55% smaller than the total diesel.

3.3. Engine Torque

Based on the test, the engine torque value is obtained. Furthermore, a comparison chart is made between torque when using diesel entirely and torque when using dual fuel.

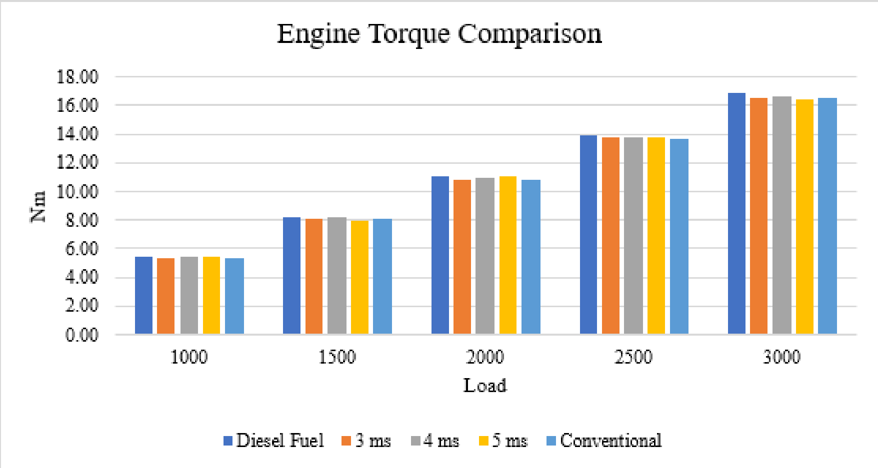

Figure 4. Comparison of engine torque

In Fig. 4 it can be concluded that the use of diesel fuel entirely has a greater engine torque than the use of dual-fuel at each loading and variations in the use of dual fuel. At a load of 1000 Watt, the average torque of dual-fuel use decreases by 0.121 Nm, at a load of 1500 Watt the average torque decreases by 0.129 Nm, at a load of 2000 Watt the average torque decreases by 0.118 Nm, at a load of 2500 Watt the average torque decreases by 0.142 Nm, at 3000 Watt load the average torque decreased by 0.218 Nm. The average difference in torque when using diesel entirely compared to dual fuel is 0.158 Nm. As a percentage, the average difference in torque produced by dual-fuel at loads of 1000 Watt, 1500 Watt, 2000 Watt, 2500 Watt, and 3000 Watt, respectively, is 2.20%, 1.57%, 1.07%, 1.02%, and 1.67% smaller than the total diesel.

3.4. Specific Fuel Consumption

In Fig. 5, it can be concluded that when using dual-fuel produces less fuel consumption when compared to all diesel. When using dual fuel, it can reduce the average fuel consumption at loads of 1000 watt, 1500 watt, 2000 watt, 2500 watt, and 3000 watts respectively by 11.3%, 16.5%, 25.5%, 28.8%, and 31% as well as when compared to diesel entirely. LPG is able to replace the average percentage of diesel consumption at 1000 watt, 1500 watt, 2000 watt, 2500 watt, and 3000 watt loads, respectively, as much as 82%, 80%, 77%, 76%, and 70%.

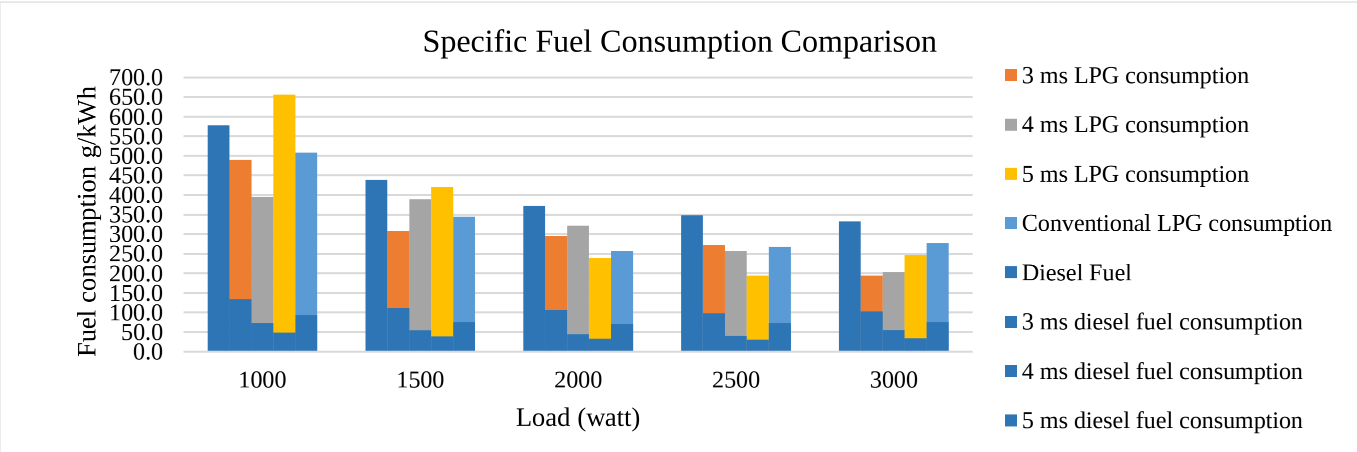

Figure 5. Comparison of specific fuel consumption

3.5. Economical Calculation of Fuel Use

The economical calculation can be shown in Table 1 and the calculations are assumed:

1. The engine is assumed to run for 8 hours a day and is divided into several times on each load.
   - At loads of 1000 Watt and 1500 Watt respectively assumed to run for 24 minutes.
   - At a load of 2000 Watt, it is assumed to run for 48 minutes.
   - At a load of 2500 Watt, it is assumed to run for 96 minutes.
   - At 3000 Watt load, it is assumed to run for 288 minutes.
2. The price of diesel fuel based on Pertamina's price is Rp. 5,150 per liter.
3. The price of LPG for the size of 3 kg is Rp. 18.000

Table 1. Amount of fuel in a day

Load (W)	Time (hour)	Diesel fuel	Dual Fuel 3ms	Dual Fuel 4ms	Dual Fuel 5ms	Conventional Converter Kit

		Diesel Fuel Cons. (L)	Diesel Fuel Cons. (L)	LPG Cons (kg)	Diesel Fuel Cons. (L)	LPG Cons (kg)	Diesel Fuel Cons. (L)	LPG Cons (kg)	Diesel Fuel Cons. (L)	LPG Cons (kg)
1000	0.4	0.32	0.07	0.16	0.04	0.15	0.03	0.28	0.05	0.18
1500	0.4	0.37	0.09	0.13	0.05	0.23	0.03	0.26	0.06	0.18
2000	0.8	0.83	0.24	0.34	0.1	0.51	0.07	0.38	0.16	0.34
2500	1.6	1.97	0.55	0.8	0.23	1	0.17	0.75	0.41	0.89
3000	4.8	6.81	2.08	1.51	1.13	2.47	0.69	3.51	1.53	3.36
Total	8	10.3	3.03	2.95	1.54	4.35	0.99	5.18	2.21	4.96

Table 1 shows if use diesel fuel of it consumes 10.3 liters of diesel fuel, while when using dual-fuel 3ms, uses 3.03 liters of diesel and 2.95 kg of LPG. When using dual-fuel 4ms consumes 1.54 liters of diesel and 4.35 kg of LPG. When using dual-fuel 5ms consumes 0.99 liters of diesel and 5.18 kg of LPG. When using a conventional converter kit, costs 2.21 liters of diesel and 4.96 kg of LPG.

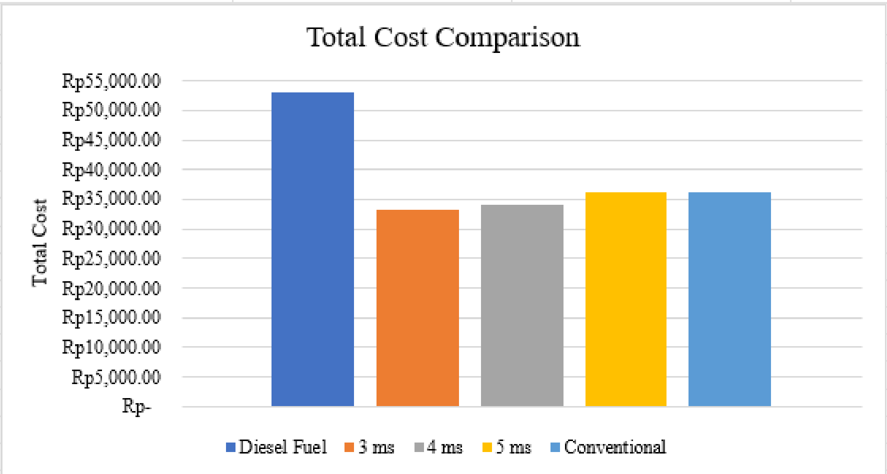

Figure 6. Comparison of total operational cost

3.6. Investment Cost

To convert a diesel engine to a dual fuel diesel engine, several components need to be added. The components and costs required to convert a diesel engine into dual fuel are shown in Table 2.

Table 2. Investment cost

Investment Cost				
No	Item	Quantity	Cost (Rp)	Total Cost (Rp)
1	ECU	1	500,000.00	500,000.00
2	Injector	1	250,000.00	250,000.00
3	Sensor	1	40,000.00	40,000.00
4	Magnet	1	3,200.00	3,200.00
5	LPG	1	180,000.00	180,000.00
6	Regulator Set	1	85,000.00	85,000.00
		Total		1,058,200.00

Table 2 shows the total investment cost that is needed to make a converter kit. To make a converter kit based on ECU we need some components like ECU, Injector, Sensor, Magnet, LPG, and Regulator set. So the total investment cost is Rp. 1,058,200

3.7. NOx Emission Level

From Fig. 7 it can be concluded that the NOx emission produced by a dual fuel diesel engine is small compared to the NOx emission level produced by a diesel-fueled diesel engine. The maximum NOx emission level produced by a diesel engine is 2.57 g/kWh. . Meanwhile, the maximum NOx levels are produced by a dual fuel diesel engine with injector openings of

3ms, 4ms, and 5ms respectively are 1.83 g/kWh, 1.48 g/kWh, and 1.81 g/kWh. The NOx emission is smaller than the maximum NOx level produced by a diesel engine with diesel fuel which is 2.46 g/kWh.

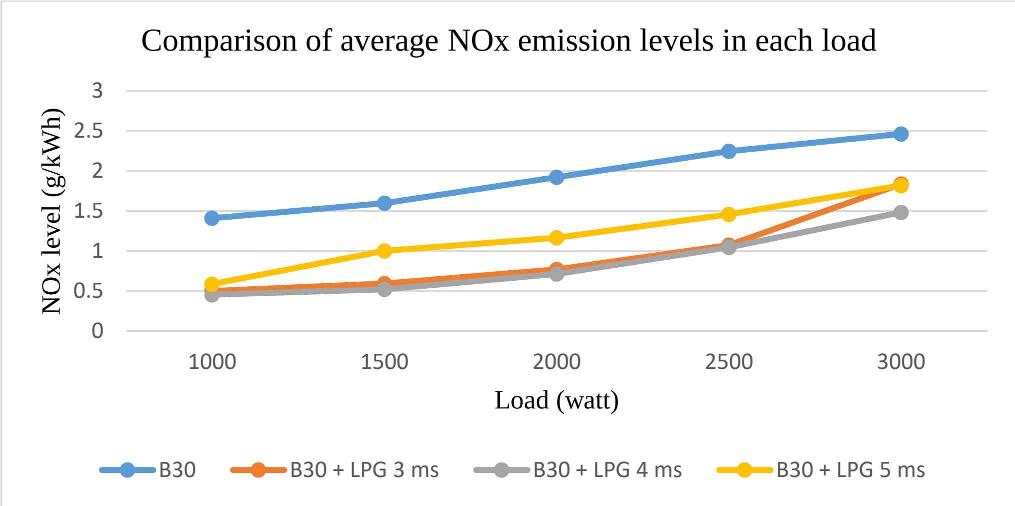

Figure 7. Comparison of average NOx emission levels in each load

3.8. Engine Vibration

Fig. 8 shows a chart comparing the level of vibration to the load given to the engine when testing. Diesel fuel has a high vibration compared to dual fuel LPG-Diesel Fuel. Diesel fuel has an average vibration amplitude of 30.64 m/s² compared to dual fuel LPG-Diesel Fuel at 3ms opening the average vibration amplitude is 28.64 m/s², at 4ms opening the average vibration amplitude is 27, 22 m/s², at 5ms opening the average vibration amplitude is 24.44 m/s². The power generated by dual-fuel LPG-diesel oil is lower, causing a lower piston thrust so that the vibration produced is also low.

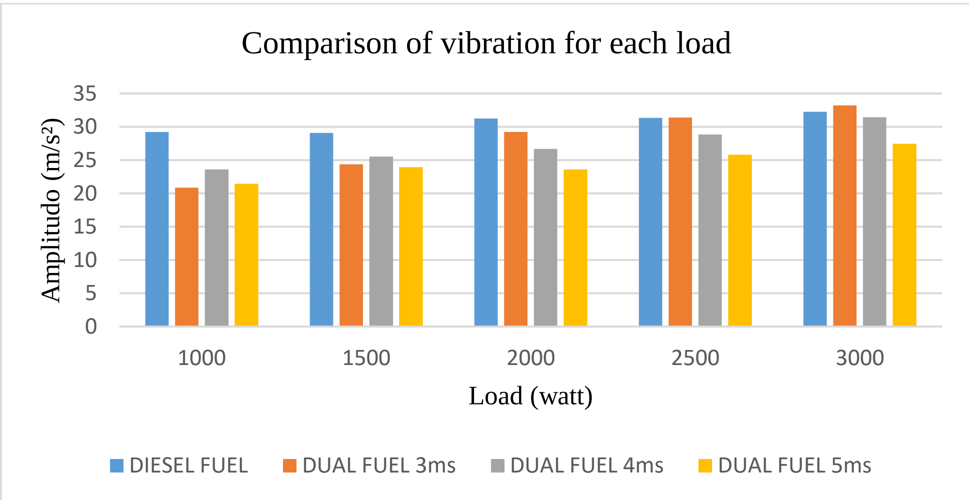

Figure 8. Comparison of vibration for each load

3.9. Engine Noise

In Fig. 9 it can be seen a chart of the comparison of the noise level generated by the engine against the load given to the engine when testing. Diesel fuel has a lower noise level compared to dual fuel LPG-diesel oil. Diesel fuel has an average noise level of 90.55 dBA compared to dual fuel LPG-diesel oil at 3ms opening the average noise level is 91.89 dBA, at 4ms opening the average noise level is 91.95 dBA, and at 5ms aperture, the average noise level is 92.30 dBA. The chart above shows that with the addition of LPG, the engine noise level produced is higher due to the knocking that occurs in the engine. Thus, the Sound Level Meter tool captures the highest sound produced.

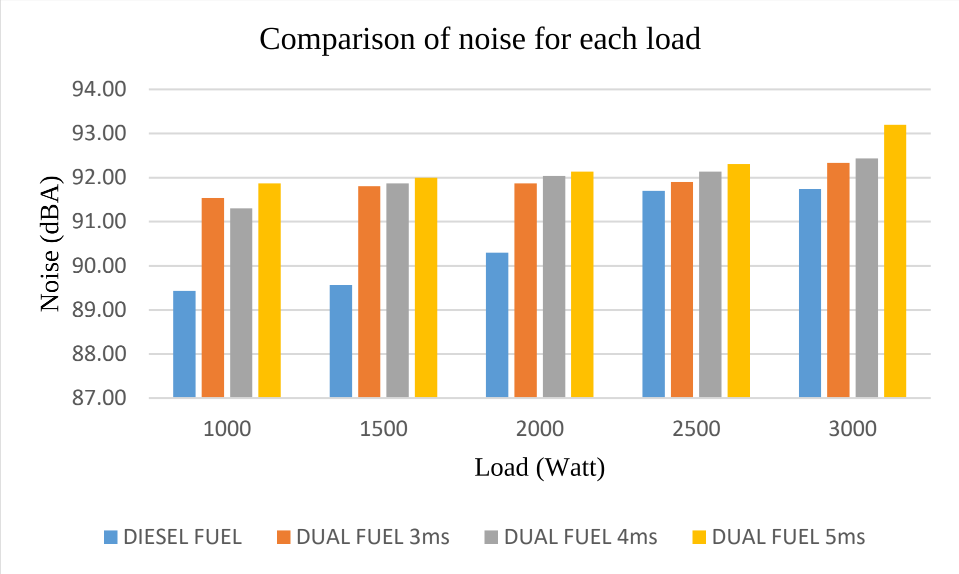

Figure 9. Comparison of noise for each load

4. Conclusion

Based on the results of experiments and data analysis that has been carried out in this research, it can be concluded that the average power produced when using dual-fuel, drops to 0.031 kW or 1.34% compared to when using single fuel mode. The average torque produced when using dual-fuel decreased by 0.142 kW or 1.51% compared to when using a single fuel mode. Then, average fuel consumption when using dual-fuel drops by 22% when compared to single fuel mode. The level of NOx emissions produced by the dual fuel diesel engine at 3ms, 4ms, and 5ms openings decreased by 28.79%, 42.412%, and 29.571%, respectively, compared to the levels of NOx emissions produced by single fuel mode. Then, the vibration when using dual fuel is lower than in diesel engines with single fuel, and the noise when using dual fuel is higher than in diesel engines with single fuel.

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