Analysis of Exhaust Gas Emissions on Dual Fuel Diesel Engine Single Cylinder Four-stroke with LPG-Diesel Oil

Adhi Iswantoro, I Made Ariana, Muhammad Syuhri*,
Department of Marine Engineering ITS, Surabaya, Indonesia
m.syuhri13@gmail.com

Abstract. Diesel engine is one of type of internal combustion engine that is applied in industry, including the maritime industry. The increasing use of diesel engines, has an effect on increasing emissions. Diesel engines emissions consist of SOx, NOx, HC, and others. To reduce the emissions, there are many methods, one of them is using dual-fuel system. The alternative fuel can be used is Gas, which is easily available, namely LPG or liquefied petroleum gas. To supply LPG to combustion chamber, a converter-kit are needed to be install on diesel engine. There are several previous research that prove that LPG can be used as an alternative in a dual-fuel system and can reduce the emissions. One of them by Ma'amuri (2016) who designed a mechanical LPG-diesel oil as dual-fuel, using a membrane converter. Result of this research provide that good diesel engine performance. In this research, LPG-diesel oil as dual-fuel using converter kit based on ECU or electronic control unit, and then, analyze the diesel engine emissions with experimental method. The purpose of this research is to determine the emissions produced by LPG-diesel oil as dual-fuel with converter kit based ECU. After taking and analytical data, known that the NOx emission from dual fuel diesel engine using ECU-based converter kit is lower than NOx emission from conventional diesel engine with B30 diesel fuel with percentage is 25.61 % for 3ms opening duration of gas injector, 39.99 % for 4 ms opening duration of gas injector and 26.5 % for 5 ms opening duration of gas injector. The NOx emission of conventional diesel engine is 2.46 g/kWh.

1. Introduction
Diesel engine is a type of motor that converts heat energy into mechanical energy through the combustion process in the combustion chamber [1]. Diesel engine are also one of the most widely used types of internal combustion engines in industry and transportation, both on land and at sea. Along with the times, the use of diesel engines in Indonesia is increasing which of course causes an increase in emissions and fuel consumption.

Emissions produced by diesel engines with biodiesel fuel oil consist of several elements, including Sulfur Oxide (SOx), Nitrogen Oxide (NOx), Hydrocarbons (HC), Carbon Monoxide (CO), and particulate matter (PM) [2]. These emission substances have the potential to damage and pollute the environment along with the increasing use of diesel engines. To reduce the emission problem, there are several solutions, including technological innovation, the use of renewable fuels, and others[3].

One alternative fuel that can be used to reduce emissions from diesel engines is LPG (liquefied petroleum gas). Liquefied Petroleum Gas (LPG) is one of the fossil fuels or non-renewable fuel. LPG comes from petroleum which is thawed and LPG is one of the gas fuel oil that has the potential to replace and reduce the use of fuel for fishing boat [4]. LPG can be used as a supporting fuel in a dual fuel system.
for diesel engines[5]. The potential benefits of using LPG in diesel engines are both economical and environmental [6]. To enter LPG gas into the combustion chamber of a diesel engine, a converter kit is needed.

Converter gas fuel conversion kit is all equipment used in the gas usage system in motor vehicles consisting of tanks and their fasteners, distribution pipes, regulators, mixers and other equipment. [7]. The converter that used in this research is ECU-based converter kit. The Engine Control Unit (ECU) is the main electronic control element in the engine which functions as a regulator of the amount of gas fuel used when combustion and also adjusts the ignition timing to produce better combustion. The ECU does its job based on the input from the sensors which will determine how much fuel is needed and the proper ignition timing in the combustion process. Some of the sensors used as input to the ECU is the manifold air pressure (MAP) sensor, throttle Position Sensor (TPS), O2 sensor, engine temperature sensor (ETS), intake air temperature (IAT) sensor, and crank position sensor (CPS) [8]. ECU is used for regulating the gas injector opening duration with input from Crank Position Sensor (CPS) that is placed at top of engine flywheel.

2. Methods
The methodology used in this journal is experimental methodology with detailed steps as follows:

1. Preparation
Collect materials and tools needed to support the research. The tools and materials needed include a diesel engine paired with a generator set, LPG, diesel, ECU, converter kit, emission analyzer, etc. The engine used in this research is a single cylinder four stroke diesel engine brand Yanmar TF 85 MH. The specifications are as follows:

| Brand         | YANMAR                  |
|---------------|-------------------------|
| Model         | TF 85MH                 |
| Number of cylinders, stroke | 1, 4 stroke             |
| Bore x Stroke | 85 mm x 87 mm           |
| Volume of combustion chamber | 493cc                   |
| Compression Ratio | 18:1                   |
| Maximum RPM   | 2200 rpm                |
| Engine power  | 8.5 HP                  |

2. Converter kit manufacture and engine setup
This stage is the making of a converter kit including the ECU, sensors, regulators, and others which are assembled into one and connected to the diesel engine and the LPG gas is channeled through the air intake manifold. The converter kit will be used to convert a conventional diesel engine to a dual fuel diesel engine.
3. *Engine running and taking data.*

At this stage the engine is run in two conditions, first is using only diesel fuel and the second condition is using dual fuel LPG-diesel. The experiment carried out were taking data on NOx emission levels in the exhaust gas of the diesel engine in each kind of the fuels. Measurement of NOx using an engine emission meter. The NOx emission meter that used is from BOSC with technical specification:

- Measurement range: 1 - 1,650 ppm
- Measurement accuracy: ± 10 – 12 ppm
- NOx response time: 3.00 ms

The test will be carried out with several variables, including:

a. Fixed variable
   • Fuel
     The fuels used in this research is B30 diesel fuel and LPG
   • RPM
     Engine RPM for emission testing carried out at 2000 RPM

b. Independent variable
   • Load
     The loadings given for emission testing are 1000 Watt, 1500 Watt, 2000 Watt, 2500 Watt, and 3000 Watt.
     • LPG injector opening
     The LPG injector openings tested were 3ms, 4ms, and 5ms.
4. **Data analysis**

   The data taken for the levels of NOx emissions produced are 50 data for each load and each type of fuel. The data taken and processed into a graph and the average data is taken to make a graph of the average of NOx levels at each load and each type of fuel.

5. **Conclusion**

   Conclusion obtained after doing analysis data. Conclusion is a result from analysis data that show the NOx emission result from both type of fuel at each load and each gas injector opening duration.

3. **Result and Discussion**

3.1. **Data analysis**

3.1.1. **NOx emission at 1000 load**

   ![](image_url)

   Figure 3 is a graph of the comparison of NOx levels produced by a B30 diesel engine with a dual fuel LPG-B30 diesel engine at a load of 1000 watts and 2000 RPM. The B30 diesel engine produces the highest NOx level at 1.47 g/kWh and the lowest at the point of 1.36 g/kWh. The diesel engine with dual
fuel B30 – LPG with an injector opening of 3ms produces the highest NOx level at 0.55 g/kWh and the lowest at 0.45 g/kWh. The diesel engine with dual fuel B30 – LPG with an injector opening of 4ms produces the highest NOx emission level at 0.59 g/kWh and the lowest at 0.31 g/kWh. And the diesel engine with dual fuel B30 – LPG with an injector opening of 5ms produces the highest NOx emission level at 0.77 g/kWh and the lowest at 0.39 g/kWh.

3.1.2. NOx emission at 1500 load

Figure 4. NOx emission at 1500 load

Figure 4 is a comparison graph of the levels of NOx produced by a B30 diesel engine with a dual fuel LPG – B30 diesel engine at a load of 1500 watts and RPM 2000. The diesel engine with B30 fuel at a load of 1500 watts and RPM 2000 produces the highest NOx level of 1.68 g/kWh and the lowest is 1.44 g/kWh. The B30-LPG dual fuel engine with 3ms injector opening produces the highest NOx emission level of 0.73 g/kWh and the lowest is 0.52 g/kWh. The diesel engine with dual fuel B30 – LPG with an injector opening of 4ms produces the largest NOx emission level at 0.67 g/kWh and the smallest at 0.41 g/kWh. And for the diesel engine with dual fuel B30 – LPG with an injector opening of 5ms, it produces the largest NOx emission level at 1.38 g/kWh and the lowest NOx level at 0.61 g/kWh.

3.1.3. NOx emission at 2000 load

Figure 5. NOx emission at 2000 load
Figure 5 is a comparison graph of the levels of NOx emissions produced by a B30 diesel engine with a B30 – LPG dual fuel diesel engine at a load of 2000 watts and 2000 RPM. The B30 diesel engine produces the largest NOx emission level at 2.05 g/kWh and the lowest level of NOx at the point of 1.75 g/kWh. The B30-LPG dual fuel diesel engine with a gas injector opening of 3ms produces the highest NOx emission level of 0.84 g/kWh and the lowest is 0.67 g/kWh. The B30 – LPG dual fuel diesel engine with a gas injector opening of 4ms produces the highest NOx emission level at 0.89 g/kWh and the lowest at 0.56 g/kWh. And the B30 – LPG dual fuel diesel engine with an injector opening of 5ms produces the highest NOx emission level at 1.79 g/kWh and produces the lowest NOx level at 0.76 g/kWh.

3.1.4. NOx emission at 2500 load

Figure 6 is a graph of the comparison of levels of NOx emissions produced between a B30-fueled diesel engine and a B30-LPG dual fuel diesel engine at a load of 2500 watts and 2000 RPM. In a B30-fueled diesel engine, the highest NOx emission level is 2.32 g/kWh and the lowest at 2.10 g/kWh. The diesel engine with dual fuel B30 – LPG with an injector opening of 3ms produces the highest NOX emission level of 1.25 g/kWh and the lowest NOx level of 0.91 g/kWh. The dual fuel B30 – LPG diesel engine with 4ms injector opening produces the highest NOx emission level at 1.26 g/kWh and the lowest NOx emission level produced at 0.90 g/kWh. And the B30 – LPG dual fuel diesel engine at 5ms injector opening produces the highest NOx emission level of 2.15 g/kWh and produces the lowest NOx emission level of 0.88 g/kWh.
3.1.5. NOx emission at 3000 load

Figure 7. NOx emission at 3000 load

Figure 7 is a comparison graph of the levels of NOx emissions produced between a B30-fueled diesel engine and a B30-LPG dual fuel diesel engine at a load of 3000 watts and 2000 RPM. The B30-fueled diesel engine produces the highest NOx emission level at 2.57 g/kWh and the lowest point is 2.24 g/kWh. The diesel engine with dual fuel B30 – LPG with a gas injector opening of 3ms produces the highest NOx emission level of 2.07 g/kWh and the lowest NOx level of 1.58 g/kWh. The diesel engine with dual fuel B30 – LPG with a gas injector opening of 4ms produces the highest NOx emission level at 1.77 g/kWh and the lowest NOx emission at 1.42 g/kWh. And the diesel engine with dual fuel B30 – LPG with an injector opening of 5ms produces the highest NOx emission level at 2.37 g/kWh and the lowest NOx level point at 1.20 g/kWh.

3.1.6. Comparison of average NOx levels in each load

Figure 8. Average NOx emission levels in each load for each fuel type
Figure 8 is a graph of the comparison of the average levels of NOx emissions at each load between a B30-fueled diesel engine and a B30-LPG dual fuel diesel engine whose injector opening duration is set to 3ms, 4ms, and 5ms. From the graph above, it can be seen that the levels of NOx emissions produced by the diesel engine fueled by dual fuel B30 – LPG are smaller than the diesel engine fueled by diesel oil. This is due to the fact that the combustion temperature in the combustion chamber of a dual fuel diesel engine is lower than a B30 diesel engine. The lower combustion temperature in the dual fuel diesel engine is caused by the even distribution of combustion temperature in the gas and air fuel mixture. During the 5ms gas injector opening duration, NOx levels increased due to the supply of LPG gas entering the combustion chamber exceeding the ideal combustion mixture limit, knocking resulting in incomplete combustion and uneven combustion temperature.

3.2. Conclusion
After obtaining data from the experimental results and conducting data analysis, the following conclusions were obtained:

1. The average level of NOx emissions produced by the B30 – LPG dual fuel diesel engine is the highest at a 3000 watt load of 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 duration.

2. The level of NOx emissions produced by the B30 diesel engine is greater than the dual fuel diesel engine. The highest NOx content of the B30 diesel engine is at 3000 watts of load with an average Nox level of 2.46 g/kWh.

References
[1] Heywood, J.B. (1998). Internal Combustion Engine Fundamentals. Singapore: McGraw-Hill Inc.
[2] Ginantaka, P. A. (2020). Analisa Proses Pembakaran dan Emisi pada Mesin Diesel Satu Silinder dengan Bahan Bakar Green Diesel Berbasis Simulasi (Doctoral dissertation, Institut Teknologi Sepuluh Nopember)
[3] Cappenberg, A. D. (2017). Pengaruh Penggunaan Bahan Bakar Solar, Biosolar dan Pertamina Dex Terhadap Prestasi Motor Diesel Silinder Tunggal. (Universitas 17 Agustus 1945)
[4] Mulyatno Imam P, Sisworo Sarjito J, Panuntun Dimas S. Kajian Teknis dan Ekonomis Penggunaan Dual Fuel System (LPG-Solar) pada Mesin Diesel Kapal Nelayan Tradisional. Kapal 2013; 10, 98-107.
[5] Kuncoro, A., Mamuri, W. S., & Wisnugroho, S. (2016). LPG sebagai Energi Alternatif untuk Bahan Bakar Dual-Fuel Mesin Kapal Nelayan Tradisional. In Seminar Nasional Sains dan Teknologi (Vol. 8, pp. 1-12).
[6] D.H. Qi, Y.ZH. Bian, ZH.Y. Ma, CH.H. Zhang, SH.Q. Liu, “Combustion and exhaust emission characteristics of a compression ignition engine using liquefied petroleum gas-Diesel blended fuel”. Energy Conversion and Management, Vol. 48, No.2, 2007, 500 -509.
[7] Ehsan, M., & Bhuiyan, S. (2009). Dual fuel performance of a small diesel eng ine for applications with less frequent load variations. Int J Mech Mechatron Eng, 9(10), 19-28.
[8] Budinurman, L. (2015). Rancang Bangun Sistem Injeksi Sepeda Motor Gas (Wisanggeni) Dengan Menggunakan ECU (D3 Teknik Mesin Electronic Control Unit) Sebagai Platform Pengembangan Ecu Injeksi Sepeda Motor Gas (Doctoral dissertation, Institut Teknologi Sepuluh Nopember).