Comparative study of the performance and economic value of a small engine fueled with B20 and B20-LPG as an effort to reduce the operating cost of diesel engines in remote areas

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Comparative study of the performance and economic value of a small engine fueled with B20 and B20-LPG as an effort to reduce the operating cost of diesel engines in remote areas

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Abstract. Indonesia is an archipelagic country that has remote locations. In such areas, the price of diesel fuel might be very costly. Hence, it is very burdensome for the community because this type of fuel is needed by diesel engines to drive generator sets, agricultural and production purposes. The utilization of dual-fuel diesel-gas engine is expected as a solution to this problem. This experimental study was carried out to compare the performance and economic value of operating a small diesel engine both with B20 biodiesel fuel and B20-LPG dual-fuel, with a variation of engine operating parameters, namely engine speed, LPG fraction and engine throttle opening. The performance parameters observed were torque, power, brake specific fuel consumption and brake thermal efficiency. Experiments were carried out in the laboratory at throttle openings of 50% and 100% with an LPG fraction of 10% to 70%. It was found that the best performance of the dual-fuel engine occurred at the throttle opening of 100% and an LPG fraction of 70%. In this condition, there was a 20% reduction in BSFC maximum, and a maximum power increase of 12%, compared to a single-fuel engine. The BTE increased by 9%, and the engine torque increased by nearly 5%. It is concluded that the performance of the dual-fuel engine generally increases compared to the single file mode. Another exciting conclusion is that the use of dual-fuel B20-LPG engines reduces operating costs by up to 40%.

1. Introduction

The usage of diesel fuel continues to show an increasing trend in Indonesia. In addition to causing supply problems, it also increases the concentration of greenhouse gas in the atmosphere. Besides, the price of fuel that has not been evenly distributed in several regions of Indonesia has led to the need for using alternative fuels, especially those that can utilize the local potential. For instance, the price of diesel fuel in Mendol Island, Pelalawan Regency, Riau Kepulauan Province, Indonesia, is IDR 10,500/liter, while in this island there are natural gas energy sources that have not been utilized. If the gas is used to run dual-fuel diesel-CNG engines, of course, the savings are very considerable.

The dual-fuel diesel-gas engine is a diesel engine that uses two types of fuel simultaneously, where gas fuel is injected with intake air by using a converter kit. The gas used can be either liquified petroleum gas (LPG) or compressed natural gas (CNG). LPG is a gas produced from petroleum refining, which consists of propane, butane, propylene, and other light hydrocarbons [1] [2]. The combustion process in the dual-fuel engine is complicated because it is a combination of the working principles of spark ignition and compression ignition engines[3] [4] [5]. With dual-fuel diesel-LPG engines, the higher the quantity of LPG injected the higher the torque, power, and efficiency, and reduce exhaust emissions [6] [7]. The low cetane number of LPG makes it challenging to use with high fractions in diesel engines [8] [9] [10]. Therefore, LPG can only be used on diesel engines as dual-fuel systems.

Dual-fuel engines have several advantages compared to single-fuel engines, namely higher thermal efficiency, lower exhaust emissions, and higher power [2]. Therefore, this type of engine can significantly reduce diesel engine emissions [11] [12] [13]. LPG with a composition of 30% butane is the best composition because besides being able to improve engine performance, it can also reduce Nox emissions by up to 35% and SOx by 69% [14] [15]. Also, the use of LPG on dual-fuel diesel engines can increase the brake thermal efficiency (BTE), as well as reduce the brake specific fuel consumption (BSFC) [16] [17].

Although there has been much research on dual-fuel diesel-LPG engines, however, there are some technical problems in its implementation, such as optimizing engine performance on engine throttle openings (TPS) and LPG fractions [18]. The dual-fuel system requires further control to get the best performance. This is because the performance of the dual-fuel engine is strongly dependent on the engine operating parameters, such as load level, engine speed, fuel ratio, timing injection, and engine intake manifold conditions[19].

In this research, an experimental study was carried out with the primary objective of comparing the performance and economic value of operating a small diesel engine fueled by B20 biodiesel and B20-LPG, in a variation of three engine operating parameters, namely engine speed, LPG fraction and engine throttle opening. The observed performance parameters were torque, power, BSFC, and BTE. The experiments were carried out in the laboratory at throttle openings of 50% and 100%, and with LPG fraction from 10% to 70%. The results of this research are expected to be applied on the Mendol island, to overcome the high price of diesel fuel, while utilizing the potential of natural gas sources.

2. Materials and methods

2.1. Measurement preparation and procedures

An experiment was carried out at the Laboratory of Efficiency and Energy Conservation, Department of Mechanical Engineering, Diponegoro University by using the Jiangsan type R-180 diesel engine, with specifications as shown in table 1. The experimental set-up system is shown in figure 1. Data collection was carried out with data acquisition system so that the LPG fraction settings and other measurable variables could be conducted in real-time, easy, fast and thorough. A conversion kit was used for gas pressure regulation as well as to vaporize the gas. The equations required in this experiment are as follows:

$$\mathrm{T} = FL \tag{1}$$

$$P = \frac{2\pi NT}{60{,}000} \tag{2}$$

$$C_{LPG} = \frac{M_{LPG}}{M_{Diesel}+M_{LPG}} \tag{3}$$

$$BSFC = \frac{3.6\ (M_{LPG}+M_{Diesel})}{P} \tag{4}$$

$$BTE = \frac{P}{(M_{LPG}LHV_{LPG}+M_{Diesel}LHV_{Diesel})} \tag{5}$$

Where:

F = dynamometer load (N)
L = load arm (m)

T = torque (Nm)
N = engine speed (rpm)
P = power (kW)
M = fuel rate (g/s)
C = mass fraction of LPG (%)
LHV = lower heating value (kJ/kg)
BSFC = brake specific fuel consumption (kg/kWh)

The measurements were carried out on throttle opening of 50% and 100% with LPG fractions of 10% up to 70%. In this test, load regulation was conducted using an eddy current dynamometer, which was equipped with an engine speed gauge (proximity sensor) and load cell. This loading in addition to adjusting the torque value also functioned to regulate engine speed and power. During the test, temperature measurements of the cooling water radiator, intake air, and exhaust gas channels were carried out, using a thermocouple sensor. The rate of consumption of diesel fuel and LPG was measured using load cells contained in the scales. From this data could be shown the value of LPG gas fraction in the dual-fuel mixture. Thus, the gas fraction value could be adjusted using a valve, and information on reading the gas fraction displayed on the computer monitor screen. In this experiment, all the measuring instruments used were connected to a computer using a data acquisition system so that reading and storing data became easier and faster.

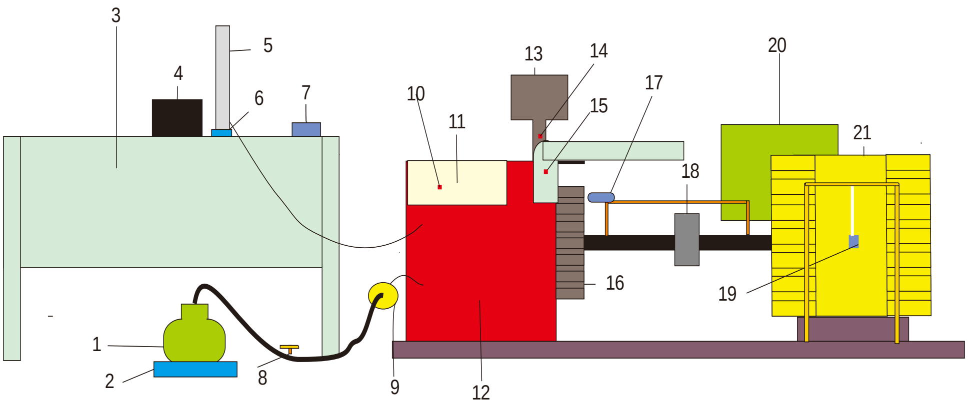

Figure 1. Experimental setup.

1. LPG tank
2. LPG scales
3. Table
4. Computer/laptop
5. Diesel oil tank
6. Diesel oil scales
7. Data acquisition
8. LPG regulator
9. Converter kit
10. Cooling water thermocouple
11. Cooling water
12. Diesel engine
13. Air filter
14. Intake air thermocouple
15. Exhaust gas thermocouple
16. Engine flywheel
17. Proximity sensor
18. Flexible coupling
19. Load cell
20. Power supply
21. Eddy current dynamometer

Table 1. Main specification of the diesel engine.

Engine type	:	Horizontal, water cooling
Brand	:	Jiangsan
Model	:	R-180
Cooling system	:	Hopper
Cylinder number	:	1 cylinder
Volume	:	402 cc
Bore x Stroke	:	80 x 80 mm
Compression ratio	:	21:1
Injection system	:	Indirect
Maximum Power	:	8 hp at 2800 rpm
Rated Power	:	7 hp at 2600 rpm

2.2. Measurement uncertainty

To find out the level of confidence in the measurement, a parameter called measurement uncertainty was used. Its value must be traceable, starting from the parameters directly measured to the calculated parameters. In this study, uncertainty estimation was calculated by the method proposed by Moffat **Error! Reference source not found.**. The parameters directly measured were intake, cooling water, and exhaust gas temperatures, the mass of biodiesel and LPG which are reduced at any time, the force on the dynamometer arm, engine rotational speed, air temperature, and humidity. The indirect parameters were torque, power, fuel consumption rate, BSFC, BTE and LPG fraction. The estimated uncertainty for these parameters is shown in table 2. From the table, it can be seen that the measurement system has a reasonably low uncertainty, where the value is lower with the higher throttle position.

Table 2. Measurement uncertainties at several throttle positions.

TPS (%)	Torque (%)	Power (%)	Fuel rate (%)	BSFC (%)	BTE (%)	LPG Fraction (%)
33	0.600	0.621	2.928	2.993	2.993	2.935
50	0.500	0.519	2.276	2.335	2.335	2.283
67	0.460	0.475	1.185	1.276	1.276	1.209
83	0.370	0.389	1.138	1.202	1.202	1.165
100	0.190	0.225	0.932	0.958	0.958	0.953

3. Results and discussion

3.1. Engine torque

Figure 2 shows the relationship between torque and engine speed, for a variety of LPG fractions at throttle position of 50% and 100%. To calculate the value of torque, equation (1) is used. It can be seen that the torque produced by the dual-fuel engine tends to be higher than the single-fuel diesel engine, although the difference is relatively small. At 50% TPS and 70% LPG fraction, the maximum torque produced by a single-fuel engine is 22.63 Nm at 1524 rpm, while the maximum torque produced by a dual-fuel engine is 23.15 Nm at 1632 rpm. As for the 100% TPS and 70% LPG fraction, the value generated by the single-fuel engine is 22.72 Nm at 1906 rpm, while the dual-fuel mode produced 23.23 Nm at 2158 rpm. Thus, in dual-fuel mode, there was an increase in engine torque of around 12%. This was because the heating value of the dual-fuel increased, while at the same time there was a decrease in fuel entering the combustion chamber.

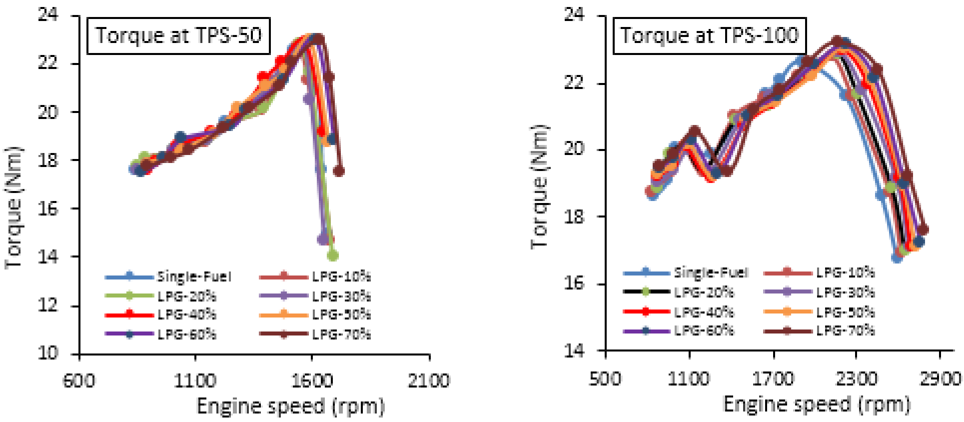

Figure 2. Engine torque for various LPG fraction and throttle positions.

3.2. Engine power

Figure 3 shows the relationship between power to engine speed in a variety of LPG fractions. To calculate the engine power, equation (2) is used. It can be seen that the power produced by the dual-fuel engine tends to be larger than the single-fuel diesel engine. At 50% TPS and 70% LPG fraction, the maximum power produced by a single-fuel engine is 3.62 kW at 1524 rpm, while the maximum power generated by the dual-fuel engine is 3.94 kW at 1632 rpm. As for the 100% TPS and 70% LPG fraction, the value produced by the single-fuel engine is 5.04 kW at 2228 rpm, while the dual-fuel engine produces 7.75 kW at 2448 rpm. Thus, in dual-fuel mode, there was an increase in engine power of around 12%. This is because the heating value of LPG was higher than biodiesel. Also, the presence of LPG burned in the combustion chamber change the biodiesel to be more flammable.

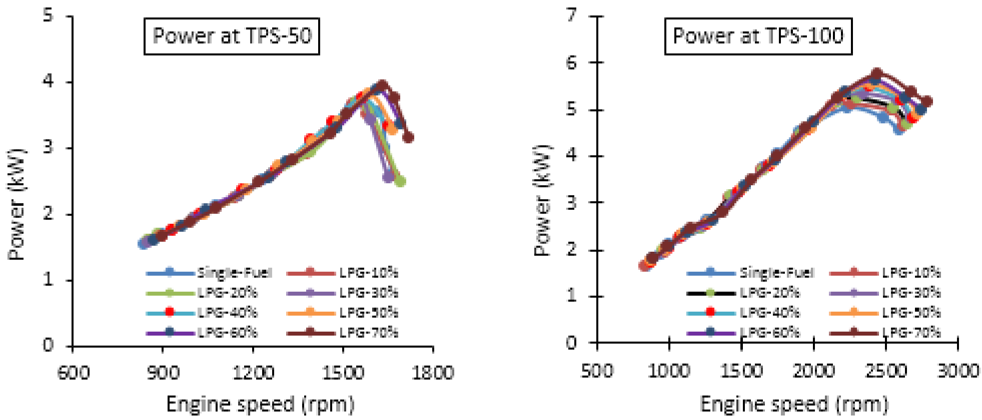

Figure 3. Engine power for various LPG fraction and throttle positions.

3.3. Brake specific fuel consumption (BSFC)

Figure 4 shows the relationship between BSFC and engine speed, where the value for dual-fuel engines tends to be smaller compared to the single-fuel. To calculate the value of the BSFC, equation (4) is used. This indicates that the dual-fuel engine was more efficient than the single engine. At 50% TPS and 70% LPG fraction, the lowest BSFC produced by a single-fuel engine is 0.31 kg/kWh at 1668 rpm, while the value for dual-fuel is 0.26 kg/kWh at 1720 rpm. As for 100% TPS and 70% LPG fraction, the amount produced by the single-fuel engine is 0.54 kg/kWh at 2592 rpm, while in the dual-fuel mode the value is 0.27 kg/kWh at 2784 rpm. This BSFC decline was caused by two things, namely due to increased power and the occurrence of a more efficient combustion process due to the presence of LPG. In this case, there was an increase in BSFC around 12% compared to the single-fuel mode. This proved that the use of dual-fuel engines might save fuel consumption.

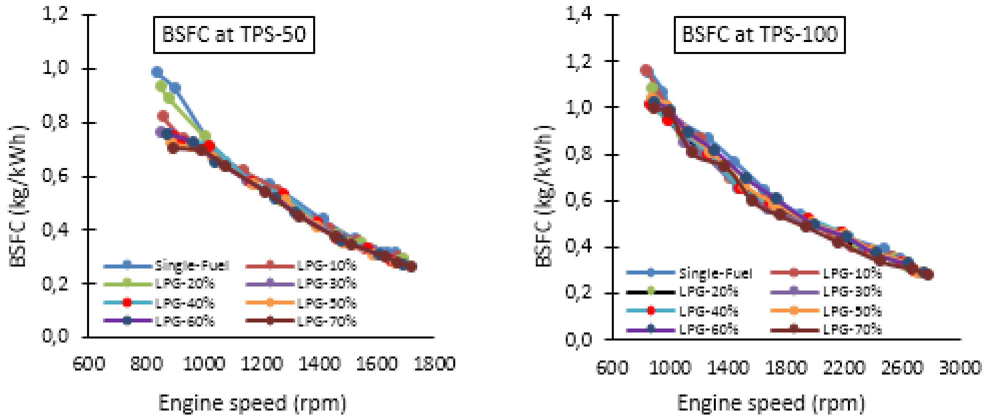

Figure 4. BSFC for various LPG fraction and throttle positions.

3.4. Brake thermal efficiency (BTE)

BTE is the ratio of the power produced and the power of the supplied fuel. To calculate the value of the BTE, equation (5) is used. Figure 5 shows the relationship between BTE and engine speed for various variations of LPG fraction. At the TPS 50% and 70% LPG fraction, the maximum BTE produced by the single-fuel engine is 30.85% at 1668 rpm, while the maximum BTE generated by the dual-fuel engine is 31.87% at 1720 rpm. As for the TPS 100% and 70% LPG fraction, the value produced by the single-fuel engine is 27.82% at 2592 rpm, while the value in dual-fuel mode is 30.31% at 2784 rpm. Thus, in dual-fuel mode, there was an increase of BTE by about 9%. The improvement of BTE in a dual-fuel engine was caused by the fact that there is more heat produced by the combustion compared to the single-fuel mode. It also proved that in dual-fuel mode, there was an increase in the efficiency of biodiesel combustion.

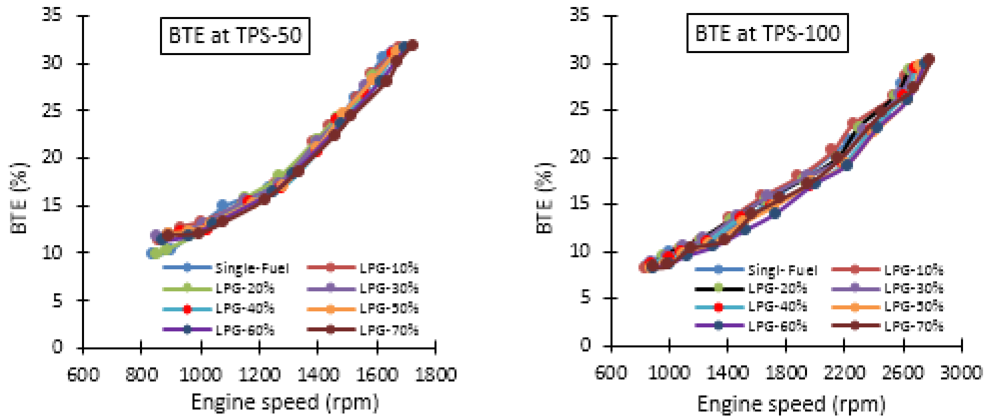

Figure 5. Brake thermal efficiency for various LPG fraction and throttle positions.

3.5. Economic analysis

From the test results described above, the use of dual-fuel engine could significantly reduce the level of fuel consumption, which was around 20%. However, this does not mean that the savings in operational costs also decrease by 20%, because the price of gas fuel is not the same as biodiesel price. The fuel price is strongly influenced by the transportation costs of these commodities. As a case study, operational costs were calculated for a small diesel engine used in remote areas, namely Mendol island, both for single and dual-fuel modes. In this case, the calculation of operating costs was based solely on fuel costs. It was assumed that the local price of biodiesel was IDR 10,500/liter, while the amount of LPG was IDR 6,000/kg, where the density of biodiesel is 0.82 kg/liter. In this study, calculations were made for the best-operating conditions, namely at 100% throttle position, with variations in the value of the LPG fraction. Based on power and BSFC data, as shown in figure 3 and 4, the operational costs and savings could be calculated. Table 3 shows the operating expenses and savings obtained, for various values of LPG fractions. It is clear that the use of a dual-fuel engine provides very significant savings, which is up to 40%. This substantial savings is undoubtedly attractive for residents on remote islands.

Table 3. Operational costs of single-fuel and dual-fuel engines at 100% TPS.

LPG fraction (%)	Engine speed (rpm)	Power (kW)	BSFC (kg/kWh)		Partial cost (IDR/kWh)		Total cost (IDR/kWh)	Cost saving
			B20	LPG	B20	LPG	B20+LPG	B20+LPG
0	2592	4.562	0.346	-	4310	-	4310	-
10	2618	4.657	0.293	0.035	3653	284	3938	8.6%
20	2644	4.707	0.250	0.064	3115	519	3634	15.7%
30	2674	4.799	0.214	0.094	2672	758	3430	20.4%
40	2690	4.826	0.179	0.121	2226	973	3199	25.8%
50	2720	4.883	0.144	0.146	1799	1181	2980	30.8%
60	2752	4.968	0.112	0.171	1401	1381	2781	35.5%
70	2784	5.140	0.081	0.194	1015	1560	2575	40.2%

4. Conclusions

It is concluded that the performance of dual-fuel engines generally increased compared to single-fuel engines. The best performance of a dual-fuel engine occurs at 100% throttle opening and 70% LPG fraction. In this condition, there is a 20% maximum reduction in BSFC, and a maximum power increase of 12%, compared to a single-fuel engine. BTE and torque increases by 9% and 5%, respectively. It is also concluded that the performance of the dual-fuel engine generally increases compared to the single file mode. Another exciting conclusion is that the use of dual-fuel B20-LPG engines might reduce operating costs by up to 40%. As a general result, it can be concluded that the use of the B20-LPG dual-fuel engine has a great potential to be developed and applied on Mendol Island, and also in areas that are difficult to obtain diesel fuel.

5. Future works

The results of this study, as well as the results of previous researches on dual-fuel engines, need to be continued to obtain a more practical method that can be applied more easily, safely, efficiently and reliably. The research that needs to be conducted is to investigate the impact of using dual-fuel on combustion chambers and other engine components. Furthermore, research should be done to develop a conversion kit that can automatically regulate the engine operations to always be in optimal condition. Research on the use of a more flexible mixture of fuels, for example by mixing ethanol, methanol or butanol fuel into diesel fuel, and combining it with LPG or CNG is expected to improve the performance and economic value of dual-fuel engines. Furthermore, it is necessary to think about increasing the portion of biofuel in diesel fuel, for example to 30% or more.

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