THE OPTIMAL MIXING RATIO OF DIESEL-LPG DUAL FUEL IN A COMMONRAIL DIESEL ENGINE FOR PICK-UP TRUCK

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ABSTRACT

The Diesel-LPG dual fuel system is interesting in combustion emission, engine performance, and economic viewpoints. The injection of LPG gas in compensating diesel reduction during engine operation is studied in this research. The 2.5 L four-stroke, four-cylinder diesel commonrail engine, model 4jk1-TC, was modified with a port injection system for LPG so that LPG gas is injected precisely into the intake manifold of the engine. The engine performance test was carried out on the water-brake engine dynamometer to measure the essential parameters for calculating the engine performance with controlled environmental parameters, such as intake air temperature, inlet-outlet cooling water temperature, and cooling water mass flow rate. The experiments were carried out with 100% diesel baseline, 10% diesel reduction, and 30% diesel reduction. Within each diesel reduction condition, the experiment was performed with three variations of LPG gas injection mode G1, G3, and G5 to systematic measurement in constructing LPG injection mapping with engine speeds of 1500, 2000, 2500, and 3000 rpm.

According to the systematic study, the results could be analyzed to acquire optimal conditions for LPG injection with possible diesel reduction to maintain the engine performance varied with engine speed. The normal idle speed of a diesel engine is approximately 750 rpm. In the operating range of an engine speed from idle to 1500 rpm, the engine must be run only by diesel. The engine speed was increased from 1500 to 2000 rpm, and the engine was able to operate with 10% diesel reduction and LPG mode G1 injection. However, in these operating conditions, increasing LPG injection did not obtain any good result, such as engine pinging occurred. The higher engine speed is similar to actual running on the highway, the engine speed from 2200 to 3000 rpm can reduce more diesel obtaining 30% diesel reduction which LPG injection was increased to G3 to maintain the engine performance, and higher power was gained from the engine in comparison to the conventional diesel fuel.

KEYWORDS: diesel commonrail engine, diesel dual fuel, LPG

1. Introduction

Transportation sector is the largest energy consumption which consumed 30,190 ktoe/year as reported in Thailand Energy Efficiency situation 2016 by Ministry of Energy Thailand [1]. Mostly, the energy consumption in transportation sector is dominated by logistics business using heavy truck, light-truck and pick-up truck. In transportation and logistics businesses, the services are provided to carry weight such as goods and people which is trying to carry at maximum capacity of the vehicles in terms of either weight or volume. Therefore, the vehicles used for transportation and logistics should have enough torque and power for the missions. Recently, the trucks are used widely in logistics and transportation sector which is driven by diesel engine. To date, the diesel engine is based on common rail direct injection technology with and without turbo charger. The diesel fuel price is increasing every year due to world demand and environmental tax. Moreover, exhaust emission from the diesel engines heavily polluted the atmosphere which contains soot, CO and NOx especially for natural aspirated engine. There are many research work reported that diesel combustion dual with gas fuel could reduce incomplete emissions.[2] Not only incomplete emissions but also the total fuel cost could be reduced by using gas fuel together with diesel oil. To overcome the price competitiveness in the business, Logistics Company may replace the original engine after worn-out with gasoline engine but installed a natural gas (NG) injection system so called re-powering since natural gas for vehicle (NGV) is cheaper than diesel. The other way of reducing fuel cost is using dual-fuel engine which NGV and LPG are typically used. However, the dual-fuel injection must be precisely injected into the engine with appropriate time and engine speed and not affecting the engine performance. The most popular dual-fuel engine is modification of gasoline engine with Liquefied Petroleum Gas (LPG) injection. But the gasoline (C_8H_{18}) with LPG (C_3H_8/C_4H_{10})

dual fuel is available in only for passenger cars.

It is clearly seen that LPG exhibits higher energy content giving more power output than NGV. In this research, a diesel common rail engine was studied with LPG dual fuel injection system. Then the Isuzu 4JK1-TC diesel common rail engine was selected to install LPG injection system on the intake manifold. The reduction of diesel injection was systematically studied with several LPG injection modes. The optimal conditions could be obtained to remap the ECU controller.

2. Methodology

The Isuzu truck is one of popular vehicle used in logistics and transportation in Thailand. Then the Isuzu engine model 4JK1-TC was selected in this study. The manufacturer specification of an engine is shown in table 1.

Table 1 Manufacturer specification of 4JK1-TC engine

Engine model	Isuzu 4jk1-TC
Engine type	4 stroke, 4 cylinders in-line
Bore	95.4 mm
Stroke	87.4 mm
Engine displacement	2,499 cc
Compression Ratio	18.3:1
Max. Power	116 Hp at 3,600 rpm
Max. Torque	280 N.m at 2,200 rpm
Fuel injection system	Direct Injection
Firing order	1 – 3 – 4 – 2
Injection Pump	Common rail

The standard engine was then modified to install the LPG injection system mounted on the intake manifold of the engine. The LPG injection system was also equipped with the liquid evaporator and pressure regulator to ensure the LPG gas flow rate. The LPG injection set up is shown in Figure 1.

Figure 1 The LPG injection system installed with the engine

The LPG injection system was integrated with its controller which injection timing was calculated and commanded with measuring signals of intake camshaft position, driving pedal, engine rpm and intake manifold pressure. The original engine sensors were installed such as engine rpm, cooling water temperature, throttle position and driving pedal position. The additional sensors were installed necessarily for the LPG injection system such as intake manifold pressure, knocking sensor and exhaust gas temperature. The ECU controller and sensors installation diagram is demonstrated in Figure 2.

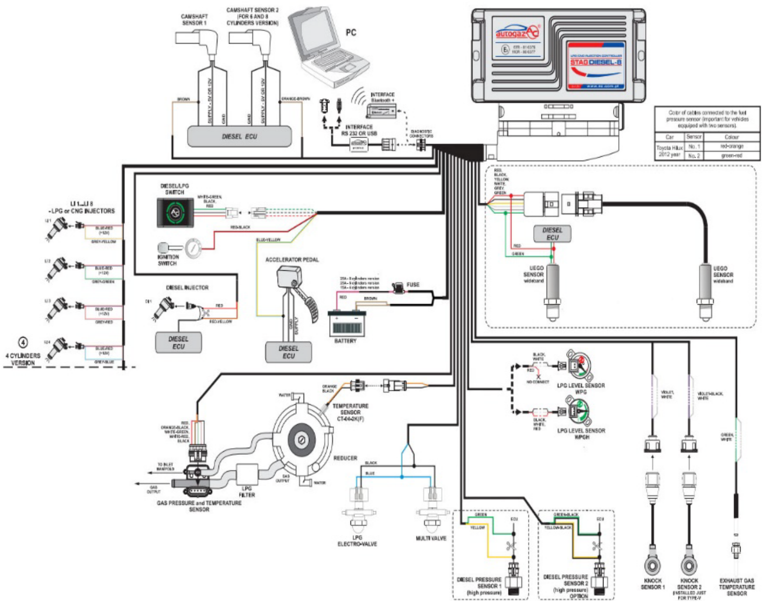

Figure 2 Electronics controllers and sensors installation diagram

The LPG injection could be adjusted with manufacturer software to reduce the diesel injection together with indicating LPG injection mapping with engine rpm. The LPG injection mode ranges from “0”, which means no LPG injection, to the maximum flow rate for “9”.

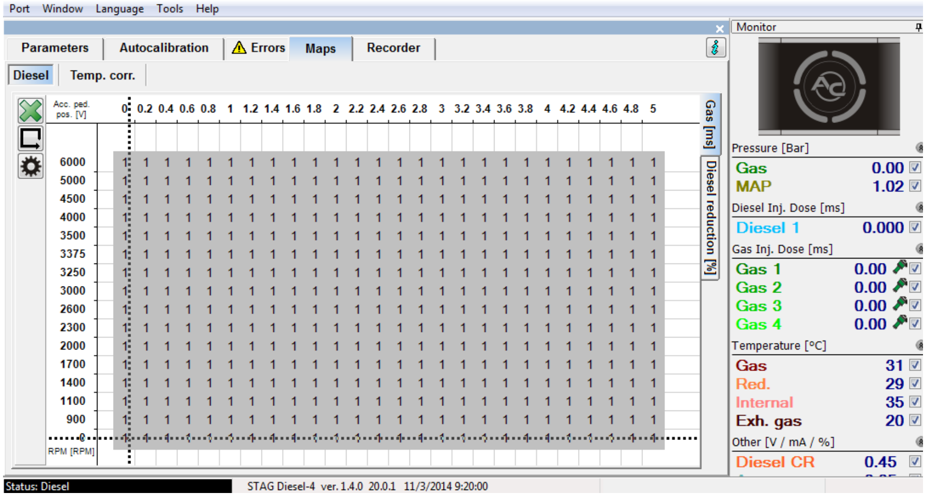

Figure 3 LPG injection system software mapping

The engine was coupled with Eddy current dynamometer to measure the parameters for calculation engine performance such as engine rpm, engine torque, fuel consumption, inlet and outlet temperature of cooling water, exhaust gas temperature, intake air temperature and air flowrate. The intake air temperature is constantly controlled by the insulated air chamber with temperature and humidity control. A photo of engine dynamometer test set is shown in Figure 4. The schematic diagram of measuring data for engine performance test is also shown in Figure 5.

Figure 4 A photo of engine dynamometer test set

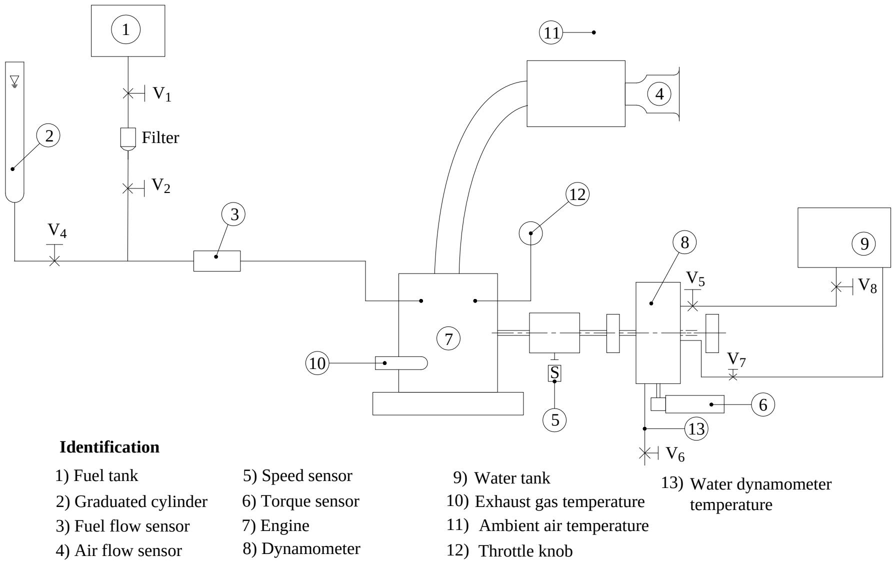

Figure 5 Schematic diagram of measuring data for engine performance test

In this study, the experiments were carried out in six conditions. First of all, the engine was tested to obtain a baseline with typical diesel running which was also checked the reliability of the test bench so called diesel 100% condition. Then the diesel injection conditions were reduced by 10% and 30% indicated diesel 90% and 70% of baseline injection respectively. The LPG injection was started herewith the reduction of diesel for each conditions with G1, G3 and G5 injection mode. The experiments were also carried out with constant engine speed at 1,500, 2,000, 2,500 and 3,000 rpm throughout all test conditions with three repeated tests. During the performance test, the engine was given mechanical load by Eddy current dynamometer at every 20 N.m until full throttle or abnormal incidence. All measuring data were then calculated to obtain engine performance such as engine torque, engine power, brake specific fuel consumption and engine thermal efficiency.

Engine power could be calculated as shown below

$$P = \frac{2\pi n\tau}{60000} \quad \text{(kW)} \qquad (1)$$

where n = Engine speed (rpm)

τ = Engine torque (N·m)

Then brake specific fuel consumption (bsfc) is calculated by

$$bsfc = \frac{\Delta M/\Delta t}{P} \quad \text{(g/min /kW)} \tag{2}$$

where ΔM = Accumulated fuel consumption)g)

Δt = time (minute)

Engine thermal efficiency is also calculated

$$\eta = \frac{P}{\frac{\Delta M}{\Delta t} \times HV} \tag{3}$$

where HV = Fuel heating value (kJ/kg)

3. Results and discussion

The experimental results obtained from the three repeating tests were average straight forward. The average values were then plotted which figure 5 demonstrated engine torque versus engine speed. The baseline data shows the torque curve in good correlation with standard engine. It is obviously seen that diesel 90% with LPG injection mode G1 was obtained at the same performance with the baseline range from 1,500-2,000 rpm. Increasing engine speed from 2,200 rpm to 3,000 rpm, only 90% diesel with LPG injection mode G3 was able to maintain the engine performance. The other conditions with rather decrease the diesel consumption with increasing LPG injection were not enough to maintain the engine power.

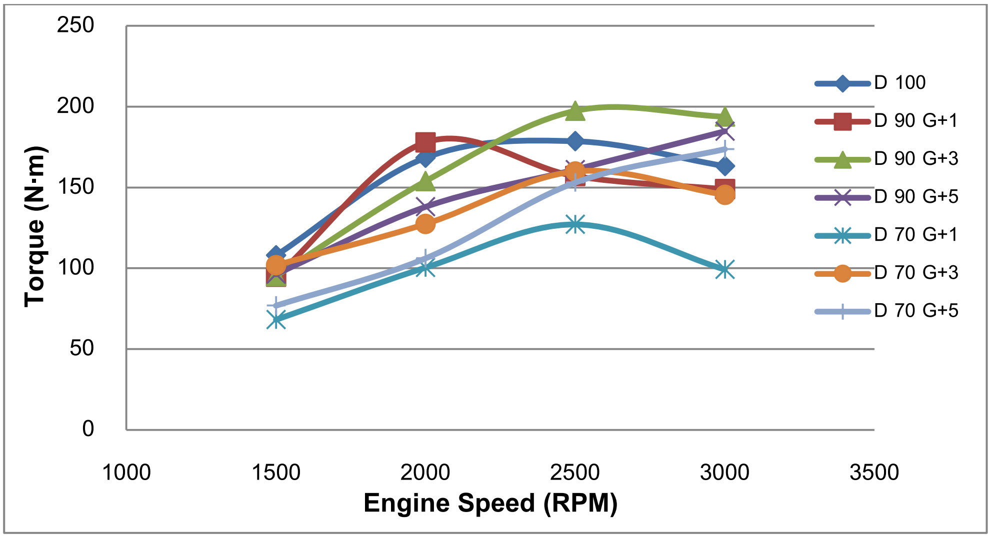

Figure 6 A plot of engine torque vs engine speed

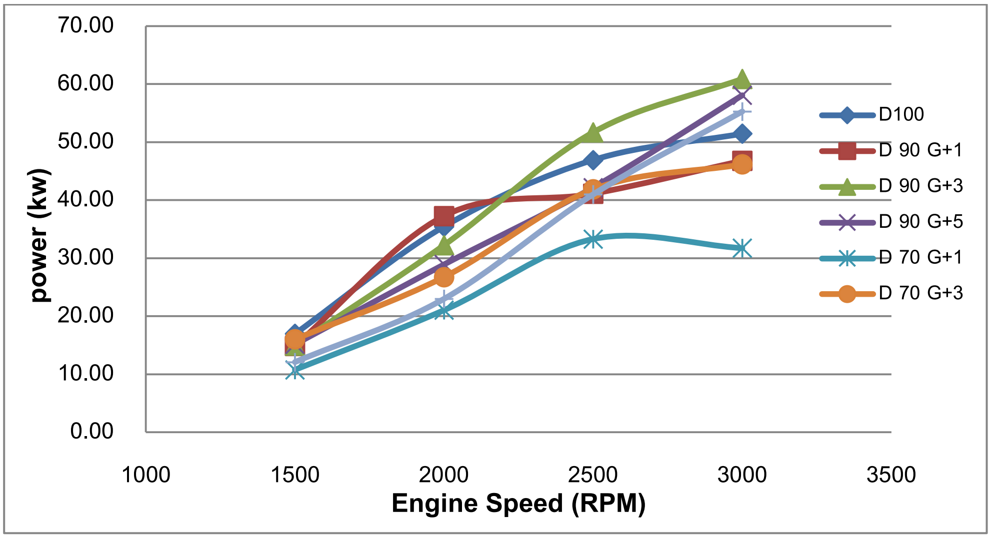

Figure 7 A plot of engine power and engine speed.

This experiment shows the power and speed of the engine. The effect of the power is the same as the torque because the power of the engine is derived from the torsion as the main variable used in the calculation. The researcher would like to clarify this information. During the engine cycle at 1500 rpm, the diesel power was higher than the gas mixture. During idle periods up to 1,500 rpm, there is no need to fill for liquid petroleum gas.

At 2,000 rpm, the reduction of diesel by 10% and adding gas at the level G1. The power is increased 5.1%, compared to diesel alone.

At 2,500 rpm, the reduction of diesel by 10% and adding gas at the level G3. The power is increased 10.16%, compared to diesel alone.

At 3,000 rpm, the reducing diesel by 10% and adding gas at the level G3. The power is increased 18.36%, compared to diesel alone.

There are two tuning adjustments which make the higher power when they are compared to diesel alone. The reduction of diesel 10% and G + 5 gas (D90 G + 5), the power increase 18.26%. The reduction of diesel 30% and G + 5 gas (D70 G + 5), the power increase 7.42%.

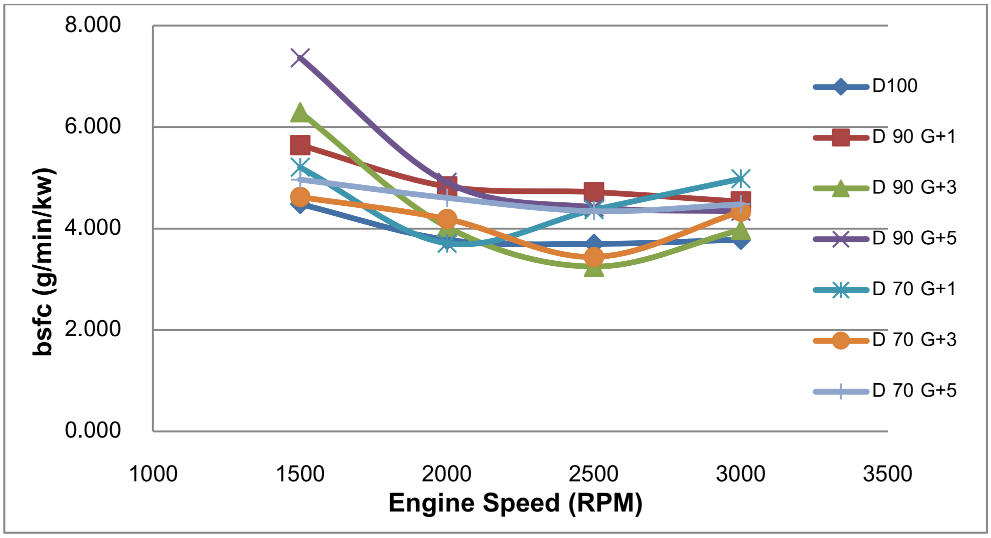

Figure 8 A plot of Specific fuel consumption (bsfc) with engine speed

Specific engine fuel consumption ratio is the ratio of fuel flow to engine power. At 1,500 rpm, diesel consumption is the lowest specific fuel consumption And the second is by reducing diesel emissions by 30% and delivering gas at G3 (D70 G + 3), the specific fuel consumption is 3.1%.

At 2,000 rpm, diesel reduction of 30% and G1 (D70 G+1) gas supply resulted reduction in specific fuel consumption 1.91% compared to diesel alone.

At 2,500 rpm, the reduction of diesel by 10% and the G3 (D90 G+3) gas supply resulted reduction in specific fuel consumption 12.09% compared to diesel alone.

At 3,000 rpm, diesel consumption is the lowest specific fuel consumption. And the second is by reducing diesel by 10% and delivering gas at G3 (D90 G+3), the specific fuel consumption is 3.1% compared to diesel alone.

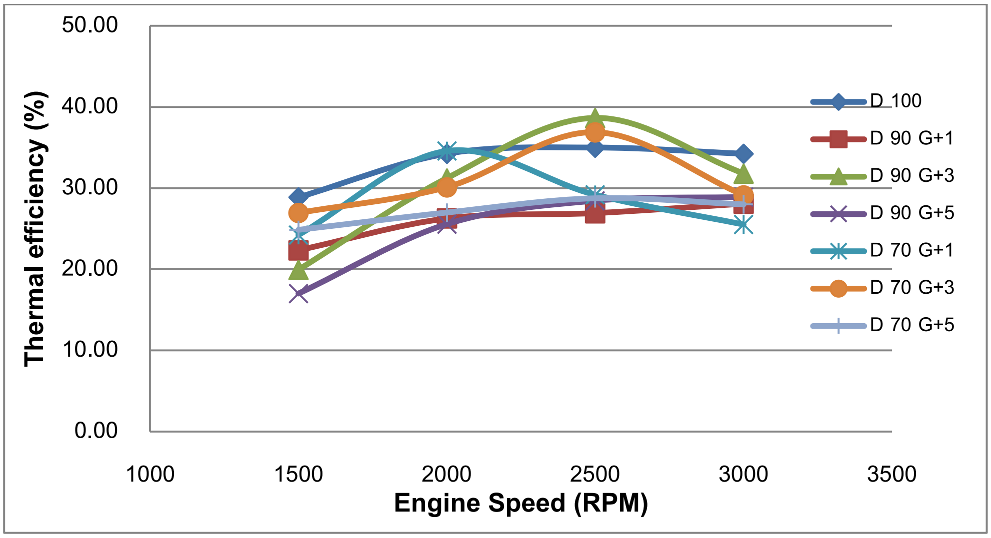

Figure 9 A plot of Thermal efficiency with engine speed

Thermal performance of the engine reflects the ability to convert heat energy from fuel combustion to shaft power output.

At 1,500 rpm, the diesel alone (D100) gave the maximum engine thermal efficiency at 28.87%.

At 2,000 rpm, the reduction of diesel fuel by 30% and gas supply at G1 (D70 G + 1) is the maximum thermal efficiency at 34.58%., meanwhile, the use of diesel alone gives a performance of 34.25% only.

At 2,500 rpm, the reduction of diesel fuel by 30% and gas supply at G3 (D70 G + 3) is the maximum thermal efficiency at 38.66%. The use of diesel alone gives a performance of 35% only.

At 3,000 rpm, diesel alone (D100) gives the maximum engine thermal efficiency at 34.24%.

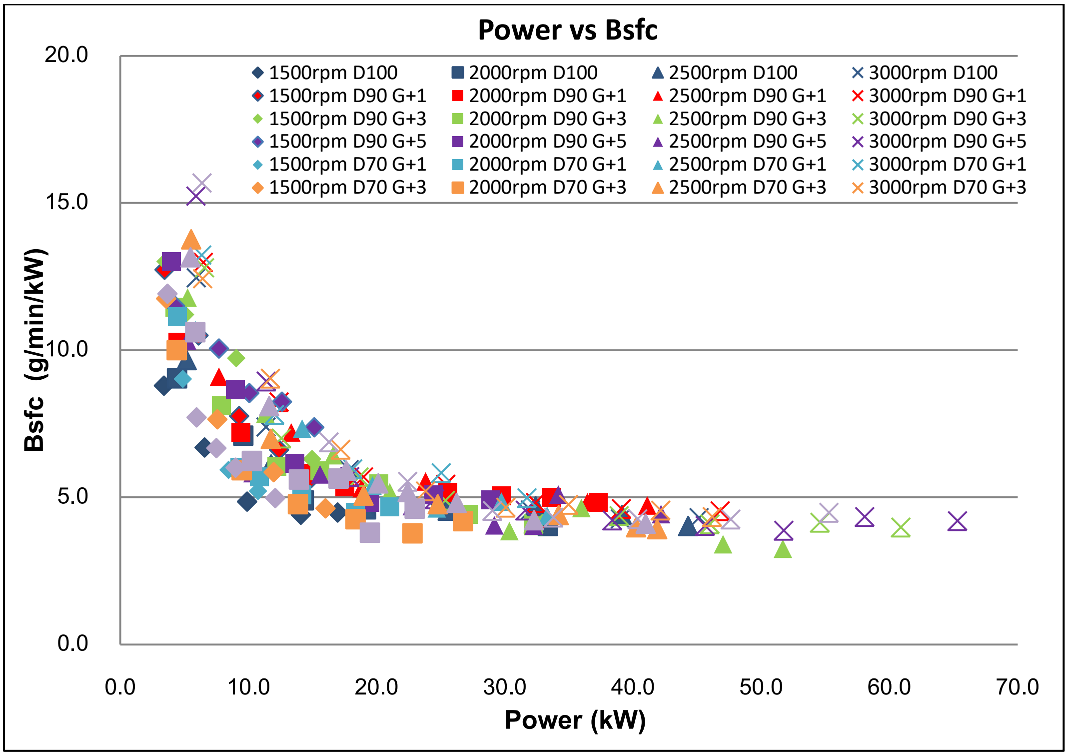

Figure 10 Specific fuel consumption (bsfc) with engine power

From figure 10, the results of the specific fuel consumption were compared with the engine power. The results of the experiment were modified by changing the engine speed and the amount of dispensing diesel and liquefied petroleum gas. By all trials, the load on the engine was increased by adding 20 N-M and recorded the maximum engine load. This result shows that at 1,500 rpm, it is not suitable for liquid petroleum gas distribution. Because it does not save cost and reduces the power of the engine. The lower ingredients may be sufficient. More gas supply may make the mixture too thick. Incomplete complete combustion affects the pressure of the cylinder. When if the mixture using in dual fuel is appropriate, it will cause higher engine power. Too much or too little mixture will give bad results with the engine.

4. Conclusion

This experiment shows that the appropriate proportion of diesel and LPG fuel can increase the torque and thermal efficiency of the engine but the fuel consumption is lower.

At this mixture rate, each engine speed range and engine load will give the different performance. Collecting data by increasing fuel consumption and engine load from the lowest to the highest enable us to see the changes and abnormalities that occur with the tested engine. The results have been analyzed and selected for tuning at 1,500-3,000 rpm. During the idling period up to 1,500 rpm, only diesel is used because the use of dual fuel will decrease engine performance. At 2,000 rpm range, diesel fuel is reduced 10% at G1 (D90 G1) at 2,500- 3,000 rpm, diesel fuel is reduced 10% at G3 (D90 G3). The test data of this tuning, we can use each proportion of fuel in different condition such as tuning the engine economically and tuning the engine to get more engine power. The tuning of the composite rate is the exhaust heat value. Too high heat of the exhaust is a sign that the temperature in the combustion chamber is higher. This may damage the parts inside the engine and make knock down engine. The noise and engine temperature will rise rapidly. [3] The engine knock detector is installed in the system to detect the knock that occurs in the combustion chamber. These two signs are used to cut off liquid fuel gas, and diesel is used instead until the engine returns to normal operation to prevent damage to the engine [4].

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