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CHARACTERISTICS OF 1500 CC LPG FUELED ENGINE AT VARIOUS OF MIXER VENTURI AREA APPLIED ON TESLA A-100 LPG VAPORIZER

Muji Setiyo[a]*, Budi Waluyo[a], Mohammad Husni[b], Djoko Wahyu Karmiadji[c]

[a]Department of Automotive Engineering, Muhammadiyah University of Magelang, Magelang, Indonesia
[b]Department of Autotronic, Vocational Education Development Center, Malang, Indonesia
[c]Agency for the Assessment and Application of Technology, Jakarta, Indonesia

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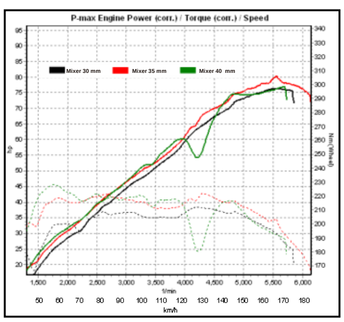
*Corresponding author
setiyo.muji@ummgl.ac.id

Graphical abstract



Abstract

In the first generation of LPG kit, are called Converter and Mixer (CM), the engine power is influenced strongly by the size of mixer venturi, but this case has not been widely discussed. LPG has lower carbon content than gasoline, so it requires less air to burn. Theoretically, the amount of air to burn LPG is 46% lower than gasoline. However, in practice, the venturi area of the mixer is made from 7.5 mm^2 to 10 mm^2 per output hp engine. To confirm this, the mixers with venturi area of 705, 960, and 1256 mm^2 are applied in Toyota 5A-FE LPG-fueled engine with Tesla A-100 LPG vaporizer. The engine performance characteristics were tested using the Hofmann Dynatest Pro chassis dynamometer and the emissions were tested using QRO-401 engine gas analyzer. The result shows that the venturi area of the mixer has a major influence on the engine power, which generates specific power characteristics. However, differences in the mixer size have little effect on emissions. This study concluded that the Toyota 5A-FE LPG-fueled engine is recommended to use a mixer with venturi area of 960 mm^2 (35 mm in diameter).

Keywords: LPG fueled engine, mixer, venturi area, engine performance

1.0 INTRODUCTION

LPG-fueled vehicles show significant progress in the past decade. Until 2015, World LPG Association reported more than 25 million LPG vehicles worldwide [1]. As one of the benefits, LPG vehicles produce lower emissions than gasoline [2-4]. However, the power produced by LPG engines was reported lower than gasoline, ranging from 5-20% [5-8]. Some researchers agree that the power reduction in LPG engine is affected by volumetric efficiency [9-11]. In the first generation of LPG kit, are called Converter and Mixer (CM), the engine power is influenced strongly by the size of mixer venturi [12], but this case has not been widely discussed. On the other hand, the CM LPG kit is the most widely used [1]. Therefore, this study focuses on the characteristics of LPG engine performance on variations of mixer venturi area. The results investigation may be one consideration in choosing the right mixer for the engine.

For the existing alternative fuels, LPG is the popular fuel besides methanol, ethanol, natural gas, and hydrogen [13]. LPG can directly substitute for gasoline and can use for the existing vehicle technology. LPG is the generic name for a mixture of propane (C_3H_8) and butane (C_4H_{10}); it may also include different hydrocarbons such as ethane, pentane, propylene, i-butane and n-butane in small amounts. It is most widely used and accepted worldwide, especially for spark ignition engine [13-16].

LPG is derived from crude oil, natural gas extraction, and oil processing into petroleum products at the refinery. Worldwide, about 60% of LPG is derived from crude oil and natural extraction of gas and about 40% of the refinery production [17]. In cold weather, more propane use in the proportion of 60-40%, where at higher temperatures may contain more butane (up 60%). LPG is maintained in storage tanks pressurized fluid throughout the infrastructure to fueling stations as well as in the vehicle. Liquid LPG is finally converted from a gaseous form into the vehicle's engine.

Global consumption of LPG showed significant growth, approximately 22.9 million tons in 2010 and reached 26.4 million tons in 2014. Now, there are more than 25 million LPG vehicles uses worldwide by more than 70 thousand refueling site [1]. However, consumption of LPG has not been evenly distributed and concentrated only in few countries. South Korea, Turkey, Russia, Thailand, and Poland being the top ranked of consumption and the number of LPG vehicles. The successful of using LPG depends on the government policy, including the prices and taxes.

LPG has been promoted as a fuel producing lower emission than the conventional fuels and also is known as the green fuel. It produces cleaner burning, less carbon crust, and less contamination of the engine oil. The US Department of Energy reported that LPG not only has lower greenhouse emissions than gasoline and CNG but also exceeded the molar amount of other fuels such as methanol and ethanol [18]. The CO, CO_2, HC, and NO_x produced by LPG engines are lower than gasoline engines, both on urban cycle and extra-urban cycle [1]. However, as a result of its properties, LPG gives a negative effect on the engine performance. It produces lower power output than the gasoline engines, ranging from 5% to 20% [5-8]. Several methods have been done to improve power loss, but the ignition timing adjustment is the most widely applied [19-23].

LPG has a high octane rating, up to 112 RON [3], makes it possible to be applied to the engine with a higher compression ratio, and thus provides a higher thermal efficiency [24]. The compression ratio of LPG engine compared to the others fuels is presented in Table 1.

Table 1 Engine types, fuel systems, and compression ratios for various fuels [25]

Fuel	Engine type	Fuel system	CR used
Gasoline	SI	mono	Up to 11
Diesel	CI	mono	18 (DI), 22 (IDI)
LPG	SI	dual, mono	11-13
Natural gas	SI	dual, mono	11-13
Methanol	SI, CI, FC	FFV, mono	9 (FFV)
Ethanol	SI	FFV, mono	9 (FFV)
Biodiesel	CI	mono (FFV)	Similar to diesel
Hydrogen	SI, FC	dual, mono	14-17
DME	CI	mono	Similar to diesel

The abbreviation in Table 1 consists of CR = Compression Ratio; CI = Compression Ignition; SI = Spark Ignition; FC = Fuel Cell; mono =vehicles running on only one fuel; dual = vehicles with two fuel systems, able to switch between the two fuels; and FFV = Flexible-fuelled vehicle, able to run on two different fuels or a mixture of them. Then, the air to fuel requirement for LPG compared to the others fuels is presented in Figure 1.

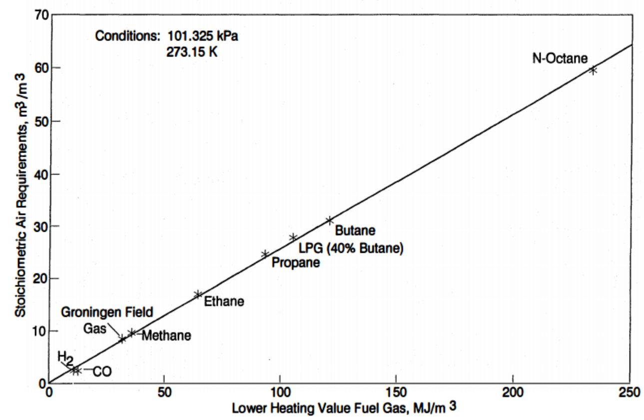


Figure 1 Stoichiometric air requirements for various fuels [26]

Generally, the LPG-fueled vehicle is operated by the bi-fuel system that it needs only slight modifications without removing the existing fuel system. The Bi-fuel vehicle is able to be switched back and forth from gasoline to the LPG, manually or automatically [27]. Until now, the Converter and Mixer (CM) LPG kits are the most widely used than Vapor Phase Injection (VPI), Liquid Phase Injection (LPI), and Liquid Phase Direct Injection (LPDI) types [1]. The schematic of CM types is presented in Figure 2. It is simple and compatible with carburetor and injection engines.

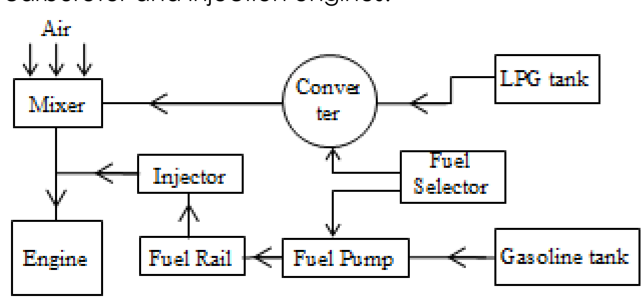


Figure 2 The schematic of converter and mixer LPG kits

In the Converter and Mixer LPG kits, LPG is stored as a liquid in LPG tank (separate steel or composite vessel) at the pressure of 8 -10 bar. LPG supply to the engine is controlled by a converter, which converts the LPG to a vapor. Then, the vapor is supplied to the mixer mounted on the throttle body, where it is mixed with air before being pulled into the combustion chamber. Finally, it is burned to produce power, as the same as using gasoline.

The converter, mostly called vaporizer, has two major functions; those are to heat up the liquid LPG and to regulate the amount of LPG that goes to the engine. Normally, to heat up the liquid LPG is done by circulating engine coolant throughout the vaporizer cavities. On the other hand, some engines have an air cooling system. In that case, the liquid LPG has to be preheated by a special heat exchanger installed in the exhaust system or by ambient air from a special fan [28]. In order to regulate the amount of LPG that goes to the engine, the vaporizer works together with a mixer to keep the right mixture of LPG and air.

Currently, various mixer designs are available for the various cars. The manufacturer of mixers has to work out the best mixer for every car. The mostly result is that the mixer gives a right mixture in the partial load and a lean mixture at full load. Not only is the shape of the mixer important but also the size of the venturi [12]. The smaller the diameter of the venturi, the higher the vacuum signals to the converter and the more accurate the LPG flow. However, a small venturi causing the engine's volumetric efficiency will decrease.

The area of a mixer venturi in principle is to get an accurate mixture. Base on the air composition, this consists of 21% oxygen and 79% nitrogen, and for an ideal gas mixture, percent of volume equals to the mole. Each mole of oxygen in the air consists of 79/21 mole of nitrogen. The mole number of nitrogen per mole of oxygen equals 3.76 moles of nitrogen. Therefore, an ideal combustion formula in gasoline and LPG is given as follows.

1. Combustion on gasoline

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2 \quad (1)$$

Then, the theoretical AFR for gasoline fuel is

$$AFR_{gasoline} = \frac{12.5(1+3.76)}{1}\frac{kmol\ air}{kmol\ gasoline}$$

$$AFR_{gasoline} = 59.5\ \frac{kmol\ air}{kmol\ gasoline}$$

2. Combustion on pure propane

$$C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \quad (2)$$

Then, the theoretical AFR for pure propane fuel is

$$AFR_{propane} = \frac{5(1+3.76)}{1}\frac{kmol\ air}{kmol\ propane}$$

$$AFR_{propane} = 23.8\ \frac{kmol\ air}{kmol\ propane}$$

3. Combustion on pure butane

$$C_4H_{10} + 6.5(O_2 + 3.76N_2) \rightarrow 4CO_2 + 5H_2O + 24.4N_2 \quad (3)$$

Then, the theoretical AFR for pure butane fuel is

$$AFR_{butane} = \frac{6.5(1+3.76)}{1}\frac{kmol\ air}{kmol\ butane}$$

$$AFR_{butane} = 30.95\ \frac{kmol\ air}{kmol\ butane}$$

From eq. (1)-(3), the theoretical AFR for LPG mix (50% propane, 50% butane) can be calculated as follows

$$AFR_{LPG} = \frac{23.8+30.95}{2}\frac{kmol\ air}{kmol\ LPG}$$

$$AFR_{LPG} = 27.38\ \frac{kmol\ air}{kmol\ LPG}$$

Assuming that the size of the throttle body of a car is ideal for establishing the accurate mixture, the ideal area of mixer venturi can be estimated as follows.

$$A_{LPG} = \frac{AFR_{LPG}}{AFR_{gasoline}} \cdot A_{gasoline} \quad (4)$$

Where, A_{LPG} is the ideal area of mixer venturi, AFR is the air to fuel, and $A_{gasoline}$ is the actual area of the throttle body.

In this study, the Toyota 5A-FE engine has throttle body of 58 mm in diameter (2640 mm^2 in area). Using equation (4), the ideal area for LPG mixer venturi is

$$A_{LPG} = \frac{27.38}{59.5} \cdot 2640\ mm^2$$

$$A_{LPG} = 1215\ mm^2\ (39.4\ mm\ in\ diameter)$$

However, Hugo van Osch [12] recommends that the ideal area of mixer venturi is 10 mm^{2}per hp engine powers. On preliminary studies using gasoline, this engine produces of 81.6 hp at 5550 rpm. The characteristic of engine power throughout the engine rotation is presented in Figure 3.

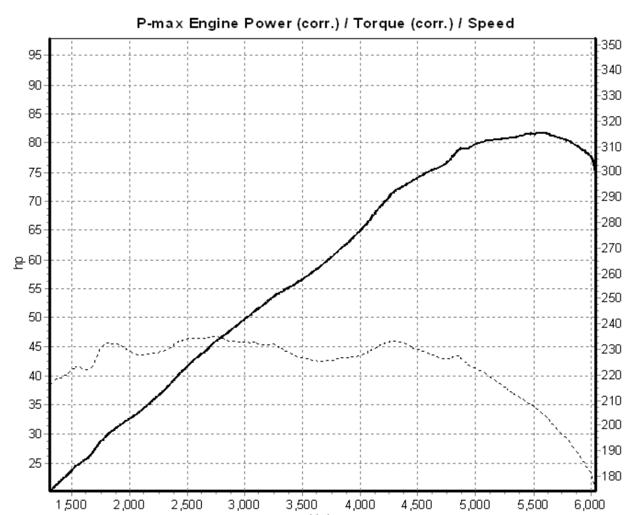


Figure 3 The Toyota 5A-FE power characteristic on preliminary study using gasoline

From Figure 3, the area of mixer venturi in this engine can be made approximating 816 mm^2 (32.2 mm in diameter). To confirm it, the engine was tested to determine the effect of the mixer venturi area to the engine power characteristics throughout the engine rotation from 1500 to 6000 rpm. The mixer venturi were tested are 705, 960, and 1256 mm^2 (30, 35, and 40 mm in diameter) applied on Tesla A-100 LPG vaporizer. Furthermore, the exhaust emissions tested for all mixer size at idling.

2.0 METHODOLOGY

2.1 Materials

The engine used in this study is a Toyota 5A-FE that has been modified to the bi-fuel system. When the engine is running by LPG, the ignition timing is adjusting at 15°BTDC. The engine specification is shown in Table 2. While the converter and mixer is presented in Figure 4 and Figure 5, respectively.

Table 2 Engine specification

Engine manufacturer	:	Toyota
Engine code	:	5A-FE
Cylinders	:	Inline 4
Capacity	:	1498 cc
Bore × Stroke	:	78.7 × 77 mm
Valve mechanism	:	DOHC, 4 valves per cylinder
Maximum power output	:	77 kw @ 6000 rpm
Maximum torque	:	135 Nm @ 4800 rpm
Compression ratio	:	9.8:1
Fuel system	:	EFI

Figure 4 The LPG converter used in this study

Figure 5 The mixer used in this study, with 30, 35, and 40 mm of venturi diameter

2.2 Engine Testing

For testing the engine power, a Hofmann Dynatest Pro chassis dynamometer was used in “Program P-Max” menu. This test was done to obtain the engine curve (power and torque). Coast-down test procedure has been performed to obtain the actual vehicle characteristics. The vehicle was accelerated from standstill to maximum speed by changing gears smoothly but quickly. Once the level of maximum power has been exceeded, the clutch was disengaged and the car was allowed to coast-down. During coasting, power loss is constantly inspected. The measured parameters of power, velocity, and torque are obtained. The experimental set up of this study is shown in Figure 6.

Figure 6 Experimental set up and test facilities

Furthermore, exhaust emissions was tested using QROTECH QRO-401 engine gas analyzer at idling. Emission test performed on the condition of the engine is operating with gasoline and LPG for all size of mixer investigated. Then, the emissions test results compared to power test results to make recommendations.

3.0 RESULTS AND DISCUSSION

3.1 Engine Power Characteristics

In this study, the engine was tested at Wide Open Throttle (WOT). Data was recorded from 1500 to 6000 rpm. A series of tests showed that the area of mixer venturi has a major influence on the engine power (Figure 7). Mixer with venturi diameter of 30 mm produces maximum power output 76.3 hp @ 5584 rpm. The best maximum power output is obtained from the mixer with venturi diameter of 35 mm, which is 80.3 hp @ 5550 rpm. Meanwhile, a mixer with venturi diameter of 40 produces maximum power output equal to a mixer with venturi diameter of 30 mm, but in the engine rotation of 4000 to 4500 rpm, loss torque has occurred. At engine rotation below 4000 rpm, mixer with a venturi diameter of 40 mm produces the best performance among the three.

The test results indicate that the smaller the size of mixer venturi produces less power. However, the larger the size of the mixer venturi will provide good power at low engine rotation, but it gives an ugly power at high engine rotation. This agreed with Osch [22], that a mixer provides the best power only on the partial condition. However, the 5A-FE engine, the use of 35 mm of mixer venturi is recommended. This mixer is able to produce a consistent power throughout the engine rotation.

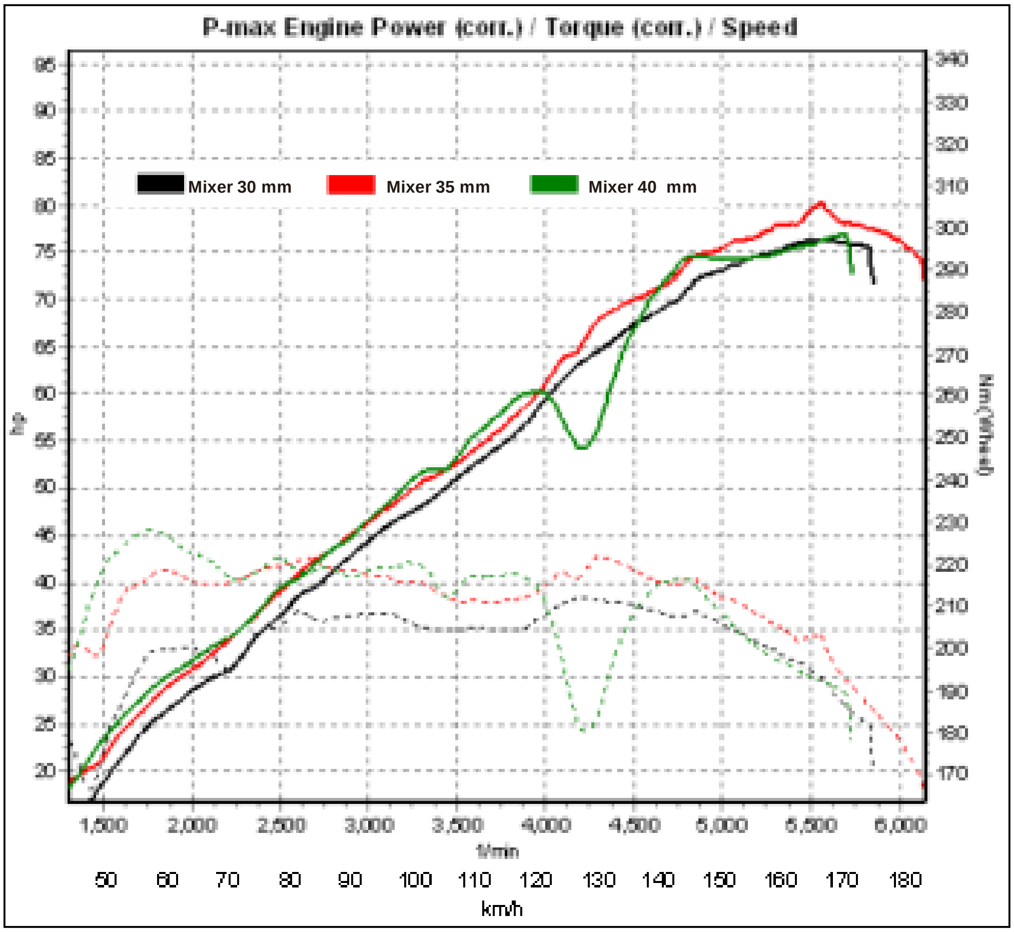


Figure 7 Engine power characteristic for various venturi diameter of LPG mixer

Inspection of Figure 7, in the application on city car or public transportation such as taxis, the mixer with diameter venturi of 35 mm and 40 mm are better than the mixer with diameter venturi of 30 mm. Due to the loss power in the mixer with diameter venturi of 40 mm occur at high engine rotation (4000 rpm) and high vehicle speed (120 km/h), this will not be a problem at light duty vehicles. The city car and taxis seldom work in these conditions. On the other hand, referring to the Figure 3 and Figure 7, the best performance of LPG-fueled engines as a result of this study is still lower than using gasoline throughout the engine rotation and vehicle speed. The disparity is even greater due to higher engine rotation.

3.2 Emission Characteristics

Figure 8 and Figure 9 present the results of emission from engine fueled gasoline and LPG for parameter of CO and HC, respectively. These results confirm the previous researchers [2-4], although with different numerical values. Test results show that the use of LPG significantly decreased on CO and HC. Meanwhile, the mixer size does not affect emissions significantly.

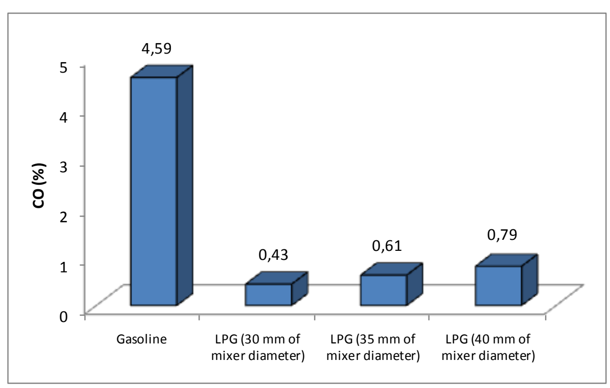


Figure 8 CO characteristic for various venturi diameter of LPG mixer compared to gasoline

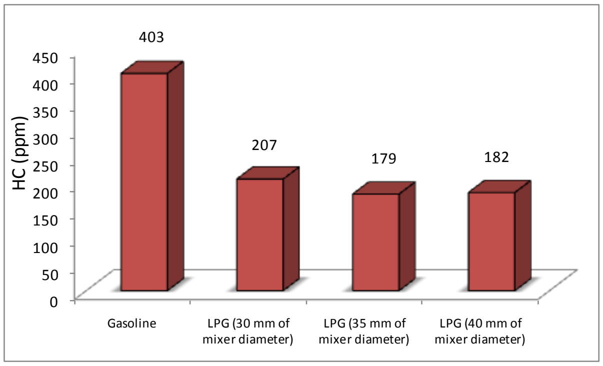


Figure 9 HC characteristic for various venturi diameter of LPG mixer compared to gasoline

Emission test results reinforce that LPG as an alternative fuel substitute for gasoline is promising for the present [29]. It is known that emissions from road vehicles have been affected in urban air quality. This is important because it impacts on human health, the troposphere ozone production, and global climate [30]. Reducing the oil dependence by diversifying into alternative fuel is a major challenge for the transport sector in the future. On the other hand, development and application of alternative fuels need comprehensive consideration related to the availability the raw materials, production process, distribution infrastructure, and compatibility with the existing engine technology [16].

4.0 CONCLUSION

In this study, LPG mixers with venturi area of 705, 960, and 1256 mm^2 (30, 35, and 40 mm in diameter) have been tested in order to obtain the best performance on Toyota 5A-FE engine fueled LPG. A series of tests showed that the area of mixer venturi has a major influence on the engine power. For each size of mixer venturi, the engine generates specific power characteristics. However, differences in the mixer size have little effect on emissions. Both CO and HC of LPG engine for all mixer size is lower than gasoline engine. In conclusion, the Toyota 5A-FE engine fueled LPG for public fleet is recommended by using the mixer with venturi diameter of 35 mm.

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