AIP Conference Proceedings

RESEARCH ARTICLE | JUNE 09 2023

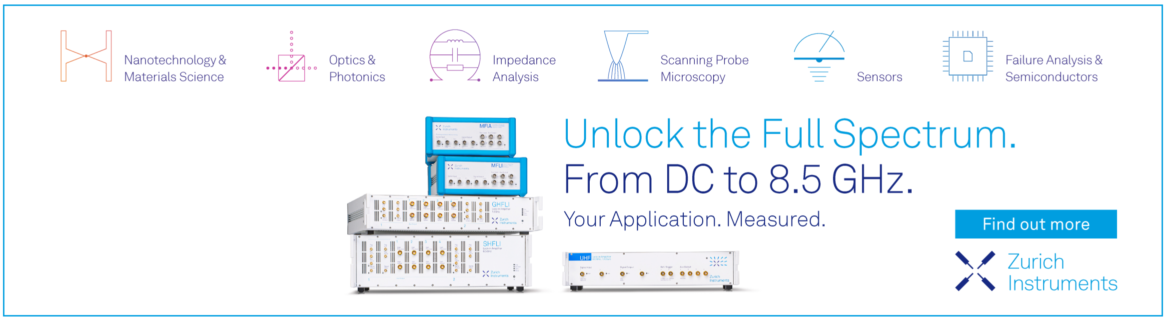
Liquid LPG injection behavior in a spark ignition engine at idle state condition

Norrizal Mustaffa ✉; Mas Fawzi; Amir Khalid; Norrizam Jaat; Mohd Mustaqim Tukiman; Khairu Kamarudin; Shaiful Rizal Masrol; Mohd Faizal Esa

AIP Conf. Proc. 2750, 050027 (2024)
https://doi.org/10.1063/5.0149255

View Online
Export Citation

27 August 2024 01:47:51



AIP Publishing

Liquid LPG Injection Behavior in a Spark Ignition Engine at Idle State Condition

Norrizal Mustaffa[1,a)], Mas Fawzi[2], Amir Khalid[1], Norrizam Jaat[1], Mohd Mustaqim Tukiman[1], Khairu Kamarudin[1], Shaiful Rizal Masrol[1] and Mohd Faizal Esa[1]

[1] *Automotive and Combustion Synergies Technology Group, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Johor, Malaysia.*
[2] *Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, Johor, Malaysia.*

[a)] Corresponding author: norrizal@uthm.edu.my

Abstract. LPG has emerged as an alternative fuel due to several reasons such as to establish the energy security for future usage. The usage of LPG in spark ignition engine has been around since few years ago. The LPG fuel injection technology has evolved from gas injection into liquid injection. Since the liquid phase injection is a latest technology, the present study aims to perform an analysis and comparison of LPG liquid phase injection and gasoline at idle state condition. The torque and performance curve were also been analyzed as an additional data. A four stroke 1.6L naturally aspirated engine was used for the experiment and few devices were attached to the engine in order to collect the required data. As summary, emissions of carbon based product of liquid phase LPG injection were found lower than gasoline and the combustion stability of LPG was observed in acceptable limit. Other than that, liquid phase LPG injection also capable to produced higher power output as compared to the gasoline.

27 August 2024 01:47:51

INTRODUCTION

The motivation for using alternative fuels in internal combustion engine for internal combustion engine are attributed to several factors such as (i) to meet the stringent emissions regulation and improve the engine performance through superior of physical or chemical properties of the alternative fuel, (ii) to reduce the unbalanced petroleum based fuel usage, (iii) to extend the sustainability of conventional fuel and diminish the anxiety of limited fossil fuel energy and (iv) to establish the energy security for future usage [1,2]. There are a few alternative fuels that received lots of attention due to their promising ability to produce similar or better engine output either in terms of performance or/and emissions. Among those alternative fuels are biodiesel, ethanol, methanol, natural gas and LPG.

Focused on LPG, it is generally used as a common fuel in the cooking activity and the properties contained in the LPG makes LPG suitable to be used as an alternative fuel in the internal combustion engine. In view of properties, higher octane rating of LPG indicates higher compression ratio may be employed while using LPG as fuel and this would give better thermal efficiency. Other than that, it also may produces lower engine knocking phenomena [3]. Other than that, higher vapor pressure of LPG compared with the gasoline will improve the mixing process and decrease the local rich mixture region during the combustion process. Consequently, the emissions of NO_x produced would be reduced as compared to gasoline [4]. For calorific value, LPG has higher value compared to conventional fuels. With this higher value, LPG will significantly improve engine operation and engine life. However, exhaust gas temperature of LPG is found to be higher than gasoline fuel [4,5]. The mileage per charge of LPG is smaller than that of gasoline due to lower energy density per unit volume. This is because gasoline has higher specific gravity than that of LPG [6]. Table 1 summarized few main properties of LPG as compared with gasoline.

Proceeding of Green Design and Manufacture 2021
AIP Conf. Proc. 2750, 050027-1–050027-6; https://doi.org/10.1063/5.0149255
Published by AIP Publishing. 978-0-7354-4879-7/$30.00

TABLE 1. Comparison of LPG properties with gasoline [7-9].

Fuel Properties	LPG	Gasoline
Chemical	C_3H_8 / C_4H_{10}	C_8H_{15}
Research octane number (RON)	96.5 - 105	89 - 98
Motor octane number (MON)	90 - 97	80 - 90
Vapor pressure (kPa)	803	700
Calorific value (kJ/kg)	45600 - 46500	42100 - 44000
Latent heat of vaporization (kJ/kg)	14.52	9.94
Carbon, % composition	82	85 - 88
Hydrogen, % composition	18	12 - 15
Stoichiometric air-fuel ratio (kg/kg)	15.5 - 15.8	14.7 - 14.9

The usage of LPG in gasoline engine has been aroud for few years ago and it has been evolved from gaseous phase injection into liquid phase injection [10-12]. Liquid phase injection is the latest technology for LPG as an alternative fuels and the study related to the LPG liquid phase injection is scarcely found. Some of the studies were found related to the engine evaluation on performance and emissions of LPG liquid phase injection has been conducted by earlier researcher [13-18]. Even so, the details study and clear information that focused on idling condition were not clearly presented and discussed. It is highly crucial to established the information and database on idling condition as the information is very useful for further analysis at various engine speed and load conditions. Therefore this study aims to perform an analysis and comparison of LPG liquid phase injection and gasoline at idle state condition. The analysis concentrate particularly on emissions and combustion stability were performed. In addition, torque and power curve have been performed as well in order to gives general picture of LPG liquid phase injection on spark ignition engine.

27 August 2024 01:47:51

EXPERIMENT DETAILS

Malaysian LPG that commercially used as cooking purpose was used as the tested fuel and the results were compared with gasoline RON 95. The fuels were tested on a 1.6L natually aspirated spark ignition (SI) engine and the engine specification is shown in Table 2. The engine was retrofitted to the latest generation of LPG injection method in order to enable the liquid phase injection similar as per reported in [19]. During the injection, fuel pressure was maintained at 10 to 12 bar as to make sure the LPG is purely in liquid phase during injection process. The exhaust emission was measured using 5 Gas Autocheck emission analyzer. The emission analyzer measure carbon dioxide (CO_2), carbon monoxide (CO) and oxygen (O_2) in percentage (%) meanwhile the emission of nitrogen oxide (NO_x) and hydrocarbon (HC) in part per million (ppm). The probe of emissions analyzer was inserted at the center of the exhaust muffler as per standard operation procedure of emission analyzer. First cylinder of the engine was installed with pressure sensor embedded in spark plug made by Kistler (6115B) in the interest to capture the in-cylinder during combustion process. Rotary encoder with the resolution 0.1 degree was installed to the engine to acquire the rotation angle of the engine as well as the engine speed. Recorded data from pressure sensor and rotary encoder were synchronous using National Instrument combustion analyzer data acquisition system (NI 9222 and NI 9411). Figure 1 shows the schematic diagram of the experimental setup. The experiments were conducted at idling speed for both LPG and gasoline. In addition, the engine was couple to the eddy current chassis dynamometer manufactured by Dynpack in interest to plot the torque and performance curve of both tested fuels.

TABLE 2. Engine specification.

Vehicle model	Proton Gen 2
Engine model	S4PH
Engine dicplacement	1.6L
Valve train	DOHC 16V
Bore x stroke	76.0mm x 88.0mm
Fuel delivery method	Indirect injection (MPI)
Compression ratio	10:1
Number of cylinders	4
Cooling system	Water-cooled

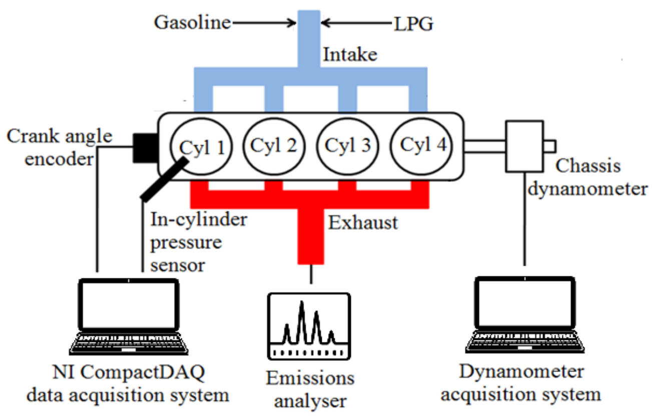


FIGURE 1. Schematic diagram of experimental setup.

27 August 2024 01:47:51

RESULT AND DISCUSSION

Idling is the condition where the engine is running at the very minimum TP opening in order to keep the engine operates smoothly when the vehicle is not in motion. During idling, the tested engine is run at lean operating condition with 0.95 equivalence ratio for both gasoline and LPG. The lean operation is highly required during this condition since it is able to reduce the fuel consumption. Thus, the leaner combustion is better for engine idling. Figure 2 shows the emission of idling condition for both tested fuels. Generally, the emissions of CO_2, CO and HC of LPG are lower than gasoline at idling condition. This is due to higher hydrogen to carbon ratio of LPG as compared to gasoline. Unfortunately, the NO_x is increased with the operation of liquid LPG injection with the increment of 3.17% and the O_2 emission for both fuels is recorded similar at this condition.

Figure 3 shows the in-cylinder pressure of both tested fuels during idling operation. Both fuels exhibit similar patterns of in-cylinder pressure. The maximum peak pressure is observed also located at the similar crank angle degree. Conversely, the in-cylinder peak pressure of LPG is slightly higher than gasoline. It is revealed that liquid LPG injection has the capability to improve the engine performance relative to the gasoline operation. Thus, it is a good indicator as the power of the engine might be improved with the liquid LPG operation.

In order to obtain further detailed analysis, 250 continuous in-cylinder peak pressure is collected at idling condition and the data are tabulated as in Fig. 4. Based on the figure, it significantly illustrates that the maximum peak in-cylinder pressure of liquid LPG injection at idling condition is always higher than gasoline throughout the 250 combustion cycles. The mean maximum peak in-cylinder pressure of liquid LPG injection is 4.76% higher than gasoline.

However, based on the observation from the maximum peak in-cylinder pressure data and statistical analysis, it is clearly indicated that gasoline has better engine stability at idling condition as compared to the liquid LPG injection. It is confirmed through the COV calculation, where the COV of gasoline is 18.35% lower than the liquid

LPG injection. Even though the liquid LPG injection has higher COV than gasoline, the COV value is still in the acceptable range. Heywood (1988) stated that the COV of an internal combustion engine should be less than 10 in order to make sure the vehicle driveability is in tolerable condition [20].

Figure 5 shows the torque and power curve of gasoline and LPG at 1500rpm until 6000rpm. The capability of LPG to produce maximum torque and power was recorded at engine speed of 4383rpm and 5800rpm with 120.32Nm and 63.02kW, respectively. Gasoline recorded lower for both torque and power with the reduction of 3.90% for torque and 6.57% for power. This improvement of torque and power were found in agreement with the study conducted by Fabbri et al., (2013).

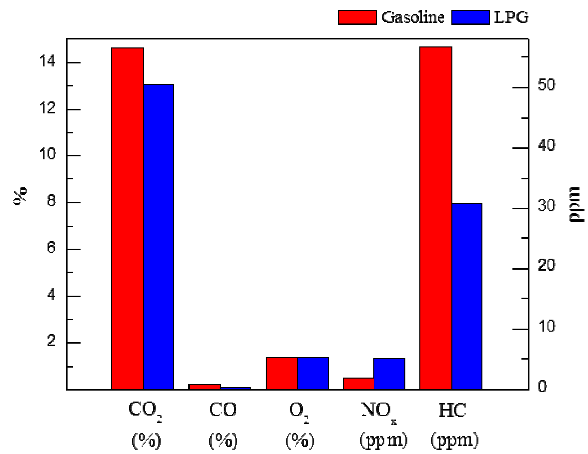


FIGURE 2. Exhaust emission of gasoline and LPG at idling condition.

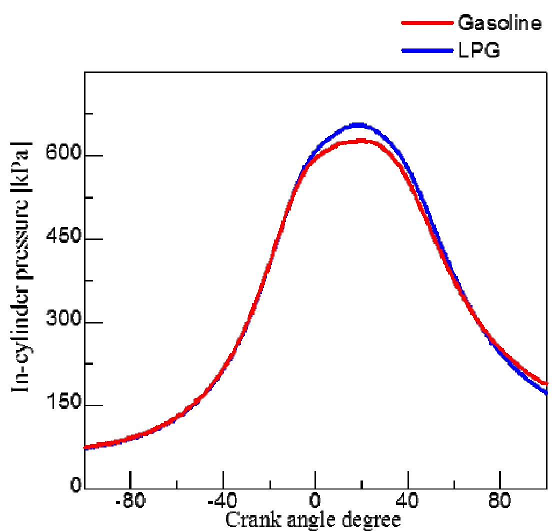


FIGURE 3. In-cylinder pressure of gasoline and LPG at idling condition.

27 August 2024 01:47:51

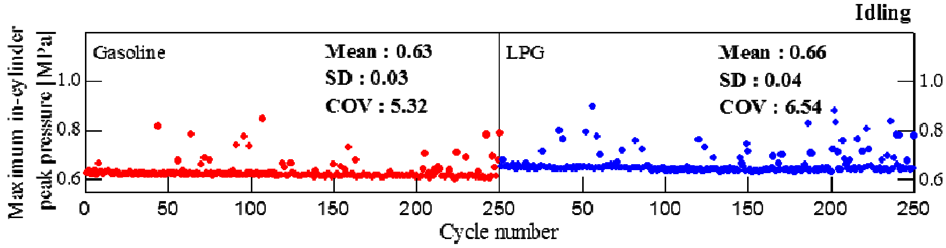


FIGURE 4. Plot of maximum in-cylinder pressure of gasoline and LPG at idling condition.

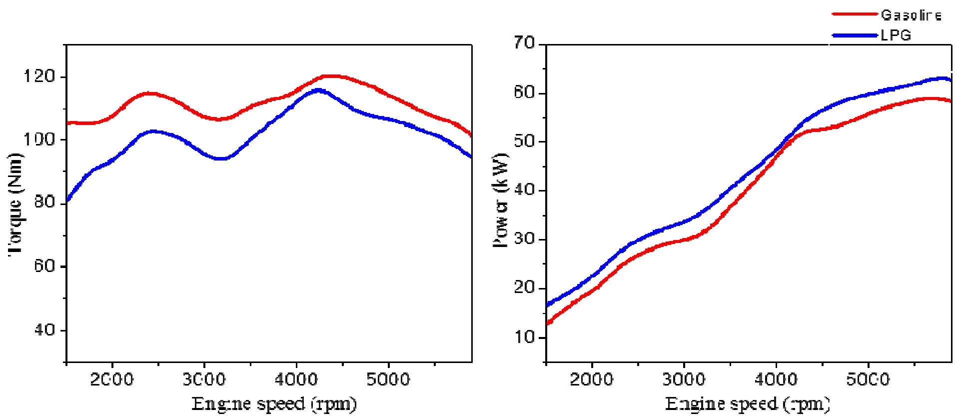


FIGURE 5. Torque and power curve of gasoline and LPG.

27 August 2024 01:47:51

CONCLUSION

As conclusion, the emissions of carbon based of combustion product from liquid phase LPG injection in the SI engine are found to be lower than gasoline at idle condition. This is due to the advantages of LPG since it has lower carbon content than gasoline. Unfortunately, NO_x emission was higher for LPG compared to gasoline. In view of performance, results of in-cylinder pressure proved that liquid phase injection of LPG is capable to produce slight increase in power output and it is supported by the graph of power curve presented in Figure 5. COV of liquid phase LPG injection also lies on the acceptable range and it indicated that liquid phase LPG injection is suitable to be used as an alternative and commercial fuel in spark ignition engine.

ACKNOWLEDGEMENT

The authors would like to thank the Universiti Tun Hussein“ Onn Malaysia for supporting this research under the Tier 1 Grant VOT. H805.

REFERENCES

1. N. Mustaffa, M. Fawzi, F. H. Zulkifli and S. A. Osman, ARPN J. Eng. Appl. Sci. **11**(18), 11000–11003 (2016).
2. Bae, Choongsik, and Jaeheun Kim. “Alternative Fuels for Internal Combustion Engines” (*Proceedings of the Combustion Institute,* 2017) **36**(3), pp. 3389–3413.
3. S. Krishnan, D. S. Kulkarni, J. P. Mohite, S. D. Rairikar and K. P. Kavathekar, “Gasoline To Gas – Revolution” (*SAE Technical Paper*. 2005).
4. C. Park, Y. Park, S. Oh, Y. Lee, T. Y. Kim, H. Kim and K. Y. Kang, “Emission Characteristics of Gasoline and LPG in a Spray-Guided-Type Direct Injection Engine” (*SAE Technical Paper*, 2013).

5. R. R. Saraf, S. S. Thipse and P. K. Saxena, "Comparative Assessment on Performance and Emissions of LPG / Gasoline Bi-fuel Passenger Car PFI Engines" (*SAE Technical Paper*, 2009).
6. A. A. Boretti and H. C. Watson, "Development of a Direct Injection High Efficiency Liquid Phase LPG Spark Ignition Engine" (*SAE Technical Paper*, 2009).
7. Mustaffa, Norrizal, Mas Fawzi, Shahrul Azmir Osman and Mohd Mustaqim Tukiman, "Experimental Analysis of Liquid LPG Injection on the Combustion, Performance and Emissions in a Spark Ignition Engine" (*IOP Conference Series: Materials Science and Engineering,* 2019) **469**(1), p. 012033.
8. M. M. Tukiman, S. A. Osman, M. Fawzi, N. Mustaffa, and R. H. Madon, Int. J. Integr. Eng. **10**(8), (2018).
9. M. Y. Sulaiman, M. R. Ayob and I. Meran, Procedia Eng. **53**, 579–585 (2013).
10. L. Raslavičius, A. Keršys, S. Mockus, N. Keršienė, and M. Starevičius, Renew. Sustain. Energy Rev. **32**, 513–525 (2014).
11. R. Biscoff, M. Akple, R. Turkson, and W. Klomegah, Energy Policy, **44**, 354–361 (2012).
12. M. A. Ceviz, İ. V Öner, A. R. İ. Kaleli, A. Mavi and A. K. Sen, "Fuel Temperature Control in LPG Fuelled SI Engines" (*IEEE International Conference on Electro/Information Technology,* 2012) pp. 1-4.
13. X. Q. Li, L. K. Yang, M. Pang and X. J. Liang, Adv. Mat. Res. **97**, 2279-2282 (2010).
14. G. F. Fabbri, M. Serra, Paschero, and F. M. Frattale Mascioli. "Development of an innovative LPG system for ICE and Extended Range Electric Vehicles" (*IEEE International Symposium on Industrial Electronics*, 2013) pp. 1-6.
15. M. Farrugia, A. Briffa and M. Farrugia, "Liquid State LPG Conversion of an Older Vehicle" (*SAE Technical Paper*, 2014).
16. C. L. Myung, K. Choi, J. Kim, Y. Lim, J. Lee, and S. Park, Energy, **44**(1), 189-196 (2012).
17. H. Kwak, C. L. Myung and S. Park, Fuel, **86**(10-11), 1475-1482 (2007).
18. C. Park, Y. Park, S. Oh, Y. Lee, T. Y. Kim, H. Kim, Y. Choi, and K. Y. Kang, "Emission Characteristics of Gasoline and LPG in a Spray-Guided-Type Direct Injection Engine" (*SAE Technical Paper*, 2013).
19. N. Mustaffa, M. M. Tukiman, M. Fawzi and S. A. Osman, ARPN J. Eng. Appl. Sci. **11**, 8568-8572 (2016).
20. J. B. Heywood, "Internal Combustion Engine Fundamentals" (McGraw-Hill Series in Mechanical Engineering. New York, 1988).

27 August 2024 01:47:51