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Development of an LPG Injection System for SI Engines

Quoc-Thai Pham

Abstract*: Recently, in the context of increasing global energy demand and environmental problems, many researchers have proposed effective solutions for transportation in the current situation. Liquefied petroleum gas (LPG) has been considered as a preferred alternative fuel for spark-ignition (SI) engines. This study describes the development of an LPG injection system for an SI engine. The proposed system was based on the analysis of fuel requirement and metering for the engine operating with LPG, as well as the effect of engine parameters on the LPG flow rate. The system cooperates with the gasoline ECU to produce the signals controlling LPG injectors. An experiment was conducted with an SI engine under different conditions of loads and engine speeds. Experimental results showed that the LPG injection system adapted all test conditions, the engine ran smoothly at all test speeds and partial opening throttle. Fueling with LPG, engine torque and energy conversion efficiency were higher, whereas exhaust gas emissions such as HC, CO, and NOx were lower compared with that as fueled with gasoline.

***Keywords*: Gas emissions, Liquefied Petroleum Gas (LPG), LPG injection system, SI engines.**

I. INTRODUCTION

The utilization of Liquefied Petroleum Gas (LPG) instead of gasoline or diesel fuel for vehicles is considered to be an effective solution to minimize pollution and to diversify the energy sources [1]–[2]. LPG established to be a recommendatory fuel for spark-ignition SI engines thanks to their higher octane rating, efficient combustion characteristics, and lower emissions [3]. There have been three methods to provide LPG fuel for SI engines, including absorbing via the carburetor, injection into intakes manifold, and direct injection into the combustion chamber. The first method does not get high technical and economic standard because of not meeting requirements of running engine modes. The direct injection method will create layered burn mixtures, fuel efficiency and reduce exhaust pollution, but requires sophisticated techniques because of injection at very high temperature and pressure. This method has not been applied yet. In this work, we investigated an electronic LPG injection system for SI engines. The proposed system cooperates with gasoline injection controller and combines with signals from the LPG supply system to inject an appropriate amount of LPG fuel into the intake manifold of the engine.

This paper is structured as follows. Following the introduction, Section 2 outlines the development of the LPG injection system for SI engines. Experiments with an SI engine fueled with gasoline and LPG are described in Section 3. Finally, Section 4 provides conclusions and future work.

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II. DEVELOPMENT OF LPG INJECTION SYSTEM

A. Basis of the LPG injection system

With a gasoline fuel engine, the amount of gasoline injected into the engine depends on the amount of air flowing into the engine and be adjusted to each operational mode of the engine. When replacing to LPG fuel system, the actual amount of LPG fuel must ensure combustion completely corresponds to the amount of engine air intake. Therefore, in this work, the main parameters to control the amount of LPG fuel are gasoline injection signals and corrected by adding the signals from temperature LPG, the pressure difference before injectors.

The relationship between the air mass flow (Q_A) and the gasoline mass flow (Q_G) can be described as

$$Q_A = Q_G.(A/F)_G = t_G.K_G.(A/F)_G \quad (1)$$

Similarly, the relationship between the air mass flow (Q_A) and the LPG mass flow (Q_{LPG}) can be written as

$$Q_A = Q_{LPG}.(A/F)_{LPG} = t_{LPG}.K_{LPG}.(A/F)_{LPG} \quad (2)$$

Where $(A/F)_G$, $(A/F)_{LPG}$ are the stoichiometric air/gasoline and air/LPG rate, respectively; t_G and t_{LPG} are respective gasoline and LPG injection timing; K_G and K_{LPG} are gasoline and LPG coefficients (at calibrated injector condition), respectively. Therefore, with the same amount of intake air, the relationship between LPG and gasoline injection timing can be determined by:

$$t_{LPG} = \frac{K_G}{K_{LPG}}.\frac{(A/F)_G}{(A/F)_{LPG}}.t_G \quad (3)$$

The amount of LPG gas injected base on injector characteristics and LPG fuel properties [2] is determined as

$$Q_{LPG} = C_{LPG}.A_{LPG}.\sqrt{2.\rho_{LPG}.\Delta p_{LPG}}.M \quad (4)$$

$\Delta p_{LPG} = p_o - p_T$: the pressure difference of LPG injector.

Where C_{LPG} and A_{LPG} are LPG flow coefficient and cross-sectional of the injector, respectively; M is the effect of compressibility of fluid to injector flow, and ρ_{LPG} is the density of LPG.

The characteristics of injectors were determined by calibration at the selected average pressure and temperature of 1.45 Bar and 315 ^{o}K, respectively. The influence of gas pressure on the flow rate is

much more than that of temperature. Therefore, LPG injection timing can be determined as

$$t_{LPG} = \frac{K_G}{K_{LPG}} \cdot \frac{(A/F)_G}{(A/F)_{LPG}} \cdot t_G . K_T . K_p . K_{\Delta p} \quad (5)$$

where K_T, K_p, and $K_{\Delta p}$ are the coefficients account for the influence of LPG temperature, pressure, and the differential pressure injector nozzle, respectively. The equation (5) presents the relationship between gasoline injection timing t_G and the LPG timing t_{LPG}. This relationship is the basis for designing the electronic control system.

B. The design of an electronic injection controller

The LPG injection system includes the following components: LPG tank, solenoid valves, vaporizer, LPG distributor, and injectors, as shown in showed in Figure 1.

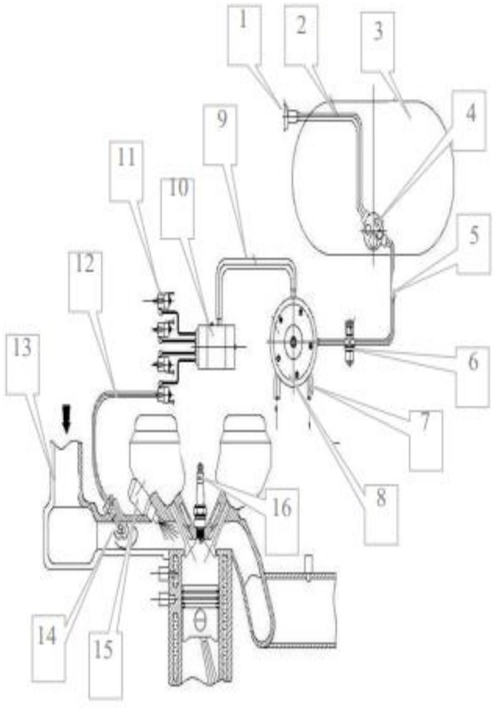

Figure 1. The LPG injection system diagram

1. Intake valve; 2. Intake pipe; 3. LPG tank; 4. Solenoid valve; 5. LPG pipe; 6. LPG filter; 7. Heated water line; 8. Vaporizer; 9. Distributor pipe; 10. Distributor; 11. LPG injector; 12. LPG intake line; 13. Intake manifold; 14. Connector; 15. Gasoline injector; 16. Spark plug.

Figure 2 shows the block diagram of the LPG injection controller. The LPG electronic controller is the brain of the LPG injection system. It communicates with a gasoline injection controller to get engine speed signal and control injection signals.

Besides, it also receives signals from the LPG supply system, including LPG temperature, the pressure difference before and after LPG injector. After getting all essential signals, the LPG controller calculates and generates signals to control LPG injectors.

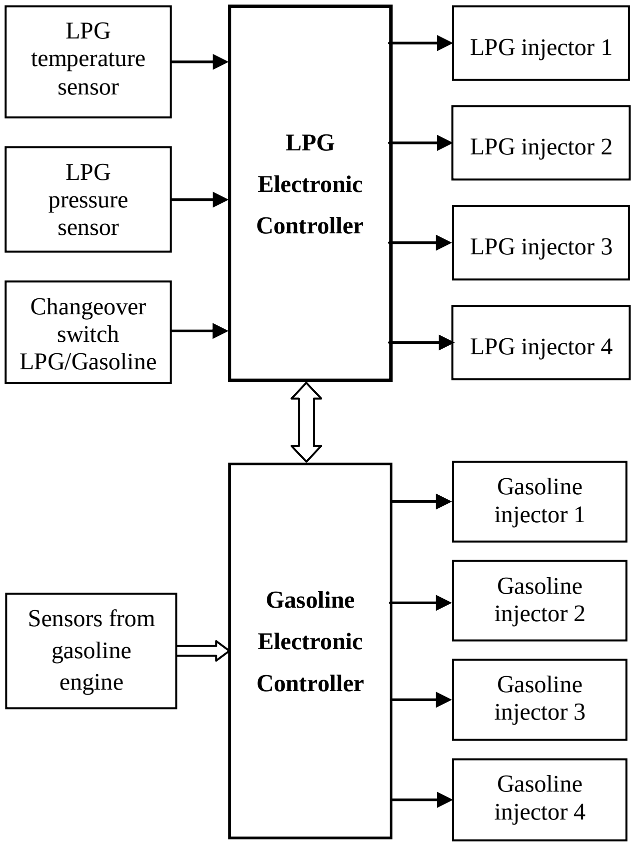

Figure 2. Block diagram of LPG injection controller

The control system consists of an AT89S52 Microcontroller, which has an 8KB Flash EEPROM memory, diverse input/output interfaces, and high process speed, meeting requirements of the control system. Furthermore, power transistor IRF540 is used to control actuators, and analogue to digital converter (ADC) 0809 is used for converting signals from LPG temperature and pressure to the controller. When the engine operates, the controller receives signals from the gasoline controller, engine speed sensor, LPG temperature, and pressure sensors. Then, it processes, calculates, and generates signals to control actuators appropriate with the operational mode of the engine. Besides, the microcontroller is compatible with C/C++ and assembly programming environment and online/offline compiler, allowing designers to develop control systems efficiently and rapidly [4]. Figure 3 and 4 show the electrical diagram and board of the LPG injection controller. The flowchart of the control strategy for the proposed system is described in Figure 5.

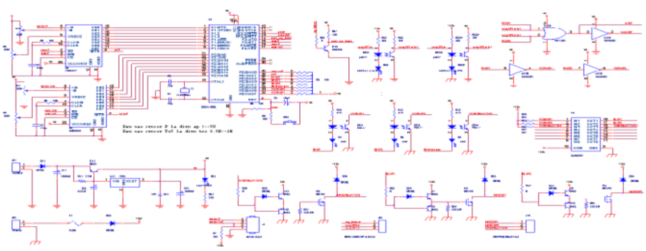

Figure 3. Electrical diagram of the LPG injection controller

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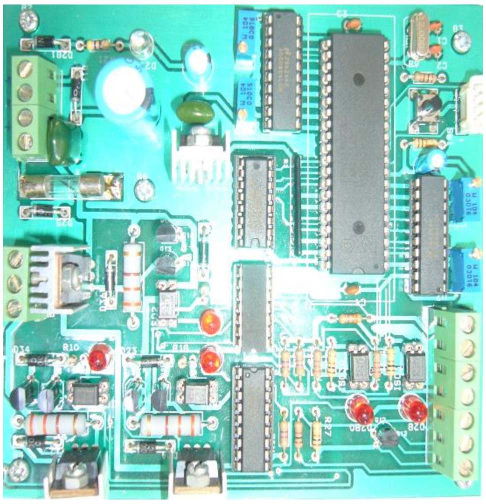

Figure 4. The proposed controller board

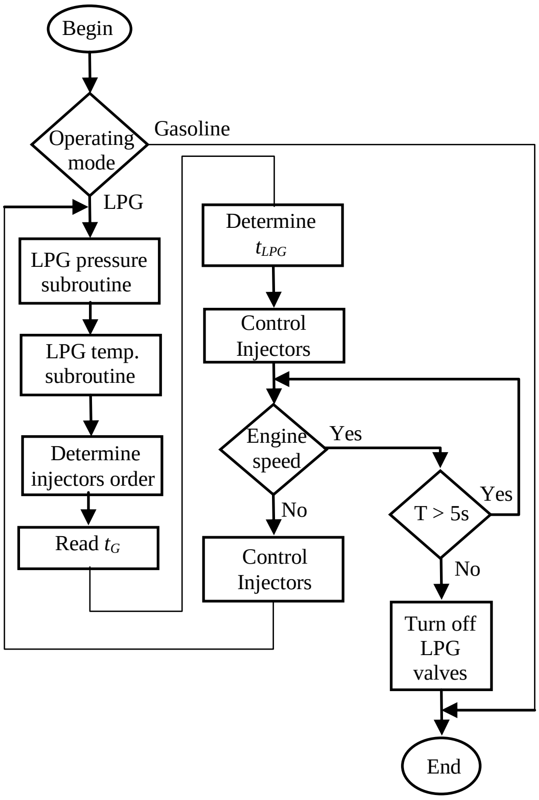

Figure 5. Control strategy of the proposed system

III. EXPERIMENT AND RESULTS

The experiment was performed under different conditions of loads and engine speeds at the Engine and Vehicle Testing Centre, The University of Danang-University of Science and Technology. The controller was used to test with DMS A16 DAEWOO engine [5]. The engine was coupled with an APA200 testbed manufactured by AVL, as shown in Figure 6.

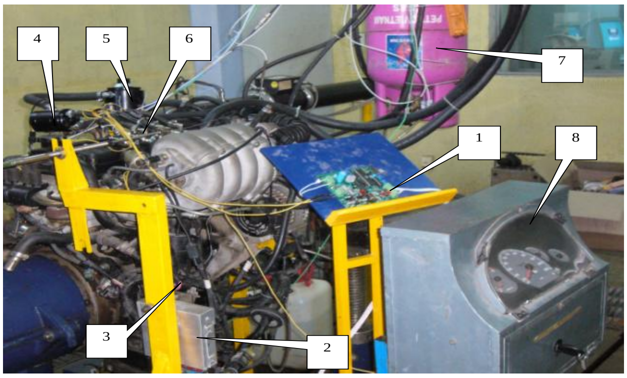

Figure 6. Test rig layout

1. LPG electronic controller; 2. Gasoline controller; 3. LPG/Gasoline switch; 4. Distributor; 5. Vaporizer; 6. LPG injectors; 7. LPG tank; 8. Dashboard

Before the experiment, coefficients K_X, K_G, K_T, and K_p were determined. After warming, the engine was tested, in steady mode, with gasoline and LPG fuels from 2500 to 4500 rpm with the step of 250 rpm, at 75% throttle. Engine torque, power, energy conversion efficiency, and pollutant emissions are corrected to standard conditions and then compared for the two fuels. The comparison is presented in Figure 7 to Figure 11.

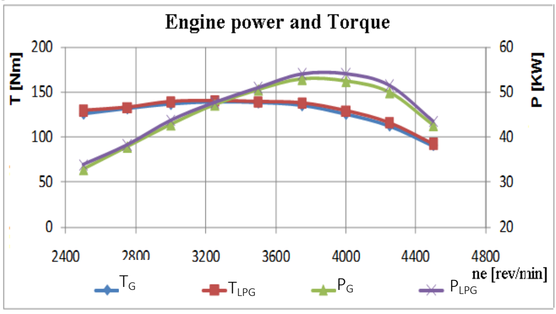

Figure 7. Comparison of engine power and torque as fuelled with gasoline/LPG

Figures 7 and 8 reveal that at 75% throttle and all engine speed, as fueled with LPG, engine torque and energy conversion efficiency were about 1% to 4% higher than that as fueled with gasoline. This improvement is maybe because the enhancement of the combustion process of LPG fuel is more dominant than the reduction of intake coefficient. Besides, injecting LPG fuel with a pressure of approximately 1.5 bar into intake manifold may improve the intake process quality.

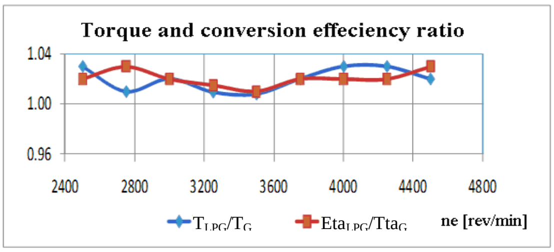

Figure 8. Comparison of energy conversion efficiency as fuelled with gasoline/LPG

It can be seen from Figures 9 to 11 that the CO, HC, and NOx concentrations in the exhaust gas as fueled with LPG decreased dramatically as compared with that as fueled with gasoline. CO concentration in the exhaust gas as fueled with gasoline fluctuates from 3% to 6% by volume, reduced to a half as the engine fueled with LPG, as shown in Figure 9. Figure 10 reveals that HC concentration ranges from 250–300 ppm by volume as fueled with gasoline, reducing to 170–220 ppm when fueling with LPG. This could be because the quality of the combustion process is improved as the engine fueled with LPG. Additionally, compared with gasoline, LPG fuel has a lower H/C ratio, leading to a decrease in HC and CO concentration in the exhaust gas.

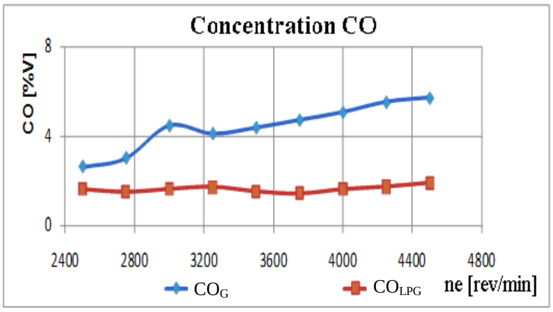

Figure 9. Comparison of CO concentration as fuelled with gasoline/LPG

Figure 11 reveals a notable point that is the NOx is also dropped from about 1100 ppm per volume to 500 ppm, while HC and CO concentration are both decreased as fueled with LPG. The reduction of NOx is the result of a combination of various factors. NOx reduction tendency (due to adiabatic temperature and burning rate of LPG is faster than that of gasoline [6], and higher A/F ratio of LPG-air mixture [2]) overwhelms the rise of NOx from the increase of burning rate during the first stage of the LPG burning process.

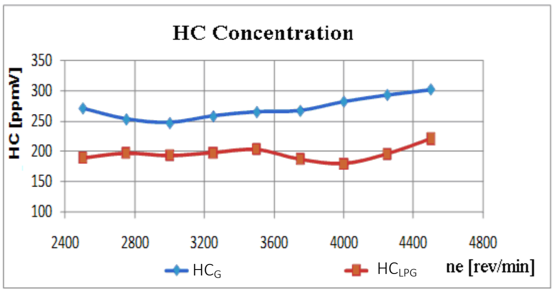

Figure 10. Comparison of HC concentration as fuelled with gasoline/LPG

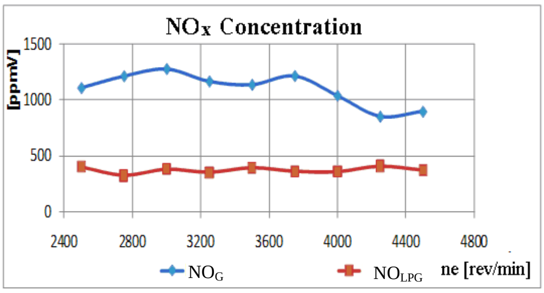

Figure 11. Comparison of NOx concentration as fuelled with gasoline/LPG

IV. INCLUSIONS

In this work, we have investigated the LPG injection system for a SI engine. The engine equipped with the proposed system operated stably and smoothly at all engine test speeds and loads. Experimental results reveal that engine torque and energy conversion efficiency were higher, and the CO, HC, NOx concentrations decreased as the engine fueled with LPG. The initial findings have proved the possibility to develop electronic LPG injection system for SI engines, contributing to the diversification of fuel sources and reduction of exhaust gas emissions. Further work will continue performing the proposed system in a transient mode of engine operation to confirm its effectiveness.

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Quoc-Thai Pham received the PhD. degree in mechanical engineering from Osaka Prefecture University, Japan in 2017. He is currently a Senior Lecturer and has been Dean of Faculty of Transportation Mechanical Engineering, University of Science and Technology, the University of Danang since 2018. His study interests include modelling, simulation, control of vehicles, automotive electronics and electrical systems, and intelligent transportation systems. Dr. Pham has been a recipient of the Japanese Government (MEXT) Scholarship for his study in Japan. Since December 2015, he has served as the Reviewer of IEEE Transactions on Intelligent Transportation Systems, International Journal of Intelligent Transportation Systems Research, and International Journal of Sustainable Transportation. He also served as the Section Co-Chair of the 2015 International Conference on Integrated and Sustainable Transportation.