# Pressure Regulator Optimization in LPG Fuel Injection Systems

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***Abstract*—LPG pressure regulator is a device which is used to change the phase of LPG from liquid to gas by decreasing the pressure. During the phase change, it is necessary to supply the latent heat of LPG to prevent excessive low temperature. Engine coolant is circulated in the pressure regulator for this purpose. Therefore, pressure regulator is a type of heat exchanger that should be designed for different engine operating conditions. The design of the regulator should ensure that the flow of LPG is in gaseous phase to the injectors during the engine steady state and transient operating conditions. The pressure regulators in the LPG gaseous injection systems currently used can easily change the phase of LPG, however, there is no any control on the LPG temperature in conventional LPG injection systems. It is possible to increase temperature excessively. In this study, a control unit has been tested to keep the LPG temperature in a band. Result of the study showed that the engine performance characteristics can be increased by using the system.**

***Keywords-LPG; temperature; pressure regulator***

## I. INTRODUCTION

LPG is a fuel liberated from lighter hydrocarbon fraction produced during petroleum refining of crude oil and from heavier components of natural gas. It is also a by-product of oil or gas mining. It is liquefied under pressure and compressed and stored in steel tanks under pressure varies from 1.03 to 1.24 MPa. LPG is a mixture of commercial butane ($C_4H_{10}$) and propane ($C_3H_8$). Butane and propane have different boiling points at atmospheric pressure. Boiling point is the temperature at which changing the phase from liquid to gas. Boiling temperature of propane is -43 °C whereas it is 0 °C for butane. Due to this difference, proportion of propane should be increased in colder climate regions to facilitate the gasification of mixture.

It is an environmentally friendly fuel for spark ignition engine, it has a potential emission advantages over gasoline [1]. LPG has some advantages over than gasoline as the following: (1) LPG produces lower exhaust emissions than gasoline, (2) it reduces engine maintenance, (3) it offers faster cold starting and (4) it provides overall lower operational cost [2].

In the last generation of LPG gaseous fuel injection systems, multi-point and sequential LPG injection strategy has been used with EOBD. There are many reports about the effects of the LPG on the engine performance and emission characteristics. Studies performed by reference [3] and [4] have shown that the hydrocarbon (HC), carbon monoxide (CO) and carbon dioxide ($CO_2$) emissions are substantially reduced, principally due to the high hydrogen/carbon ratio of LPG when compared to gasoline.

Many studies, like one conducted by reference [5] have shown that higher thermal efficiency and therefore improved fuel economy can be obtained from internal combustion engines running on LPG. But LPG displaces 15-20% greater volume than gasoline. Thus the power output decreases 5-10%. This reduction can reach 30% at very lean conditions [2, 6].

It is known that the temperature of the fuel-air charge has an effect on the engine performance and exhaust emissions characteristics of spark ignition engines. Increase in the fuel temperature can cause to produce more $NO_x$ emissions. Additionally, it can lead to decrease in the volumetric efficiency due to the decrease in the density of fuel-air charge. Reference [7] has performed a study on an SI engine fuelled with third generation LPG injection system at steady state and transient conditions. Results of the study have showed that the temperature of LPG is an important parameter on the engine performance.

According to our observations, thermal conditions of LPG pressure regulator has an important effect on engine performance. LPG can be extra heated in LPG regulator and it causes a decrease in engine performance due to the decrease in volumetric efficiency.

In this paper, a control system to keep the LPG temperature in a desired band and an application of this system on an engine test bend are presented.

## II. MAIN COMPONENTS

### A. Control System

Schematic diagram of engine test bed has been shown in Figure 1. Technical specifications of test engine has been given in Table 1.

TABLE I. ENGINE SPECIFICATIONS

| | |
|---|---|
| Engine type | Ford MVH-418, fuel injected |
| Number of cylinders | 4 |
| Compression ratio | 10:1 |
| Bore (mm) | 80.6 |
| Stroke (mm) | 88 |
| Displacement volume (mm3) | 1796 x 103 |
| Max. power | 93 kNm/s at 6250 rpm |
| Max. torque | 157 Nm at 4500 rpm |
| Cooling system | Water-cooled |

 

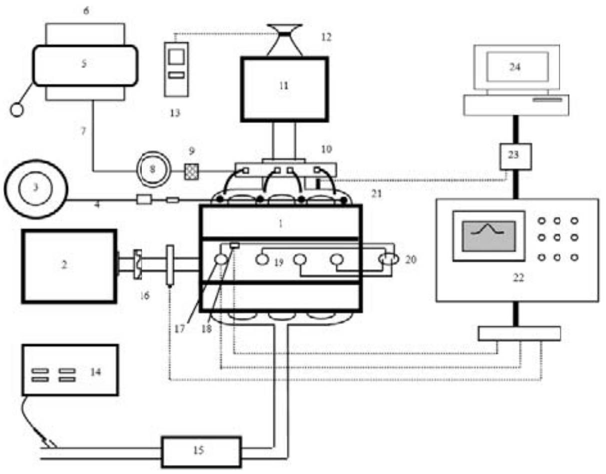

FIGURE I. SCHEMATIC DIAGRAM OF ENGINE TEST BED

| | |
|---|---|
| 1- Engine | 13- Air flow meter |
| 2- Hydraulic dynamometer | 14- Exhaust gas analyzer |
| 3- Gasoline tank | 15- Muffler |
| 4- Gasoline fuel line | 16- Shaft encoder |
| 5- LPG Tank | 17- Spark Plug mounted piezoelectric transducer |
| 6- Digital balance | 18- Ignition pick-up |
| 7- LPG fuel line | 19- Spark plugs |
| 8- LPG evaporator | 20- Distributor |
| 9- LPG filter | 21- MAP sensor |
| 10- Splitter and LPG | 22- Charge amplifier and oscilloscope |
| 11- Air surge tank | 23- Analog to digital converter |
| 12-Air flow meter probe | 24- Personal computer |

Schematic diagram of produced control system has been shown in Figure 2. The operating principle of the system is described below. Thermocouple (7) is used to measure the LPG fuel temperature which is the control parameter in the system. According to the set value of LPG temperature, the control valve (12) regulates the coolant flow rate circulating in the pressure regulator supplying the LPG latent heat. The control valve is derived by a linear positioner (11).

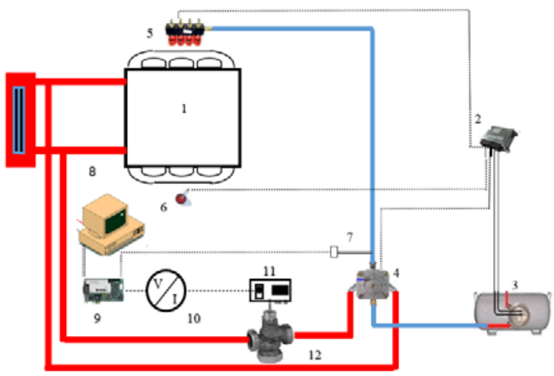

FIGURE II. THE SCHEMATIC LAYOUT OF THE CONTROL SYSTEM

1- Engine
2- LPG ECU
3- LPG tank
4- Pressure regulator
5- LPG Injectors
6- Oxygen sensor
7- Thermocouple (TLPG-regulator)
8- Computer
9- Data acquisition and control card
10- Voltage-current converter
11- Vane Positioner
12- Globe vane

## B. *PID Control Algorithm*

Proportional-integral derivative (PID) controllers are the most frequently used controllers in practical process applications due to their robust performance and simple structure. However, the performance of PID control depends on appropriate choice of the PID gains. Therefore, tuning these parameters are very important.

The PID controller function is given in Eq. 1.

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int_0^t e(t)\,dt + T_d\frac{de(t)}{dt}\right) \quad (1)$$

where u is the control signal, $e(t)$ is the control error where between setpoint and process measurement, $K_p$ is the controller gain, and $T_i$ is the integral time. $K_p$ and $T_i$ are the PID parameters to be tuned.

In this study, experimental method is presented for PID controller parameters. This parameter tuning method was presented in [8] and it is referred to as the Good Gain method and it can be applied to real time processes without any information about the plant mathematical model.

The closed loop PID control system block diagram is given in Figure 3.

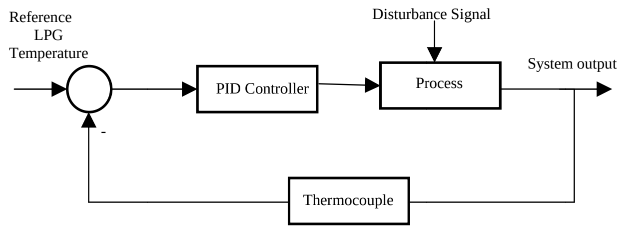


FIGURE III. CLOSED LOOP CONTROL SYSTEM BLOCK DIAGRAM

## III. RESULTS AND DISCUSSIONS

The positioning signal is produced by a PID unit prepared by authors. According to the measurement of LPG temperature, the control card produces a positioning digital voltage signal, and the signal is converted to the electrical current to drive the positioner. Testing of control system showed that the LPG temperature can be kept in the range of any desired band. Figure 2 shows the system performance test results. The experiments has been started at 20 °C LPG temperature and after about 200 s the set value has been increased to 30 °C. LPG temperature increased to 30 °C after about 5 s. It has been in the band of 30 ±5 °C. Then, it has been increased to 40 °C, and system has increased it to the set value. Lastly, set value has been increased to the 50 °C and system has increased LPG temperature to the desired band.

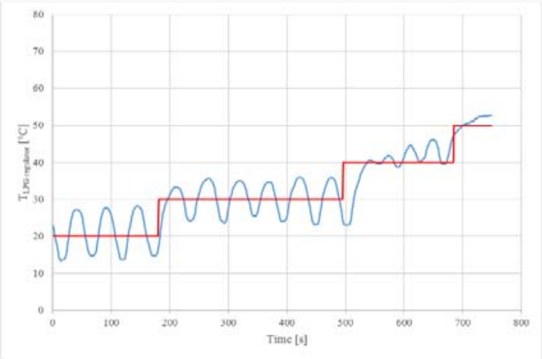


FIGURE IV. LPG SET TEMPERATURE (RED LINE) AND LPG TEMPERATURE AFTER REGULATOR (BLUE LINE)

## IV. CONCLUSIONS

This paper shows that the LPG temperature which is changing in a wide band in SI engine applications is an effective parameter on engine performance and NO emission characteristics. A new control system for keeping the LPG temperature in a desired band has been presented in this paper. A new control system regulating the mass flow rate of coolant in the pressure regulator circuit has been produced and tested successfully to control the LPG temperature at the exit of pressure regulator. The control system uses LPG temperature measurement data as a control parameter. PID unit produces a positioning signal to drive vane to regulate the heat transfer to the LPG. The produced control system can keep the LPG temperature in a narrow band.

## ACKNOWLEDGMENT

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