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A Study on LPG-Injection-Based Speed Regulator for Dual Fuel Diesel Engine

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ABSTRACT

Diesel engines are popularly interested due to their great economic efficiency and the high amount of harmful emissions released. The conversion of using multi-fuel engines aims to reduce emissions, and diversifying alternative energy sources to replace diesel fuel, is a potential solution. This paper presents a method to convert the fuel system of the DI-diesel engine type Vikyno RV125 to LPG-diesel dual combustion mode and preliminarily evaluate performance characteristics operating with the LPG injection-based speed regulator. An LPG injector controller circuit was actuated to operate the engine with different load modes up to 5.0kW at corresponding engine speeds. The air intake manifold was modified to calibrate the air-mass flow to effective performance. The experimental result revealed that the changed system could operate in LPG-diesel dual combustion mode. The operating stability of the engine was recognized at speeds up to 1600rpm. A study on engine exhaust emissions will be performed in the next research stage.

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1. Introduction

The population growth and technological evolution require an increasing demand for energy consumption, especially energy derived from fossil fuels (gasoline, diesel) in the transportation field [1]. With higher economic efficiency and larger torque than gasoline engines, besides applications in the field of transportation, diesel engines are widely used in many other fields such as agriculture, generator, construction, etc. However, diesel engines emit a large number of polluting emissions (NOx and soot) [2]. Among diverse emission reduction methods (common rail electronic fuel injection, exhaust gas recirculation, catalytic filter, ...), the application of alternative fuels is a potential solution for many countries. LPG (Liquified Petroleum Gas) is one of them with suitable characteristics for fueling diesel engines and is being studied extensively [3], [4], [5].

Liquefied Petroleum Gas (LPG) is a product of natural gas extraction or oil refining process which mainly has chemical compositions of Propane (C_3H_8) and Butane (C_4H_{10}). LPG liquefies at a pressure of 0.7-0.8 MPa at room temperature, making it easier to transport and store than other gasses [6]. With a low cetane number, LPG can effectively be used on diesel engines with dual-fuel mode (diesel as the pilot fuel) [7]. This property allows the conversion of a traditional diesel engine to use the LPG-Diesel dual-fuel mode with few modifications in engine structure [8].

Many studies revealed that the amount of soot produced in the LPG-Diesel operating mode tends to decrease because of the good vaporization of LPG when entering the combustion chamber [9]. In addition, it is reported that NO_x emission is notably decreased when increasing the LPG mixing ratio at all operating conditions [10]. The use of LPG-Diesel combustion mode on diesel engines at the same engine speed and load shows a significant reduction in exhaust gas temperature and less fuel consumption compared to pure diesel engines [11].

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LPG fuel can be used in gas or liquid form on diesel engines [12], [13]. In the gaseous form, LPG is mixed with air and sucked into the combustion chamber through the intake manifold. In liquid form, LPG will be blended with diesel fuel at a pressure higher than 0.5 MPa through a high-pressure pump and directly injected into the combustion chamber. It is well-known that the blending homogeneous mixture of LPG-air in the flammable ratio combined with the diesel injection as a priming ignition strongly affected the flame propagation, thus influencing engine performance and exhaust gas emissions. However, for a mechanical LPG fuel system type venturi diffuser, the amount of LPG flowing into the engine will not be optimal under continuously changing conditions such as when the fuel quality changes or when the engine operates at different loads and speeds [14]. This limitation led to an increase in LPG fuel consumption and polluting emissions [15] - [17]. From the above point of view, it is necessary to know an innovative LPG fuel supply system can improve the injection and mixing characteristics and thus achieve fewer emissions and less energy consumption. In this study, a consideration of the fabrication feasibility of the LPG electronic injector system on the intake manifold was developed with approaching by using the PID speed controller. Concurrently, the intake pipe was modified to mix air with the injected LPG based on the signal from the crank angle encoder while the mechanical speed regulator pulls the fuel control rack at the fixed position. A preliminary experiment was conducted to evaluate the operating efficiency of the conversion dual LPG-diesel fuel system-based LPG-injection speed regulator.

2. Research Methods and Experimental Setup

2.1. Control method of LPG injection

The injection process is controlled by a PID speed controller (Proportional Integral Derivative). The PID controller calculates "error" which is the difference between the measured and desired values. The controller will minimize this error by adjusting the output control value.

Figure 1 shows the principle of the PID controller in the LPG fuel supply system. The desired engine speed from user input will be compared with the actual engine speed acquired by an encoder. From

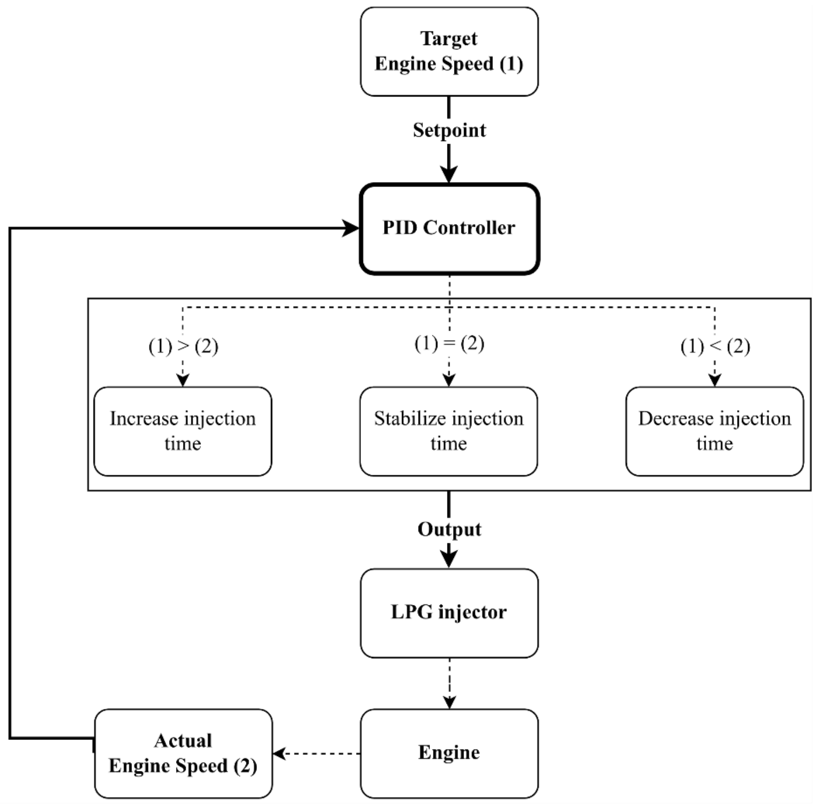

Figure 1. *LPG injection control algorithm*

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there, through the calculation steps in terms of proportional, integral, and derivative, the injection duration of the LPG injector in each control cycle will be correspondingly changed to ensure the reality engine speed which is always closest to the desired value. A data acquisition and control system (DAC) was created to control the operation of the engine, including measuring the mass air flow (MAF), indicating engine speed from a signal of the encoder, and sending it to ECU as the reference value for the PID controller.

2.2. Installation of LPG injector and MAF calibration procedure

The schematic of the intake manifold modified to install an LPG injector and mass air flow rate meter is described in figure 2. An LPG injector (SNG 0280150846) was used to provide LPG fuel at 3 bar of injection pressure which is driven by a MOSFET circuit and recorded control signal by oscilloscope. MAF was utilized in this system to indicate the amount of airflow for each operating speed. Because the MAF meter needed to calibrate when applying to the new dimension of the intake manifold, a schematic experimental setup for calibration of MAF was designed and shown in figure 3. The calibrating conditions were carried out by changing the inverter frequency from zero to 30Hz which corresponded to the airflow rate from zero to 102 kg/h of the ABB sensor recording. The measured data from this

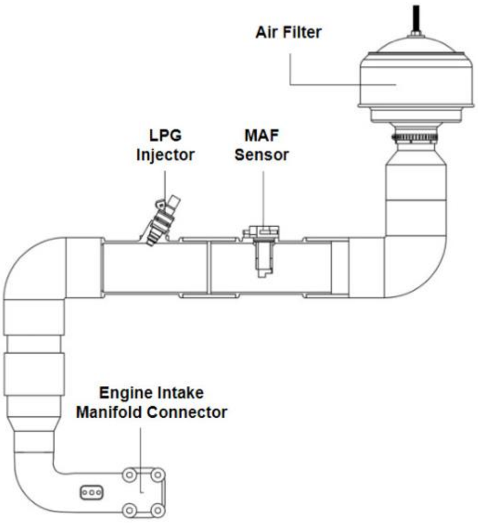

Figure 2. *The arrangement apparatus on the intake system*

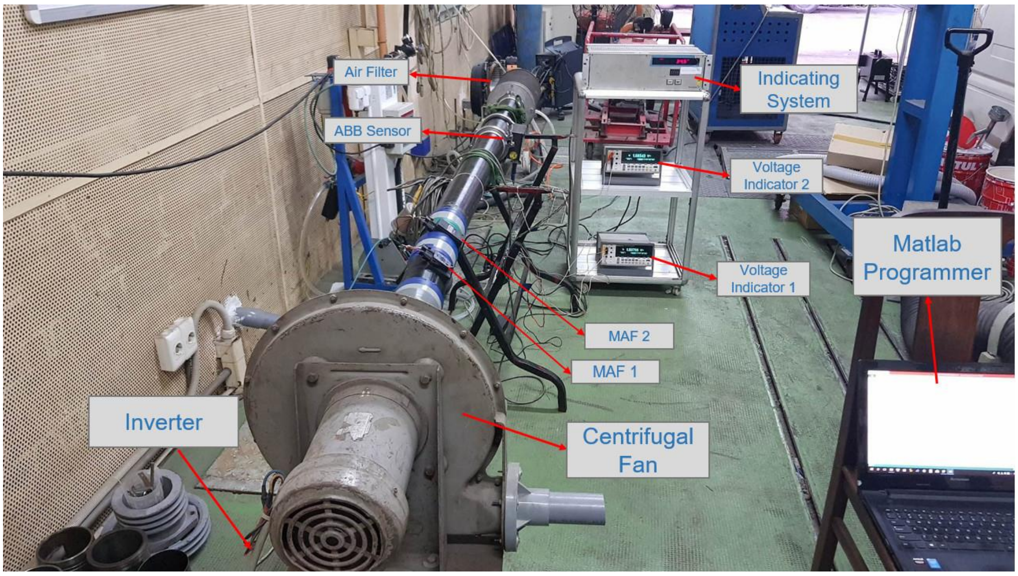

Figure 3. *The schematic experimental system for MAF calibration*

system plotted in figure 4 were used to calibrate the mass air flow rate in the intake pipe of the Vikyno engine.

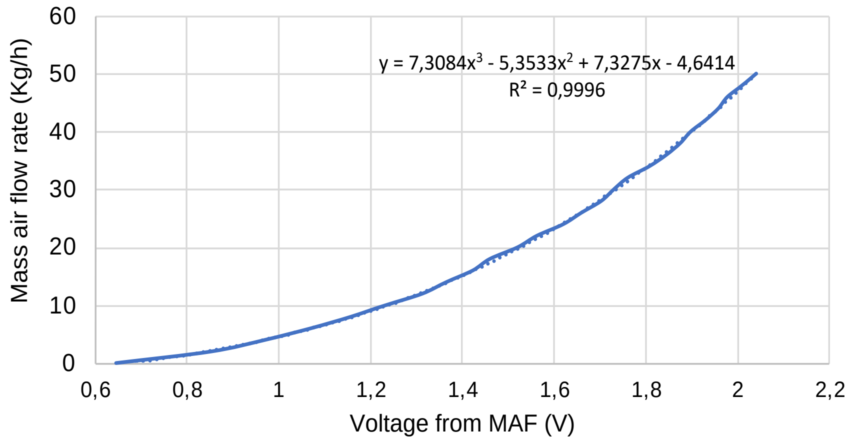

Figure 4. *The flow rate characteristic of MAF*

2.3. Experimental setup and test conditions

Figure 5 shows the schematic arrangement of the experimental apparatus for investigating the operating possibility of the DAC system and the performance of the converted Vikyno RV125 diesel engine to LPG-diesel dual-fuel combustion mode. The engine was connected to a 5.0 kW, 220V, 50Hz electric generator. The electric generator produced power to series thermistors to vary engine loads. The test fuels consisting of diesel and LPG were located on weight measurement and fuel rate consumption was recorded by time. The engine speed was measured by the angle encoder and transmitted signal to DAC to control the LPG injection length following the change of engine speeds and loads. The LPG

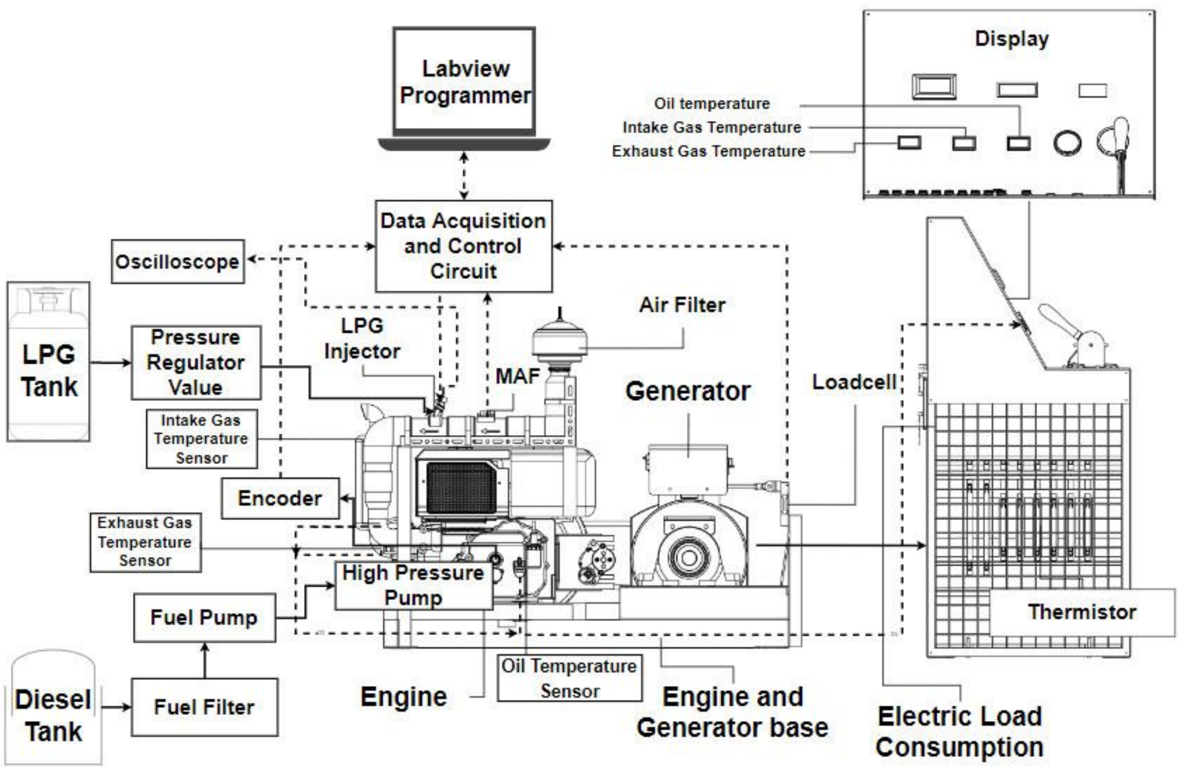

Figure 5. *Schematic arrangement of experimental apparatus*

injector's activating pulse was indicated by an oscilloscope. The temperature of cooling water, lubricant, intake air, exhaust gas, and mass airflow was measured for observing and analyzing the steady state engine operation. The control signals were collected, analyzed by DAC, and displayed on the LabVIEW programmer.

Table 1. *Experiment conditions*

Fuels	Diesel (DO 0.05S-II), LPG
Changing load (kW)	Idle to 5.0 kW
Load increments (kW)	1.0
Measuring time/condition (minutes)	10
Engine speed (rpm)	1600

Table 2. *Fuel Properties of LPG and Diesel*

Chemical Properties	Propane	Butane	Diesel
Liquid Density [kg /m^3]	514		828
Low calorific value [MJ/kg]	46,1	45,46	42,5
Boiling point (^{o}C)	-43	-0.5	150-560

Table 1 and Table 2 show the testing conditions and the fuel properties, respectively. From these tables, the tests were conducted at a constant speed of 1600 rpm, the load was varied from idle mode to 5.0kW with the rising step of 1.0 kW. The fuels used are commercial diesel (DO 0.05S-II) as a reference fuel and liquefied petroleum gas (LPG) mixed with diesel [6], [18]. As increasing the load consumption on the engine, the engine speed was not stably kept at 1600rpm, the system had to control the amount of LPG fuel to ensure that the engine continue operating under the given test conditions. It is noted that the fuel control rack did not move during engine running in the dual fuel combustion mode. Understandably, the LPG/diesel ratio is not constant across the speed range and load level to maintain engine speed. At every measured point, data was recorded in 100 cycles. The results of the calculation process were an average of 5 measurements. Before testing, the engine was warmed up in idle mode until getting the steady state condition of 85^{0}C water temperature, 80^{0}C of lubricant temperature, and diesel fuel temperature remained 30^{0}C during the experiment process.

3. Results and Discussion

The engine was run at a constant speed of 1600 rpm and the load was changed up to 5.0kW. The results of this research were discussed in two parts. The first part presented the operation possibility of an LPG injector control circuit and the Data Acquisition-Control system (DAC) for collecting signals, analyzing, and showing on the man-machine interface of the Labview programmer. The second part discussed engine performance characteristics by using an LPG injection-based speed regulator.

3.1. The operation possibility of the LPG control system and the DAC system

Figure 6 shows the activating pulse of the LPG injector measured from the LPG electronic control circuit under a dual fuel mode of 3kW engine load. From this figure as the representative, the circuit illustrates the working well of injector lifting length to ensure the stability of the engine at different loads in LPG-Diesel dual-fuel mode.

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Figure 7 shows the speed change between the actual engine speed (blue line) from the angle encoder and desired speed (red line) from the input user at LPG-Diesel dual-fuel mode of 3kW load and 1600 rpm. Through the figure, the difference value in the 2 types of speed is insignificant. Therefore, the DAC system can satisfy the PID's algorithm control of engine speed to follow the operating requirements as well as indicate the working process with time. Besides, this system can observe the result of engine power, torque, mass air flow rate.

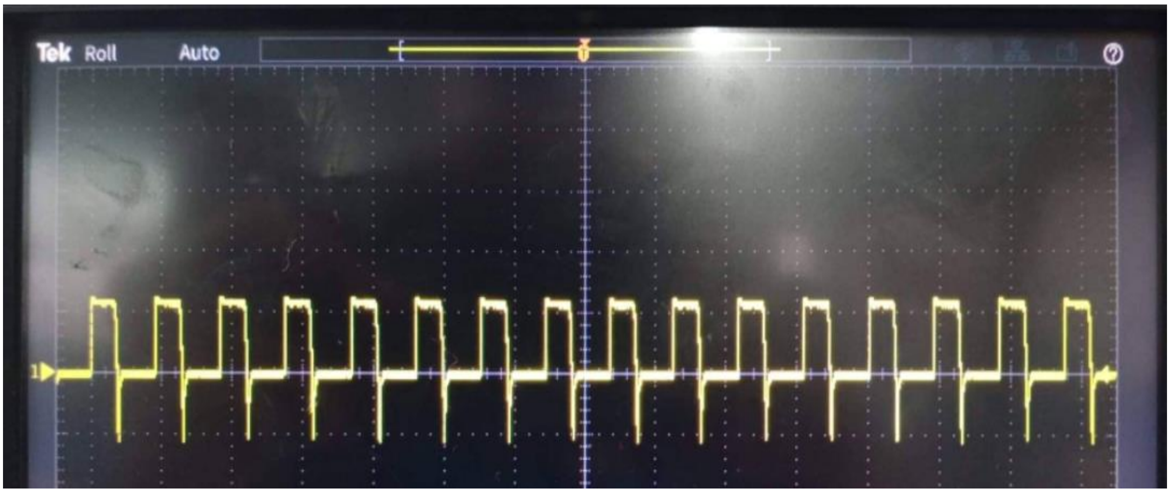

Figure 6. *LPG injector control pulse under dual fuel combustion mode of 3kW, and 1600 rpm*

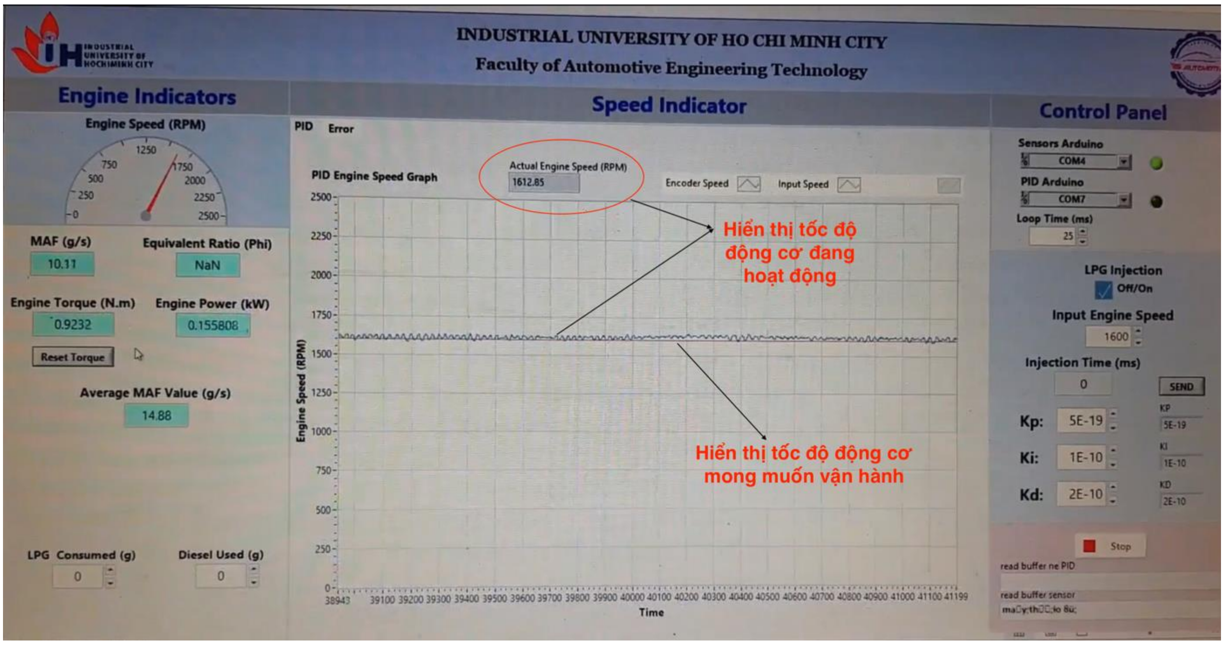

Figure 7. *PID control's engine speed signal*

3.2. Engine performance characteristics

3.2.1. Brake specific fuel consumption (BSFC) and Brake thermal efficiency (BTE)

Figure 8 shows the brake specific fuel consumption for various engine loads under a constant engine speed of 1600 rpm. In general, at higher load, BSFC gradually decreases from about 550 g/kWh to 280 g/kWh in both LPG-diesel mixture and diesel fuel mode approximately. Furthermore, according to this figure, the observation of the BSFC trend shows that the amount consumption of LPG-diesel mixture is lower than diesel fuel. It can be explained by the contribution to better combustion and higher energy conversion from the heating value and charging efficiency properties of LPG are the main amount of fuel consumption in dual fuel mode while diesel is used as a pilot injection. The difference of the BSFC also implies different combustion characteristics, owing to the chemical and physical properties of the fuel, and engine operating parameters causing an effect on combustible mixture formation [19]. This result trend is consistent with other studies by Saleh [2], Goto [4], Ashok [7], Rao [10].

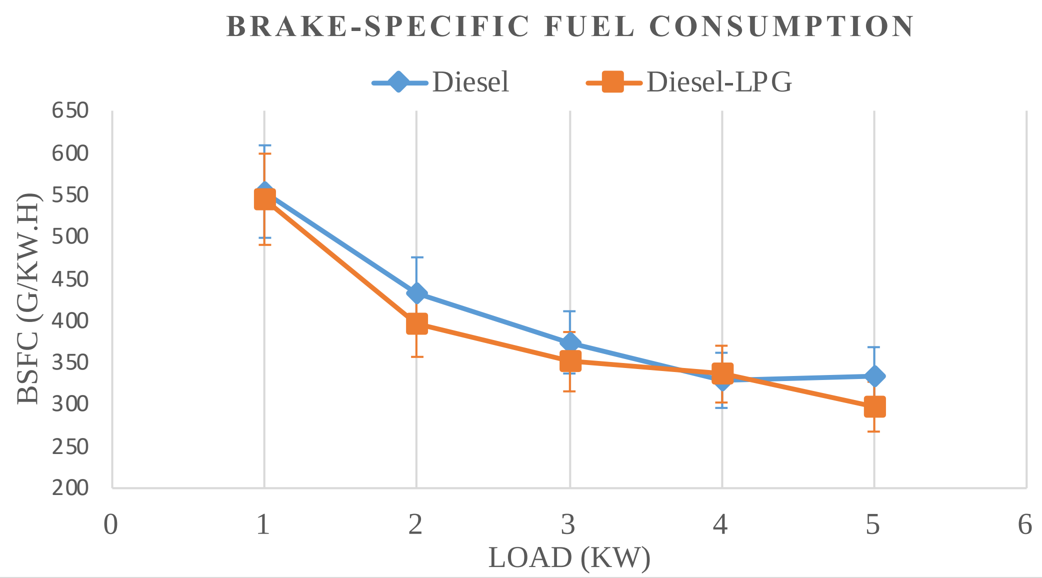

Figure 8. *Brake specific fuel consumption under constant 1600rpm and various engine loads*

Thermal efficiency is the inversion of BSFC. Figure 9 shows the thermal efficiency of the engine for various engine loads at a constant engine speed of 1600rpm. In the figure, thermal efficiency in dual fuel combustion mode increases from 15.1% to 27.9% corresponding to the increase of engine load from 1.0kW to 5.0kW, respectively. In dual fuel combustion mode, LPG played the role of the primary consuming fuel, has a slightly lower trend of BTE than diesel fuel mode. This might be from the use of less diesel fuel causing poor ignition quality [19]. However, the study on the effects of different speeds and loads on engine performance has needed to carry for providing more information.

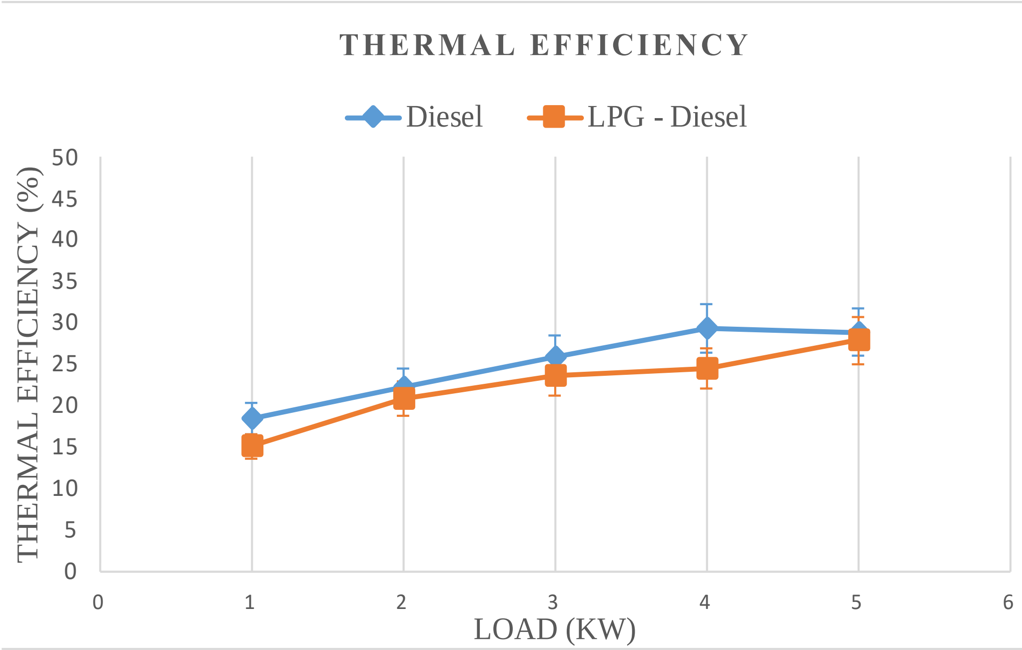

Figure 9. *Brake thermal efficiency under constant 1600rpm and various engine loads*

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3.2.2. Exhaust gas temperature

The exhaust gas temperature was plotted in figure 10. From this figure, exhaust gas temperature has the same trend for both fuel-providing modes, exhaust gas temperature increases with the increase of engine load. The results from exhaust gas temperature ensure that the engine works in the same conditions for testing. At higher loads, the difference in exhaust temperature between diesel fuel mode and dual fuel mode shows more clearly. The lower exhaust gas temperature of the dual fuel combustion mode might be caused by the faster flame speed in the diffusion combustion phase that results in more complete combustion and less amount of unburned fuel continued in the late combustion phase [20], [21]

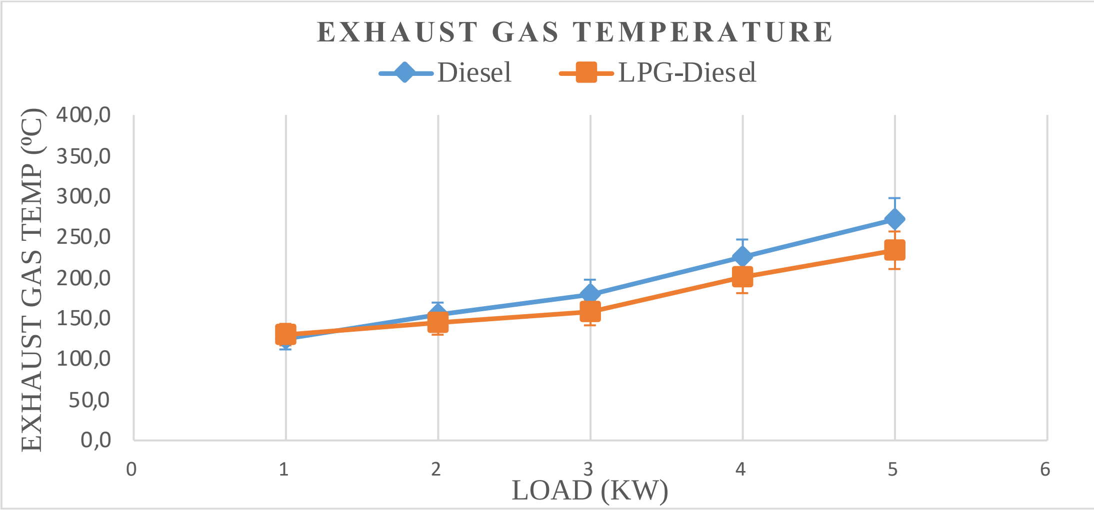

Figure 10. *Exhaust gas temperature under constant 1600rpm and various engine loads*

4. Conclusions

This study was carried out to investigate the operating possibility of the LPG electronic injector system and data acquisition-control system (DAC) by applying to the DI-single cylinder-diesel engine converted to dual LPG-diesel fuel combustion mode. The research is concluded as follows:

- The LPG electronic injector control circuit and DAC system present a good operation in both engine running modes (diesel and LPG-diesel dual combustion modes). The LPG injection-based speed regulator ensures that the engine speed is maintained at an assigned speed.
- The fabricated LPG supply system on the engine intake manifold allows a stable operation and can easily change between pure diesel mode and LPG - Diesel dual fuel mode without modification much to the original engine.
- The compared results of engine performance characteristics such as BSFC, BTE, and exhaust gas temperature in both fuel-providing modes reveal the feasibility of the conversion of diesel engines to using the dual fuel mode of LPG-diesel. It is a premise to conduct further studies on optimal operating conditions, emissions evaluation, and other related potential-gaseous fuels in diesel conversion research to reduce pollutant emissions.

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