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HC EMISSION STABLE AND POWER OPTIMATION OF THE MOTORCYCLE LPG ENGINE BY HEAT TRANSFER TO THE INJECTOR

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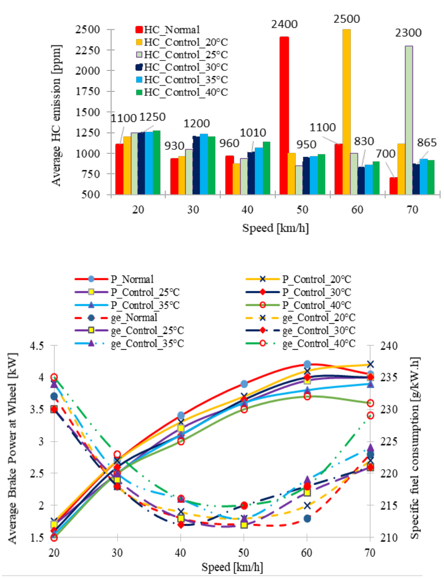
Graphical abstract



Abstract

This study was conducted on a motorcycle engine that already has bi-fuel, with liquid phase LPG injection. However, when conducting experiments on the concentration of substances in the exhaust gas, the results show that the concentration of hydrocarbon in the tests has different effects. It is possible to see a sudden high hydrocarbon concentration at some point in time. Over time, the nozzle tip will gradually form ice around the nozzle due to LPG evaporation and heat collection. When forming large lumps, this ice will break off and move into the combustion chamber. A part of ice has not yet mixed with the air to create an explosive mixture, and the combustion process is not completed. The solution proposed is to use the method of heat transfer to the nozzle body by an electronic heating device. The experiment measured brake power at the wheel, fuel consumption, and concentration of pollutants in the exhaust gas according to each controlled temperature to supply to the nozzle body. With this result, a suitable nozzle supply temperature is selected to ensure that the engine achieves the most optimal power and fuel consumption and eliminates the phenomenon of abnormal hydrocarbon concentration. From the test results, 30^{O}C is the most suitable temperature when adjusting the heating device around the nozzle.

Keywords: HC stable; optimal power; bi – fuel; LPG injection; electronic heating.

1.0 INTRODUCTION

Environmental pollution due to the exhaust gases of vehicles is a serious problem. In Vietnam, the majority of personal vehicles are motorcycles. There were 57 million motorcycles of all kinds in use in Vietnam (equivalent to one for every 1.6 people) [1,2]. These vehicles cause 85% of total Carbon monoxide (CO) pollution in big cities in Vietnam [3-5]. Meanwhile, the number of motorcycles is increasing; it is forecasted that by 2025 there will be about 75 million motorcycles. With this situation, Vietnam needs solutions to reduce pollution from motorcycle engines using traditional fuels.

Electric motorcycles are a solution. In Vietnam, Vinfast is a pioneer manufacturer with the goal of electric motorcycles gradually replacing internal combustion engine motorcycles. However, after two years of implementing this plan, sales of electric vehicles are still lower than expected. The reason is that people are still used to using internal combustion engine vehicles. Moreover, electric motorcycles take a long time to charge the battery and have short battery life. Therefore, electric motorcycles still need more time to become more prevalent in Vietnam.

Nowadays, alternative fuels for gasoline are being researched. Liquefied petroleum gas (LPG) is an alternative fuel that has been popular globally to apply in engines. The LPG fuel system for the internal combustion engine can be a dual fuel system or bi-fuel system: a dual fuel system used for compression ignition (CI) engines and a bi-fuel system used for spark ignition engine (SI) engines. There are three bi-fuel fuel systems [6,7]: the mixer, LPG fuel injected in the intake manifold, and LPG fuel injected directly into the combustion chamber.

The LPG direct injection system is rarely used because it directly interferes with the engine and combustion chamber

[8,9]. The other two types are common. The mixer type is simple and easy to install but difficult to control the fuel-air mixing ratio, resulting in a relatively significant reduction in engine power compared to gasoline [10,11]. The type of liquid LPG fuel injection system on the intake manifold requires a redesign of the electronic control unit [ECU], but engine power is higher [12]. This study uses a bi-fuel system based on the original motorcycle engine. When using gasoline, SI engines use carburetors. Which is a relatively common type and accounts for 70% of all motorcycles in Vietnam [3], and when using LPG, fuel injects into the intake manifold. LPG fuel injection control is an ECU based on sensors and signals received from sensors to precise control injection time and ignition angle.

However, when studying the intake manifold's LPG injection fuel injection system. The measurement results from the concentration of hydrocarbon (HC) increasing suddenly, inconsistently, and irregularly. It can occur at any experimental time (Figure 1).

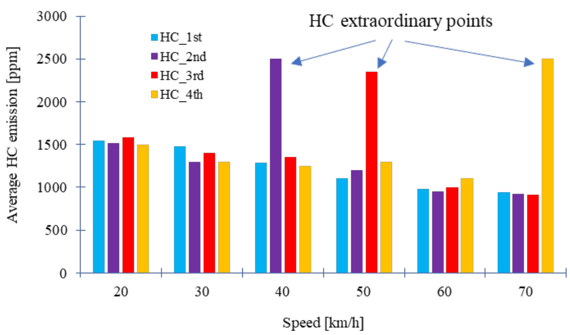


Figure 1 The graph shows the abnormality of HC concentration in the experimental times.

The cause of the abnormally high HC concentration is due to the freezing of the LPG nozzle [11-14]. The ice around the nozzle is formed depending on the nozzle material, injection time, injection pressure, nozzle tube diameter, and nozzle top surface smoothness. Sometimes the ice is broken and moved into the combustion chamber. This frozen HC will have a part that has not yet mixed with the air and cannot burn completely, which causes an abnormal increase in HC if LPG freezes. When LPG is injected into the intake manifold, it evaporates quickly and collects heat, creating freezing at the top of the nozzle. Many authors discovered and published this research result [15–19]. Solutions have been implemented, such as changing the structure or materials of the nozzle, smoothing the nozzle surface, etc. However, these studies only reduce the freezing phenomenon and do not solve the complete freezing of LPG.

In the study by Jan Mareš et al. [20] of a liquid LPG fuel system of the company Vialle, the injector was mounted on the intake manifold. To evaluate the nozzle top's freezing level, change the steel and plastic nozzle material. The results showed that. The plastic injector significantly improves the icing on the injector top at the crankshaft rotation speed of 3000 rpm and medium load. However, all other modes do not improve much.

In Park's research [21], the nozzle was made into two parts: the nozzle body with the nozzle hole in the middle and the bushing part around the nozzle (Figure 2). The nozzle has modified from the original design to allow experiments with different nozzle geometry and materials by replacing the nozzle without modifying the injector and bushing. The anti-freeze bushing has been other materials and sizes of inner and outer nozzle diameters. The bushing is connected when the disturbance matches the nozzle's preferred tolerance for the nozzle tip. The results also show that the surrounding plastic material can reduce the freezing phenomenon. However, the measurement results at the test times are not uniform and cannot make accurate conclusions. Studies on the surface roughness of housing materials are needed.

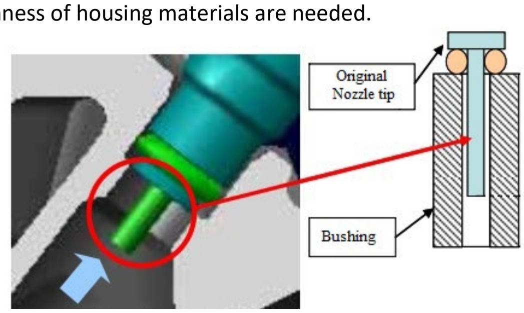


Figure 2 LPG nozzle type with bushing surrounded by plastic material [21].

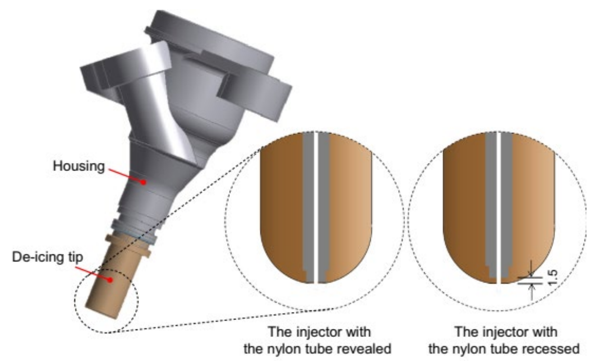


Figure 3 One nozzle type has a brass tube cover with variable roughness around the tube [22].

A similar study by Kim et al. [22] showed the freezing and condensing properties of LPG depending on the surface roughness of the nozzle body. Use brass material to cover the nozzle head surface and then polish the brass surface (Figure 3). After polishing, the average surface roughness is 30 nm. Experiment with this nozzle. The results have shown that freezing is significantly reduced with polished surfaces, especially at low engine speed operating modes.

In the study of Tuan and Dong [23], the software was set up to simulate the influence of parameters such as nozzle shape, size of pipes in the nozzle, nozzle diameter, fabrication material, injection pressure, and injection duration on the nozzle top icing formation. However, this software confirmed that it is impossible to prevent freezing completely without adding heat from the outside.

Other studies [24,25] have used engine coolant to pass through the injectors, which has prevented LPG from freezing at the nozzle top. However, the research results have not evaluated the effect of adding temperature on engine performance and emissions concentration. The solution in this study is to add a thermal component around the nozzle. However, how to control the temperature to ensure that the HC concentration does not occur abnormally. At the same time, this study will also solved the engine power the most optimal.

2.0 EXPERIMENTAL STUDY

2.1 Fuel System And Motorcycle Test

The experiment was conducted on the Havico motorcycle with a bi-fuel engine. The motorcycle's engine parameters are shown in Table 1. Engine Motorcycles can use LPG or gasoline. The gasoline fuel supply system uses the original carburetor. When using LPG fuel, the engine uses a fuel injection system on the intake manifold. The signals from the sensors of fuel injection time, fuel injection pressure, and ignition timing have been designed to be suitable when the engine uses LPG. LPG fuel was injected into the intake manifold by two independent injectors with 12 holes and a mass flow rate of 120 cc/min, the material for making the nozzle is steel. The experimental fuel was LPG comprising 50% propane and 50% butane.

Table 1 Engine and motorcycle parameters.

Motorcycle model	Havico
Weight	93 kg
Transmission	4 - speed
Bi-fuel system	Carburetor and LPG injection system
Engine	SI, Single cylinder
Displacement	97 cm^3
Bore x Stroke	50.0 x 49.5 mm
Cooling system	Air-cooled
Max Power	5.6 kW/6500 rpm
Max Torque	7.2 Nm/5500 rpm
Specific fuel consumption	≤ 350 g/kW.h
Max engine speed	7000 rpm
Compression ratio	9.1
Mileage	50000 km

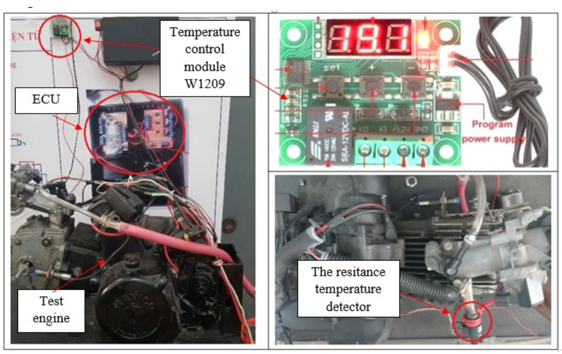


Figure 4. The experimental engine has been installed with an ECU to control the LPG fuel system. A temperature control module at the resistor is wound around the top of the nozzle.

For the addition of heat to the nozzle tip, in this study, a temperature control circuit has been designed and fabricated to provide heat to the nozzle body utilizing a wire wound around the nozzle. There is also an additional temperature sensor to measure the nozzle temperature on the injector. The temperature change at the nozzle is through the control switch. The ECU controls, the temperature control circuit, and the engine's LPG fuel system diagram are shown in Figures 4 and 5.

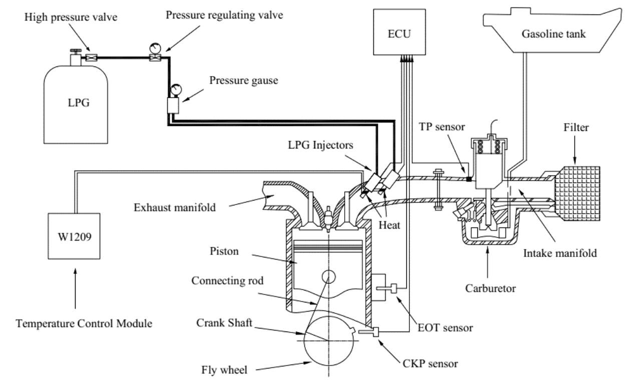


Figure 5 Diagram the bi-fuel system with an additional temperature control system for LPG injectors.

2.2 Measure Equipment

Motorcycles are tested on a chassis dynamometer. The test dynamometer consists of two rollers loaded from the rear wheel. The parameters measured by the dynamometer are the motorcycle speed, the power at the wheel, and the specific fuel consumption. The dynamometer also includes a load-inducing device, a purely resistive load transformer, and a speed sensor to determine the wheel's rotational speed. The parameters of the motorcycle test bench are shown in Table 2.

Table 2 Specifications of the chassis dynamometer [1].

Specifications	Value
Roller (length x diameter)	500 x 135 mm x mm
Power supply	220 V-AC
Frequency	50 Hz
Maximum test speed	80 km/h
Maximum brake power	8 kW

The exhaust gas measuring device used in this study is the Testo 350. A flame ionization detector determines the HC concentration, non-dispersive infrared determines the CO concentration, and a chemiluminescence detector measures the (nitrogen oxides NOx) concentration. All instrument parameters, measuring ranges, and accuracy are described in Table 3.

Table 3. Measurement equipments, range and accuracy

Measurement	Range	Accuracy
NDIR for CO_2	0-25%	±1%
NDIR for CO	0-10000 ppm	±1%
CLD for NO_x	0-10000 ppm	±1%
FID for THC and CH_4	100-40000 ppm	±0.5%

The schematic diagram of the experimental equipment and the motorcycle mounted on the test bench is shown in Figures 6 and 7. All of these devices are connected to the computer to display the data from the experiment. Experimental data is exported from the computer software through the computer connection with the testing equipment. The motorcycle operates stably with the throttle fully open, the fuel injection pressure is 3 bar, the ambient temperature at the time of the test is 27^{O}C, and the vehicle speed is tested in the speed range from 20 km/h up to 70 km/h. Each experimental mode is performed for 5 minutes, and the experimental results are the average value of the 5 minutes of the experiment. Concentrations of toxic substances, power, and engine fuel consumption when changing the temperature added to the injector are presented in Figures 8-11.

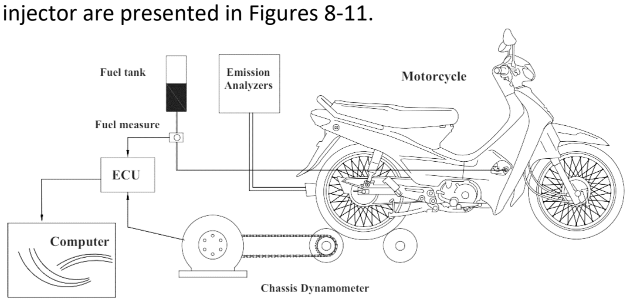


Figure 6 The experimental system schematic.

Figure 7 Test motorcycles assembled in the chassis dynamometer.

3.0 RESULTS AND DISCUSSION

3.1 Comparison Of Power And Fuel Consumption

The average brake power at the wheel varies depending on the temperature supplied to the nozzle. The average brake power at the wheel curve has the same trend as the average brake power at the wheel increases gradually as the motorcycle speed increases. The maximum average brake power at wheel value in the speed is 60-70 km/h.

When adding the nozzle temperature of 40^{O}C, the average brake power at the wheel curve has the lowest value. Without adding the nozzle temperature, the average brake power at the wheel has the highest value. The average brake power at the wheel decreases as the added temperature increases to the LPG nozzle body. Cause the nozzle temperature increased; then ice could not form on the nozzle tip. However, the high temperature will transfer to the LPG fuel in the nozzle tube, making the LPG evaporate faster. Making the LPG density decrease and increasing the volume occupied by LPG when injected into the combustion chamber. With the same amount of LPG injection, the amount of air entering the combustion chamber will decrease in each engine's working cycle, and the ratio of air and fuel is changed (A/F increases). This is the cause of the average brake power at the wheel decreased and HC concentration increase. The graph also shows that the power difference is not much when increasing the nozzle temperature at low-speed mode, but this power difference is more significant at high speed.

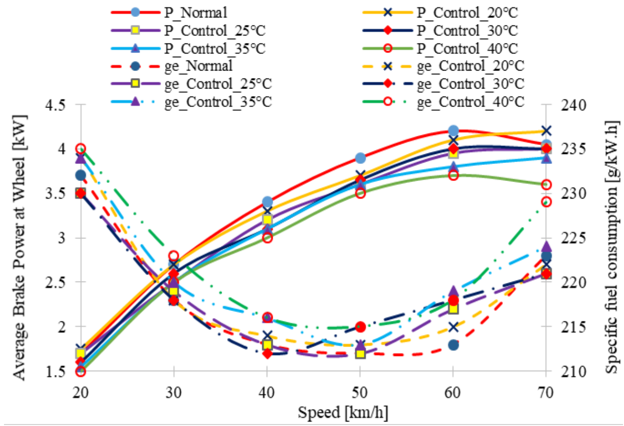


Figure 8 Experimental result of average brake power at the wheel and specific fuel consumption with gasoline and LPG.

Meanwhile, the specific fuel consumption of adding temperature at the LPG injector of 40^{O}C will have the most significant value and the lowest value in the mode without adding heat. However, the difference in specific fuel consumption is not much. For example, on the graph at 20 km/h, the specific fuel consumption without adding heat is 232 g/kW.h, while the specific fuel consumption when adding 40^{O}C around the nozzle is 235 g/kW.h, a slight difference of only 3g/kW.h. At a speed of 70 km/h, the fuel consumption without adding heat is 223 g/kW.h, while the specific fuel consumption when adding 40^{O}C to the injector is 229 g/kW.h, a slight difference of only 6 g/kW.h.

In experimental results, increasing the temperature causes the fuel and air mixture mass to decrease and reduce the average brake power at the wheel. However, choosing a suitable temperature so that the engine power does not decrease much but completely prevents freezing needs HC concentration measurement results from the evaluation. This result is shown in Figure 9.

3.2 Comparison Of Exhaust Emissions

Figures 9-11 show the concentration of harmful substances in the exhaust gas in temperature control modes with the added of the nozzle top from 20^{O}C to 45^{O}C (interval 5^{O}C) and no heat added (Normal). The procedure is measured multiple times to determine the exhaust gas concentration. The result is the average value over the measurement time of about 5 minutes in each test mode. Figure 9 shows that HC concentration decreased steadily from low to high motorcycle speed in all experimental ways. HC concentrations tend to be higher with increasing temperature added to the nozzle around. However, when adding heat to the nozzle of 20^{O}C or 25^{O}C, the test results were repeated many times, the time lasted up to 15 minutes, the measurement results showed that many times the concentration of HC was abnormally high, the time longer the experiment, the easier it is to see this outlier. The maximum HC concentration was measured at 50 km/h with a value of 1800 ppm in no heat mode. At 25^{O}C heat mode, at 70 km/h, the maximum measured HC value is 1500 ppm. However, freezing is not fixed at a specific speed. It can happen at any motorcycle speed because the ice will form gradually over time. The time is long or short depending on the temperature added to the nozzle after each cycle. It begins to form ice until the ice has a large ice amount and then breaks off and enters the combustion chamber. When adjusting the supply temperature for the nozzle to 30°C, the test time in this mode is extended to 30 minutes. The results did not show any abnormal phenomenon of HC concentration, but the graph shows the HC concentration curve trend decreasing when the motorcycle speed increases. With this test result, it can be confirmed that when adding a temperature of 30°C around the nozzle, the freezing phenomenon did not occur. Of course, the freezing will not occur when the temperature increases by more than 30°C. However, the HC concentration will increase. Further, the engine power will also decrease. Therefore do not extend the test time at the additional nozzle temperature of 35°C and 40°C.

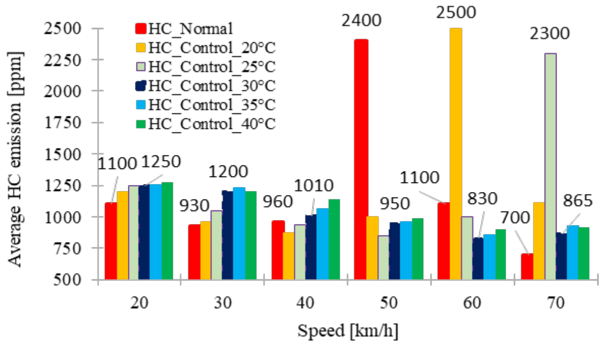


Figure 9 HC concentration measurement results in the case of temperature added to the nozzle.

The results are similar to the CO concentration results. Adding temperature to the nozzle has the effect of reducing the CO concentration. In the mode without adding heat to the nozzle, the CO concentration tends to be higher than when adding heat to the nozzle. CO concentration gradually decreased from 20 km/h to 60 km/h and increased slightly at 70 km/h in all experimental modes.

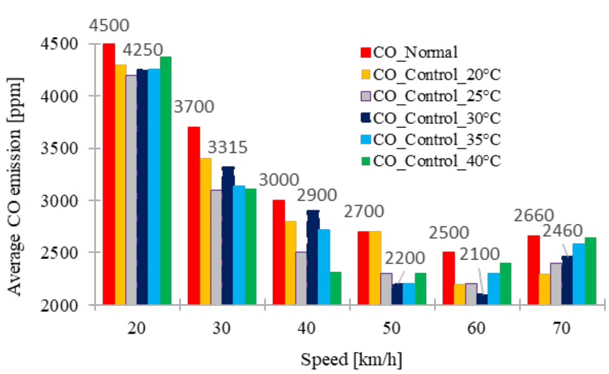


Figure 10 CO concentration measurement results in the case of temperature added to the nozzle.

The graph in Figure 11 shows the NOx concentration measured at the exhaust pipe during the same time of the experiment. The NOx concentration increases gradually with the motorcycle's speed. Depending on the test mode, the maximum NOx concentration is 630 ppm at 60-70 km/h. In contrast to the concentration of HC, the temperature addition has become an advantage in reducing the concentration of NOx released into the environment. NOx concentration tends to decrease when adding temperature to LPG injectors. The higher the LPG nozzle temperature, the lower the NOx concentration.

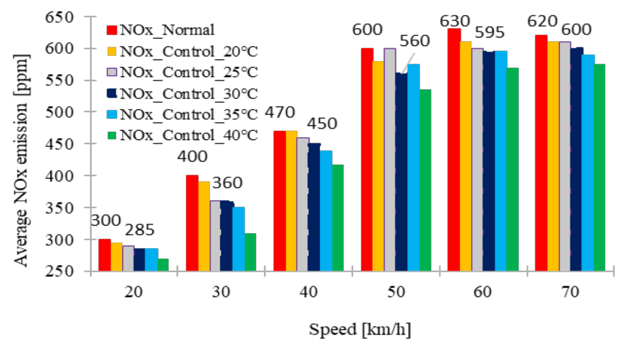


Figure 11 NOx concentration measurement results in the case of temperature added to the nozzle.

4.0 CONCLUSION

In a bi-fuel system of LPG and gasoline on a motorcycle available, experimental research on HC concentration and research results of scientists have discovered the phenomenon of freezing on the LPG nozzle tip. The experiment used an electric heater to transfer heat to the nozzle body, which is a simple and easy solution to install and take advantage of the 12V power supply of the motorcycle battery. The electronic heating adjusted the temperature around the nozzle was 30°C, and freezing did not occur. Because when adding heat, the LPG evaporates quickly, increasing the LPG volume, and the increased volume will displace the air volume, leading to a decrease in combustion efficiency, causing the concentration of HC to increase. The most significant increase in HC concentration was 25% at 30 km/h. The CO concentration increases due to the lack of combustion, the highest decrease in CO was 19% at 50km/h. Lower combustion temperature reduces NOx concentration, with NOx maximum reduction of 30% at 30km/h. Similarly, average brake power at the wheel will decrease with a maximum reduction of 9% at 40 km/h. Fuel consumption is almost unchanged, with a slight increase, but only the most significant expansion of 2% at 60km/h. In this study, the freezing phenomenon was only solved by heating the nozzle at a fixed temperature of 30°C. However, as the result of this study, the following research direction needs to automatically adjust the temperature according to the temperature at the nozzle body to have an optimal temperature range, which will further improve engine power and ensure no freezing. In the future, to solve the freezing problem, we will continue to study the influence of injector material, nozzle pipe size, nozzle shape, fuel injection pressure, and fuel injection duration on the formation of ice around the nozzle, thereby providing the right solution to prevent this phenomenon.

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Abbreviations

CI	Compression ignition engine
SI	Spark ignition engine
ECU	Electronic control unit
LPG	Liquefied petroleum gas
HC	Hydrocarbon
NOx	Nitrogen Oxides
CO	Carbon monoxide

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