ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume VI (XVI), 2007

RESEARCHES REGARDING USING LPG ON DIESEL ENGINE

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Keywords: liquefied petroleum gas–diesel dual fuel, electronic control, comparison of engine and automobile performances, reduction in pollutant emissions and fuel consumption

Abstract: In this paper, the control scheme of a liquefied petroleum gas (LPG)–diesel dual-fuel engine with electronic control is illustrated, the external characteristics and load characteristics of the LPG– diesel dual-fuel engine and the diesel engine are compared and analyzed. The experimental results show that, compared with diesel, the output performance of dual fuel is not reduced, while smoke emission of dual fuel is significantly reduced, NO*x* emission of dual fuel is hardly changed, but HC emission and CO emission of dual fuel are increased and fuel consumption of dual fuel is reduced.

1. INTRODUCTION

Reducing the pollution of automobile emission and studying the application of an automobile alternate fuel are crucial subjects in the field of automobiles at present. With the constant increase in high-grade highway mileage and the significant improvement in production technology of the high-speed diesel engine and the increasing need for heavy-duty trucks for transportation, the number of diesel vehicles is increasing. Many cities in China have prohibited the running of diesel vehicles in urban areas because diesel automobiles have heavy smoke emission and loud noise and people feel that diesel automobiles are very harmful to the environment. Therefore, reducing the smoke emission of diesel automobiles, especially to used diesel automobiles, has become a problem that calls for an urgent solution. Smoke emission can be largely reduced if diesel vehicles are changed to fuel with liquefied petroleum gas (LPG)– diesel dual fuel, which is one of the efficient ways to reduce the smoke emission of diesel vehicles.

The following list describes the potential health risks associated with these emissions:

- Carbon Monoxide (CO): An odorless and colorless gas which is highly poisonous. CO can reduce the blood's ability to carry oxygen and can aggravate lung and heart disease. Exposure to high concentrations can cause headaches, fatigue and dizziness.

- Nitrogen Oxides (NO_x) and Nitrogen Dioxide (NO_2): These chemicals form the yellowish-brown haze seen over dirty cities. When combined with oxygen from the atmosphere, NO becomes NO_2, a poisonous gas that can damage lung tissue.

- Hydrocarbons (HC): This is a group of pollutants containing hydrogen and carbon. Hydrocarbons can react to form ozone. Some are carcinogenic and other can irritate mucous membranes. Hydrocarbons include: Volatile organic compounds (VOC); Volatile organic gases (VOG); Reactive organic gases (ROG); Reactive organic compounds (ROC); Non-methane hydrocarbons (NMHC); Non-methane organic gases (NMOG).

- Ozone (O_3): This is the white haze or smog seen over many cities. Ozone is formed in the lower atmosphere when NMOG and NO_x react with heat and sunlight. Ozone can irritate the respiratory system, decrease lung function and aggravate chronic lung disease such as asthma.

2. THE CONTROL SCHEME AND CONTROL DEVICE

The study on co-combustion characteristics of LPG– diesel dual fuel shows that, after co-burning LPG, the smoke emission of diesel engine at high loads can be significantly reduced, but at low loads, the specific fuel consumption is increased and the hydrocarbon (HC) emission and carbon monoxide (CO) emission are also increased. So, the way in which fuel consumption, HC emission and CO emission at middle and low loads can be reduced has become an urgent problem when dual fuel has to be adopted to reduce the smoke emission of diesel vehicles.

To improve fuel economy, and to reduce HC emission and CO emission of dual-fuel engines at partial load, used the method of electronic control compressed natural gas (CNG) injection outside the cylinder and adopted the 'stopping-cylinder technique'. In other words, this method continues diesel supply of all cylinders and stops the CNG supply of some cylinders. It makes 'the working cylinders' operate at the optimum excess air ratio. This scheme is limited to the condition of applying electronically controlled gaseous-fuel injection. To ensure complete combustion and to reduce HC emission and CO emission of dual-fuel engines at partial load, used the intake-throttling method to increase the concentration of the gaseous-fuel pre-mixture. The performance of this kind of dual-fuel engine is close to that of a gasoline engine at partial load. Its fuel consumption increases because of the reduction in filling efficiency. This scheme has been tested only by the manual method. To reduce the HC emission of discharged dual-fuel engines due to the scavenging of the gaseous fuel pre-mixture in the valves' overlap period, used the gaseous-fuel mixer fixed in the intake manifold. The mixer is one kind of pipe system and uses the fluid dynamic effect to control the initial timing of the gaseous-fuel intake. This scheme has poor adaptability to variable operating conditions of engines.

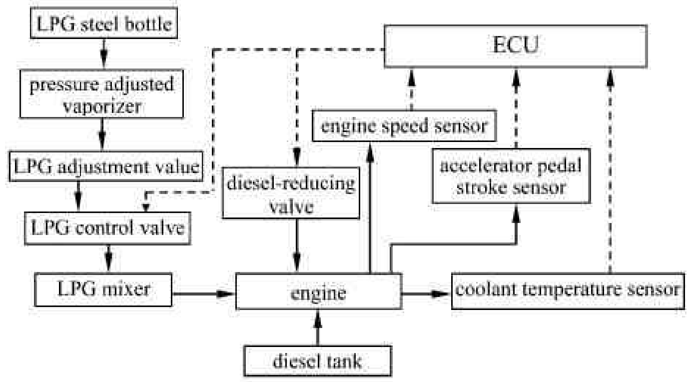

Fig. 1. The LPG-diesel dual-fuel, electronically controlled engine

This paper describes the development of an electronically controlled scheme, in which the engine is fuelled with diesel at low loads, and with LPG– diesel dual fuel after the engine load reaches a preset level. The advantage of this scheme is not only to adopt low-fuel consumption and emissions of HC and CO of diesel engines at low loads, but also to diminish heavy smoke emission at high loads and full load of diesel engines, by co-burning LPG.

The LPG–diesel dual-fuel, electronically controlled engine is shown in Fig. 1. The electronic control unit (ECU) controls a diesel-reducing valve and an LPG control valve according to the signals from sensors, including engine speed, coolant temperature and accelerator pedal stroke, which indicate the engine's operating condition. The diesel-reducing valve, located on the high-pressure pump, is to reduce diesel supply when it is on. The LPG control valve, located between the pressure-adjusted vaporizer and LPG mixer, is to control the LPG supply. The engine resumes its operation with diesel when the ECU turns off the diesel-reducing valve to resume the diesel supply and shuts off the LPG control valve to stop the LPG supply.

The electronic control device developed in this paper is shown in Fig. 2. The input signals of the control device are the accelerator pedal stroke, engine speed, and coolant temperature. The accelerator pedal stroke signal is supplied by a linear resistance installed at the speed-adjustment axle of the high-pressure pump. The engine speed signal, entering the single-chip computer system as a square wave after plastic handling and a wave filter, is supplied by an electromagnetic sensor. The frequency of the square wave signal is directly proportional to the engine speed. The coolant temperature signal, after electric-level transformation and comparison, is supplied as a switch signal to enter the single-chip computer system.

No matter what the model of the speed governor of original diesel engine is, the device can complete the designed control characteristics of fuel supply by changing the read-only memory with a written relevant program.

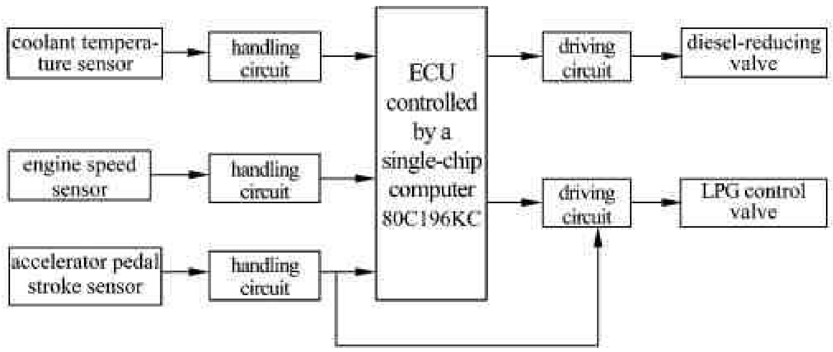

Fig. 2 The electronic control device

The single-chip computer program for the all-speed governor is illustrated below. After entering the subroutine, under the condition that the accelerator stroke is larger than the idle opening, as the coolant temperature is higher than 60°C, and the engine speed is higher than the idle speed and lower than the maximum speed, it is determined by the control table whether the diesel-reducing valve and LPG control valve works or not: under the condition when the engine speed is higher than the maximum value, the diesel supply is reduced and the LPG supply is shut off; under the condition when the coolant temperature is lower than 60°C, the LPG supply is shut off, and the engine is operated by diesel considering that LPG vaporizing condition is not good and control accuracy of the LPG control valve to LPG flow is reduce.

3. THE RESULTS AND ANALYSES OF ENGINE PERFORMANCES

Engine performance tests were completed on a four-cylinder supercharged direct-injection SOFIM 8140.27S.27 diesel engine with electronic control.

When the engine is fuelled with LPG–diesel dual-fuel, the brake specific fuel consumption (BSFC) is taken to be the LPG consumption which is commuted to diesel consumption according to their low calorific values, and the co-combustion ratio (CCR) is defined as the percentage ratio of LPG energy to the dual-fuel energy, given by

$$CCR = \frac{m_{LPG} H_{uLPG}}{m_{LPG} H_{uLPG} + m_{diesel} H_{udiesel}} \times 100 \ [\%] \quad (1)$$

where m_{LPG} is the consumption of LPG, H_{uLPG} is the low calorific value of LPG (45.31 MJ/kg), m_{diesel} is the consumption of diesel, and $H_{udiesel}$ is the low calorific value of diesel (42.50 MJ/kg).

3.1 The comparison and analysis of the engine external characteristics

3.1.1 Torque

The comparison between the torques of the external characteristics of LPG–diesel dual fuel and diesel is shown in Fig. 3. The torque of the dual fuel is slightly less than that of diesel, but the difference is very small; so the dynamic characteristic of the dual-fuel engine almost does not decline. To avoid knocking of the LPG mixture, CCRs are controlled in the range from 29.7 to 33.8 per cent when the compression ratio of the engine is not changed.

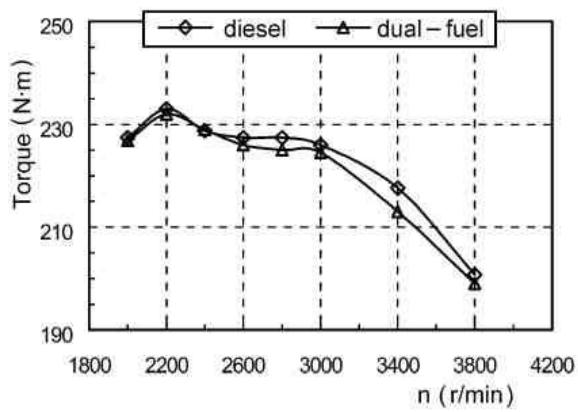

Fig. 3 The comparison of torques at full load

The air–fuel ratio of dual fuel is slightly smaller than that of diesel. Although the LPG pre-mixture causes a small decrease in the engine's intake air amount, the torque of dual fuel is almost equal to that of diesel because the reduction in air–fuel ratio of the LPG pre-mixture makes the heat value of the mixture in the cylinder recover, and dual fuel has a higher combustion efficiency than diesel.

3.1.2 Fuel consumption

The comparison between the BSFCs of the external characteristics of LPG–diesel dual fuel and diesel is shown in Fig. 4. The BSFC of dual fuel is slightly less than that of diesel. Becase of the good quality of the mixture and high combustion efficiency of dual fuel, the BSFC of dual fuel at full load is low.

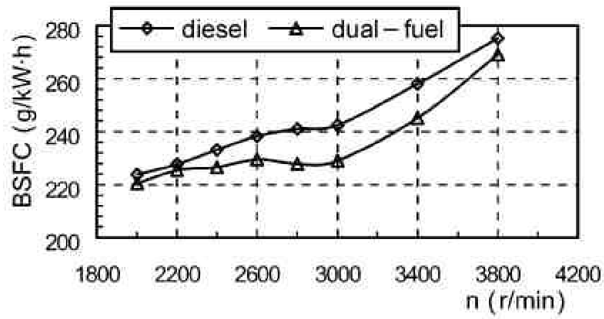

Fig. 4 The comparison of BSFCs at full load

3.1.3 Smoke emission

The comparison between the smoke emissions, *R*b, of the external characteristics of LPG–diesel dual fuel and diesel is shown in Fig. 5. Compared with the smoke emission of the diesel engine, that of the dual-fuel engine is reduced significantly, 59 per cent on average. When the engine is fuelled with dual fuel, consumption of diesel is reduced. The possibility of producing smoke is reduced due to the reduction in the possibility that oxygen is absent at high temperatures for diesel. The combustion velocity is increased and the burning duration is shortened, which also helps to restrain smoke production. Therefore, the LPG–diesel dual-fuel engine's smoke emission is reduced.

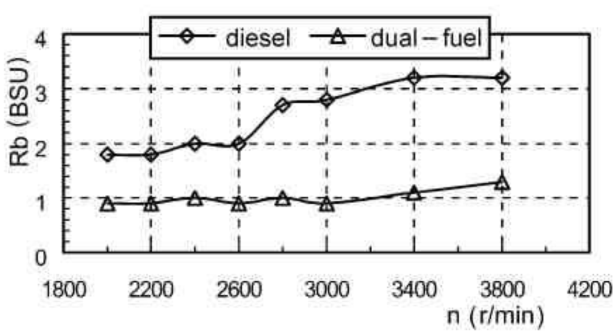

Fig. 5 The comparison of smoke emissions at full load

3.1.3 NOx emission

The comparison between the nitrogen oxides (NO*x*) emissions of the external characteristics of LPG– diesel dual fuel and diesel is shown in Fig. 6.

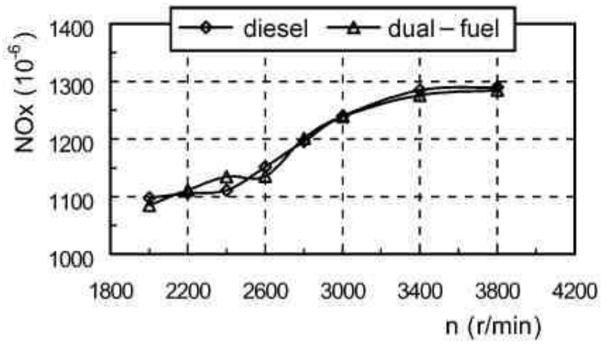

Fig. 6 The comparison of NOx emissions at full load

The NO*x* emission of dual fuel is almost equal to that of diesel. The change in the creation of NO*x* is determined by factors such as the mixture concentration and the combustion temperature, which are slightly changed. Therefore, the NO*x* emission is slightly changed.

3.1.5 HC emission

The comparison between the HC emissions of the external characteristics of LPG–diesel dual fuel and diesel is shown in Fig. 7.

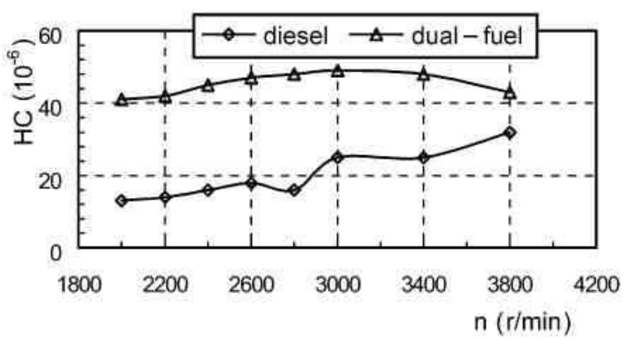

Fig. 7 The comparison of HC emissions at full load

At full load, the HC emission of dual fuel is higher than that of diesel, which is caused by two key factors; the first is that the LPG pre-mixture is scavenged to outside from the cylinder in the overlap period of the valves of the discharged dual-fuel engine, and the second is that the LPG pre-mixture that is pressed into the cooled crevices during compression stroke is difficult to burn.

3.1.6 CO emission

The comparison between the CO emissions of the external characteristics of LPG–diesel dual fuel and diesel is shown in Fig. 8.

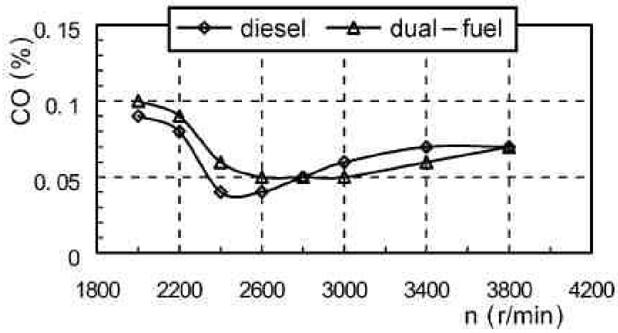

Fig. 8 The comparison of CO emissions at full load

At full load, the CO emission of dual fuel is almost equal to that of diesel. The formation of CO is related to the mixture concentration and fuel composition; the change in CO emission is the result of the two factors that exert effects at the same time.

4 CONCLUSIONS

1. Smoke emission can be largely reduced by using dual-fuel operation. However, the problems remain of how the fuel consumption, HC emission and CO emission of the dual-fuel engine are reduced at middle loads and low loads; this needs urgent attention. The electronically controlled scheme developed by our research group is that the engine burns diesel fuel at low loads and the engine burns LPG–diesel dual fuel after the engine load reaches the preset limit. This measure not only utilizes the diesel engine's good economy and low emissions of HC and CO but also reduces the diesel engine's high smoke emission at high loads and full load, by co-burning LPG.

2. The electronically controlled LPG-diesel dual-fuel scheme takes the accelerator pedal stroke, coolant temperature and engine speed as input signals, and the results of stand tests show that, when the engine burns dual fuel, the power output does not reduce; the electronically controlled scheme overcomes the common dual-fuel controlled scheme disadvantage of poor fuel economy and high emissions of HC and CO at low loads, but the ratio of diesel alternated by LPG is reduced. Despite the increase in HC emission and CO emission resulting from the engine's co-burning LPG, the HC and CO emissions of the dual-fuel engine are still generally lower than those of common gasoline engines.

3. Attempts may also be made to apply the electronically controlled scheme and the electronic control device, after a little modification, to CNG– diesel dual-fuel vehicles because CNG and LPG, as fuels, have many similar properties.

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