에너지공학, 제14권 제3호(2005)
Journal of Energy Engineering, Vol. 14, No. 3, pp. 187~193 (2005)

Performance and Emissions Characteristics of a Converted Liquefied Petroleum Gas (LPG) Engine with Mixer and Liquid Propane Injection (LPi) System

Gyeung Ho Choi*, Jin Ho Kim, Ung Lae Cho**, Yon Jong Chung*** and Sung Bin Han****,†**

**Department of Mechanical & Automotive Engineering, Keimyung University, Daegu, Korea*
***Department of Automotive Engineering, Keimyung University, Daegu, Korea*
****Department of Automotive Engineering, Daegu Mirae College, Daegu, Korea*
*****Department of Mechanical Engineering, Induk Institute of Technology, Seoul, Korea*

(Received 22 April 2005, Accepted 15 July 2005)

Abstract — In this study, the performance and emission characteristics of a liquefied petroleum gas (LPG) engine converted from a diesel engine were examined by using mixer system and liquid propane injection (LPi) system. A compression ratio of 21 for the base diesel engine, was modified to 8, 8.5, 9 and 9.5. The engine performance and emissions characteristics are analyzed by investigating engine power, brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), volumetric efficiency, CO, THC and NOx. Experimental results showed that the LPi system generated higher power and lower emissions than the conventional mixer fuel supply method.

Key words: Liquid propane injection (LPi), Mixer, liquefied petroleum gas (LPG), Compression ratio, CO, THC, NOx, Brake mean effective pressure (BMEP)

1. Introduction

With the recent strengthening of automotive emissions regulations and rising interest in environmental pollution, demand for reductions in automotive emissions and more fuel-efficiency technology are increasing. In addition, as fuel prices keep rising and protecting the environment, especially from air pollution, becomes more important, regulations on automotive emissions will become even stricter[1][2].

Due to the strengthening of environmental regulations, the development of low-pollution engines has become much more active. As part of this active development, the research is being conducted to reduce exhaust gases by using a clean fuel. Out of clean fuels such as methanol, ethanol, hydrogen, CNG, LPG, etc., LPG is being considered as the best alternative fuel due to its existing infrastructure in Korea and low price. LPG has become the topic of many research in Korea and in other countries, and LPG vehicles are already in wide use[3][4].

Currently, most LPG fuelled vehicles use a mixer type fuel supply system. However, many research are being done recently on closed circuit, liquid atomization methods. It has been reported that such LPG atomization methods reduce exhaust gases, increase the engine efficiency, and power output[5][6].

The conventional method of using LPG as fuel uses a mixer and a gaseous fuel that has been heated through the carburetor. Therefore, the density of the fuel is reduced, and a reduction in power takes place due to the decreased volumetric efficiency. Conventional mixer type methods evaporate the fuel and mix it with air inside the mixer. This process is controlled electronically with some degree of precision, but more precise control of air-fuel ratio is impossible with this method. Due to the such imprecision in the control of the air-fuel ratio, increased exhaust gases and reduced power output are resulted, and because

†To whom correspondence should be addressed.
Dept. of Mech. Eng., Induk Institute of Technology, San 76 Wolgye-dong, Nowon-gu, Seoul 139-749, Korea
Tel: 02-950-7545
E-mail: sungbinhan@induk.ac.kr

the mixer is installed on the inlet manifold, the backfiring can occur frequently. On the other hand, the LPi method pressurizes the fuel and supplies it in liquid form. The precise control of the air-fuel ratio is possible with the fuel injector. Advantages of this method include reduced exhaust gases, increased power output due to use of liquid fuel, and decreased backfiring[7][8].

However, such high pressure fuel remains in the fuel line even after the engine has been shut off and leaks through fine gaps in the injector. Fuel that has leaked in this manner remains in the intake system as a dense mixture and is responsible for reduced starting performance upon restarting the engine.

This research is an experimental investigation of the effects of the fuel supply method, known as Mixer and LPi methods, on engine performance and emission characteristics. These experiments, in which an old compression ignition engine is converted into a spark ignition engine, should contribute to a definite reduction in automotive emissions. Therefore, this research aims to reduce harmful emissions of diesel vehicles and experimentally find out the optimum compression ratio needed when converting an old diesel engine into a LPG engine. Also, the mixer and LPi methods are tested with variations in compression ratio, relative air-fuel ratio, etc. in order to investigate the effects of the two fuel supply methods on engine performance and exhaust gas characteristics.

2. Experimental Setup and Method

The schematic diagram of the experimental apparatus is shown in Fig. 1. The engine used in the experiment was a water-cooled, 4-cylinder, truck diesel engine with a displacement of 3568 cubic centimeter. The direct injection diesel engine was converted into a LPG engine, and the main specifications are shown in Table 1.

The desired compression ratio can be obtained by changing the height of the piston crown. The process of converting a diesel engine into a LPG engine is, unlike the process of converting a gasoline engine into a LPG engine, technically very complex. Namely, the conversion from a compression ignition engine to a spark ignition engine requires major changes in the engine's parts. Consequently, in order to make the compression ratio more suitable for a LPG engine, the compression ratio of the diesel engine, which was 21, was reduced to 8, 8.5, 9, and 9.5 by varying the crown height of the piston head.

A 2000cc-grade mixer was used. LPi fuel tank and

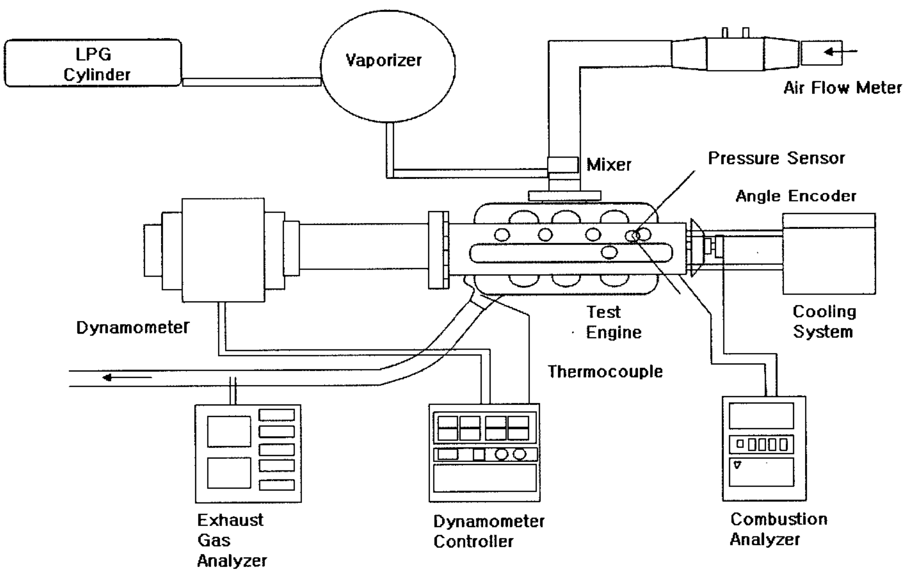

Fig. 1. Schematic diagram of experimental apparatus.

Table 1. Engine specifications.

Number of cylinder	4
Fuel supply	Mixer, LPi
Displacement volume	3,568 cc
Bore × stroke	104×105
Compression ratio	8~9.5

pressure regulator made by Vialle was used, and bottom feed type LPi injectors made by Siemens were used.

In addition, the spray nozzle located on the cylinder head was removed and replaced with a spark plug. A spark coil and distributor were used to provide spark energy. The diesel engine's fuel spray pump was removed and replaced with the distributor. Spark timing control was performed with MoTec's M8 ECU so that the desired spark timing could be controlled during operation of the engine.

In order to promote smooth operation of each part, the ignition control equipment was used to warm up the engine using the arbitrarily chosen conditions of 8BTDC and 600 rpm. Also, all experiments took place after the coolant temperature reached 80°C. Engine operating conditions were at wide open throttle (WOT), 1400 rpm, minimum spark advance for best Torque (MBT), relative air-fuel ratio of 0.8 to 1.3, and compression ratios of 8, 8.5, 9, 9.5. The compression ratios were controlled by using 4 different types of pistons.

3. Experimental Results and Discussion

Figure 2 shows the engine's power output characteristics for mixer and LPi type methods at different compression ratios as the relative air-fuel ratio is increased from 0.8 to 1.3 at WOT, MBT, and 1400 rpm. For the mixer type method, the highest power output was obtained with the compression ratio of 8~9 and relative air-fuel ratio of 0.9~1.0, but the overall dependence of power on compression ratio was not very significant. However, the LPi method resulted in a relatively higher power output compared

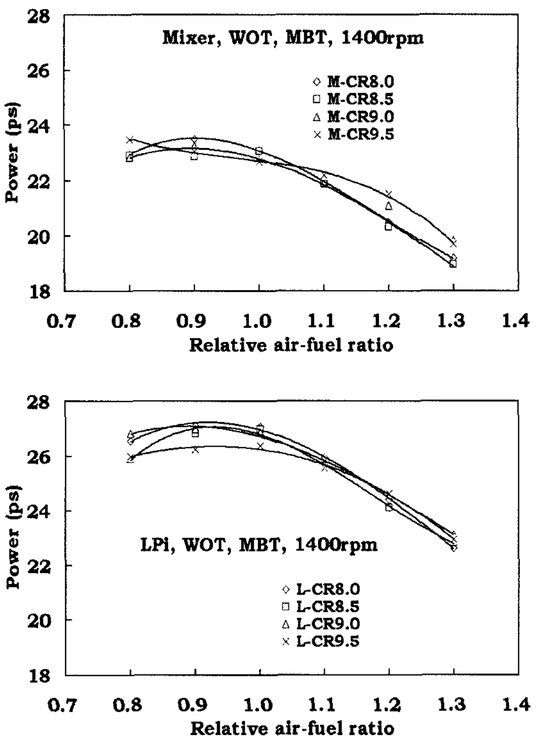

Fig. 2. Effect of compression ratios with mixer and LPi system fuel supply methods on power.

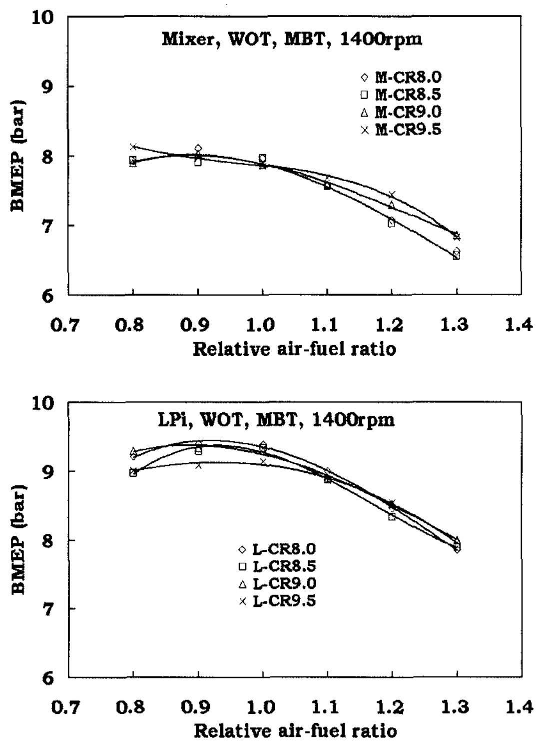

Fig. 3. Effect of compression ratios with mixer and LPi system fuel supply methods on BMEP.

to the mixer method. For example, with the relative air-fuel ratio of 1.0, the LPi method exhibited 17% more power than the mixer method at the compression ratio of 8, 17% more at the compression ratio of 8.5, 18% more at the compression ratio of 9, and 16% more at the compression ratio of 9.5.

Figure 3 shows the dependence of BMEP on the relative air-fuel ratio under the same testing conditions as above. The results are almost identical to the power output results shown in Fig. 2. Generally, BMEP increases with compression ratio up to the certain point, after which it decreases. Although the dependence is slight, IMEP increases with the compression ratio in this experiment. Since power and BMEP start to decrease at around the compression ratio of 9.5, compression of about 9 can be said to be the optimum compression ratio based on power output and IMEP.

Figure 4 and Fig. 5 show the curves for intake temperature and volumetric efficiency, respectively. The main reason for the power increase shown in Fig. 3 is most likely attributed to the fact that the LPi method results in an increased volumetric efficiency over the mixer method. In the LPi method, the fuel is evaporated due to a pressure drop that occurs just as the liquid fuel is atomized, and because of the large evaporation of heat at this point, the intake temperature becomes lower than the mixer method. In extreme cases, icing can occur as the intake temperature falls below the freezing point. The spray nozzles can become clogged due to icing, and the particles formed during icing can fall off and damage the valves or change the air-fuel ratio.

For the mixer type, volumetric efficiency is not significantly affected by changes in compression ratio as seen in Fig. 5. The mixer type method shows a volumetric efficiency of around 80~85%, and the LPi type shows a volumetric efficiency of around 95%. Therefore, likely due to the fact that the LPi method exhibits an increased volumetric efficiency with lower

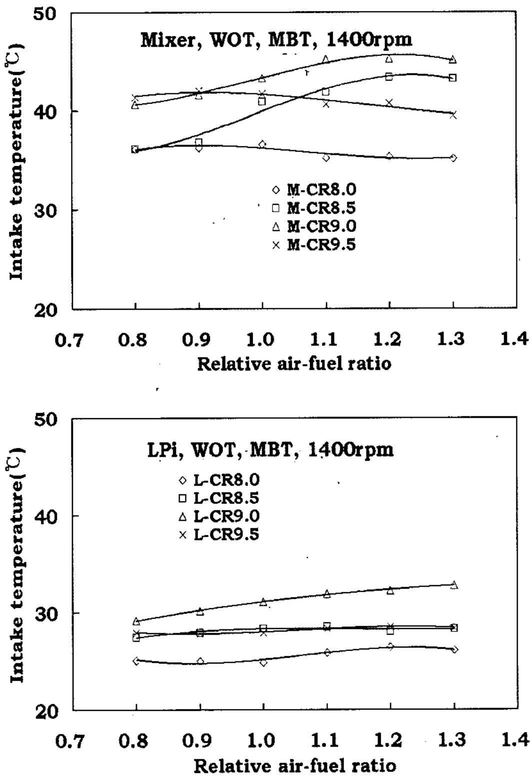

Fig. 4. Effect of compression ratios with mixer and LPi system fuel supply methods on intake temperature.

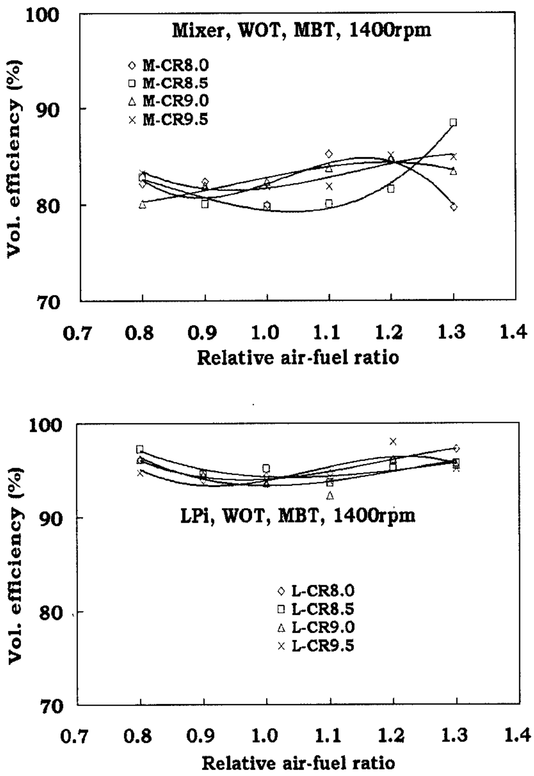

Fig. 5. Effect of compression ratios with mixer and LPi system fuel supply methods on volumetric efficiency.

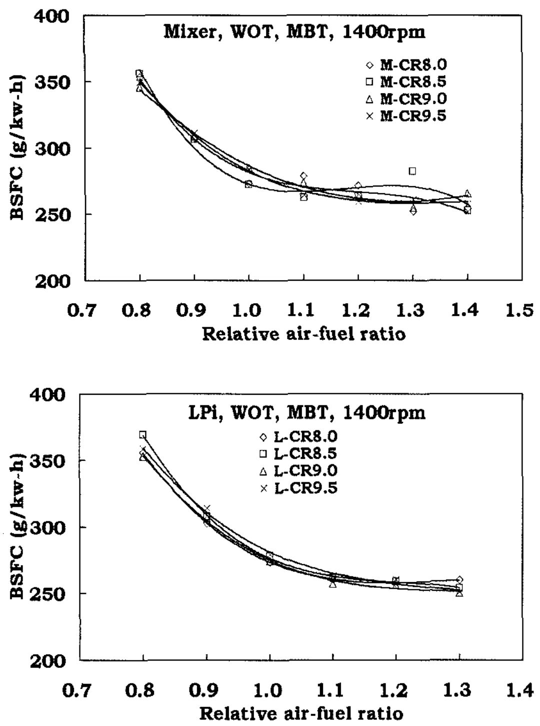

Fig. 6. Effect of compression ratios with mixer and LPi system fuel supply methods on brake specific fuel consumption.

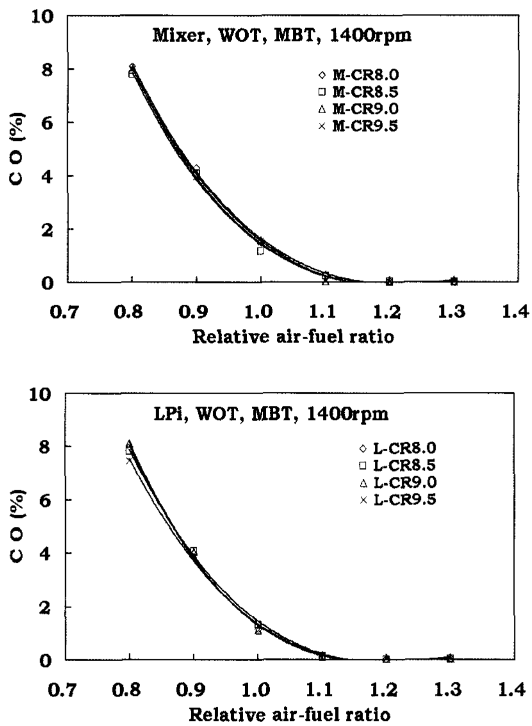

Fig. 7. Effect of compression ratios with mixer and LPi system fuel supply methods on CO emissions.

intake temperatures, the power output and BMEP increase as shown in Fig. 2 and Fig. 3.

Figure 6 shows the curves for brake specific fuel consumption (BSFC). The figure seems to indicate that BSFC is not affected significantly by the different fuel supply methods and changes in the compression ratio. At first glance, it may appear that BSFC for the LPi method should be higher since a lower intake temperature and higher volumetric efficiency, which means that more mixture is being injected into the cylinder. However, the fact that Fig. 6 does not show significant differences between the BSFC's of the two supply methods seems to indicate that the LPi method exhibits a power increase due to the increased volumetric efficiency that arises from the increased intake air density.

Figure 7 shows the CO emission levels for mixer and LPi type methods at different compression ratios as the relative air-fuel ratio is increased from 0.8 to 1.3 at WOT, MBT, and 1400rpm. The figure shows that the greatest amount of CO is produced in the rich region where air is insufficient, therefore almost none is produced in the lean region where air is sufficient. In addition, the results show that there is little difference between CO emission levels for different fuel supply methods or compression ratios.

Figure 8 shows the HC emission levels for different fuel supply methods and compression ratios as the relative air-fuel ratio is varied from 0.8 to 1.3. Highest amount of HC is produced for the mixer type at the compression ratio of 8, and HC emissions decrease as compression ratio increases. Crevice/-+s in the combustion chamber are the main source of HC emissions from spark ignition engines fueled by natural gas. The formation of combustion chamber deposits in modern spark ignition engines is predominantly derived from hydrocarbon fuels and occurs as a consequence of the quenching action of the combustion chamber walls on the flame. In general, HC emission levels show similar trends as CO emission levels in the regions where the relative air-fuel ratio is rich. Furthermore, in rich regions with the unstable

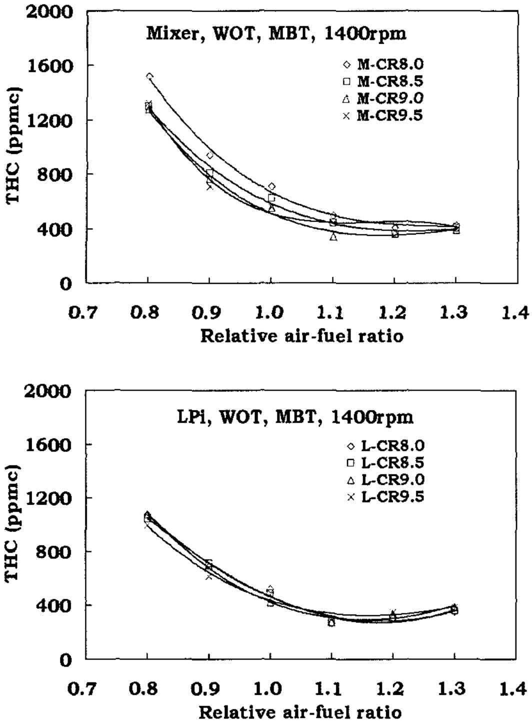

Fig. 8. Effect of compression ratios with mixer and LPi system fuel supply methods on THC emissions.

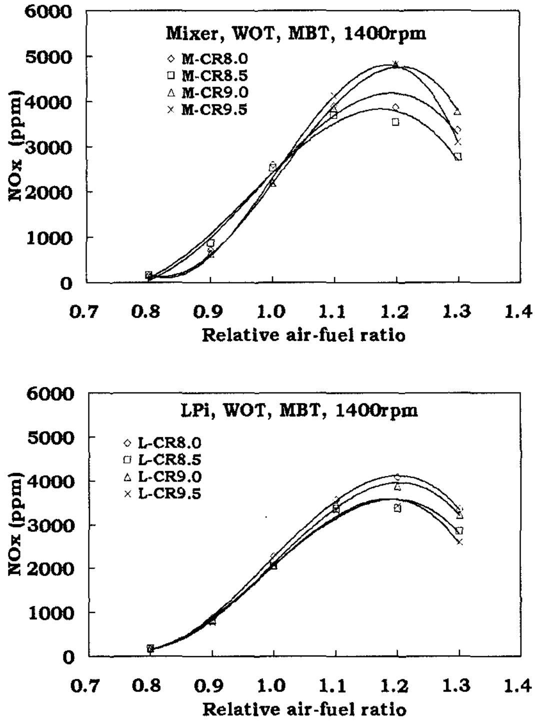

Fig. 9. Effect of compression ratios with mixer and LPi system fuel supply methods on NOx emissions.

combustion or in lean regions, HC emission levels increase. It is generally known that HC emissions decrease as an engine speed and IMEP increase. One of the main reasons for HC emission is the incomplete combustion that stems from bulk quenching due to slow combustion.

In Fig. 8, when comparing the mixer method and LPi methods at the relative air-fuel ratio of 1.0, the LPi method shows a 26% reduction in HC emission levels at the compression ratio of 8, 21% reduction at the compression ratio of 8.5, 23% reduction at the compression ratio of 9, and 13% reduction at the compression ratio of 9.5. Regardless of the fuel supply methods, emission characteristics obtained from this experiment seem to indicate that the compression ratio of 8~9 is the most optimal for a converted LPG engine.

Figure 9 shows the NOx levels for different compression ratios. The trend shown in the figure is very similar to those of typical relative air-fuel ratio curves. Namely, NOx levels are relatively low in the rich region and decrease past the ideal equivalence ratio into the lean region. Also, it can be seen that NOx emissions are affected by the exhaust gas temperature. When the compression ratio is high, the temperature inside the combustion chamber, and NOx levels increase as a result. When comparing the mixer method and LPi methods at the relative air-fuel ratio of 1.0, the LPi method shows a 12% reduction in NOx emission levels at the compression ratio of 8, 19% reduction at the compression ratio of 8.5, 6% reduction at the compression ratio of 9, and 6% reduction at the compression ratio of 9.5.

4. Conclusions

A 4-cylinder diesel engine was converted into a LPG engine, and the following results were obtained as the compression ratio varies for mixer and LPi type fuel supply methods.

1. Engine output was the highest at the compression ratio of 8~9 and relative air-fuel ratio of 0.9~1.0.

At the relative air-fuel ratio of 1.0, a greater increase in power is shown for the LPi method than the mixer method as compression ratio is increased.

2. The results of CO emissions show that the greatest amount of CO is produced in the rich region where there air is insufficient, therefore almost none is produced in the lean region where there is sufficient air. In addition, the results show that there is little difference between CO emission levels for different fuel supply methods or compression ratios.

3. The LPi method shows a 26% reduction in HC emission levels at the compression ratio of 8, 21% reduction at the compression ratio of 8.5, 23% reduction at the compression ratio of 9, and 13% reduction at the compression ratio of 9.5. Regardless of the fuel supply methods, emission characteristics obtained from this experiment seem to indicate that the compression ratio of 8~9 is the most optimal for a converted LPG engine.

4. When comparing the mixer method and LPi methods at the relative air-fuel ratio of 1.0, the LPi method shows a 12% reduction in NOx emission levels at the compression ratio of 8, 19% reduction at the compression ratio of 8.5, 6% reduction at the compression ratio of 9, and 6% reduction at the compression ratio of 9.5. The LPi method is better at reducing NOx emission levels than the mixer method at the relative air-fuel ratio of 1.0.

Acknowledgements

This work was supported by grant No. RTI04-03-02 from the Regional Technology Innovation Program of the Ministry of Commerce, Industry and Energy (MOCIE).

References

1. Michael, P.W. Global trends in diesel emissions control-A 1997 update. SAE paper 970719, 1997.
2. Cho, B.H.; Han, Y.T.; Lee, K.H.; Lee, C.S. "A Study on the Mixture Formation Process and Combustion Characteristics According to Injection Timing in Premixed Charge Compression Ignition", Transactions of the KSME B, 2002, 26(12), 1692-1698.
3. Lee, L.H.; Lee, C.H.; Ryu, J.D.; Choi, G.M. "Analysis of Combustion and Flame Propagation Characteristics of LPG and Gasoline Fuels by Laser Deflection Method", KSME International Journal, 2002, 16(7), 935-941.
4. Choi, G.H.; Han, S.B.; Chung, Y.J. "The Effect of Hydrogen Enrichment on Exhaust Emissions and Thermal Efficiency in a LPG Fuelled Engine", KSME International Journal, 2003, 17(8), 1196-1202.
5. Poonia, M.P.; Ramesh, A.; Gaur, R.R. "Experimental Investigation of the Factors Affecting the Performance of a LPG - Diesel Dual Fuel Engine", SAE paper 1999-01-1123, 1999.
6. Kang, K.; Lee, D.; Oh, S.; Kim, C. "Performance of an Liquid Phase LPG Injection Engine for Heavy Duty Vehicles", SAE paper 2001-01-1958, 2001.
7. Yeom, J.K.; Fujimoto, H. "A Study on the Behavior Characteristics of Diesel Spray by using a High Pressure Injection System with Common Rail Apparatus", KSME International Journal, 2003, 17(9), 1371-1379.
8. Kajiwara, M.; Sugiyama, K.; Sagara, M.; Mori, M.; Goto, S.; Alam, M. "Performance and Emission Characteristics of an LPG Direct Injection Diesel Engine", SAE paper 2002-01-0869, 2002.