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Research Article

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A Study on Engine Performance and Emission Characteristics of LPG Engine with Hydrogen Addition

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Abstract The purpose of this study is to investigate various performance and characteristics of exhaust gas when adding hydrogen fuel to butane which is an LPG fuel. Due to the higher lower heat value of hydrogen, as the amount of hydrogenation increases, it shows higher power than pure LPG (butane). In the case of hydrogen addition, the thermal efficiency tends to be higher than that of pure LPG (butane).As the relative air-fuel ratio (λ) changes, the amount of CO, CO_2, and HC decreases with increasing hydrogen content in LPG fuel. However, it was found that NOx increases as the amount of hydrogen in the LPG fuel increases. By adding a small amount of hydrogen to an engine using butane fuel, it is expected that the power and thermal efficiency can be increased and the exhaust gas can be reduced.

Keywords LPG (Liquefied petroleum gas), Butane, Hydrogen, MBT(Maximum brake torque timing), Relative air-fuel ratio, WOT(Wide open throttle), CO, HC, NOx

Introduction

Environmental pollution is becoming a major concern as the global automobile volume increases and environmental pollution intensifies and regulations on automobile emissions are strengthened. Currently used car fuels include CNG, LPG, gasoline, and diesel. Although these are advantageous in terms of infrastructure and safety, the emission of CO_2, CO, and HC is a major drawback because these fuels contain carbon atoms. The development of clean and alternative fuels is essential when considering ZEV (Zero Emission Vehicle) development [1-3].

One solution to this problem is to use hydrogen fuel, which is being seen as a next-generation fuel. Hydrogen has an excellent effect on reduction of carbon-based exhaust gas because it is almost pollution-free because it does not contain carbon atoms in fuel. Because hydrogen burning speed is about 4 times faster than LPG, The thermal efficiency can be increased. However, since the adiabatic flame temperature is high, NOx emission is increased and backfire occurs in a high load region [4,5].

Using LPG fuel produces lower power than gasoline. On the other hand, LPG fuel has a higher octane number compared to gasoline, so there is relatively more room for knocking. Therefore, a method of increasing the compression ratio of the cylinder is used as a way to compensate for the lower output. By increasing the compression ratio, higher output can be obtained, which can reduce the difference in output from the gasoline engine.

The development of vehicles using hydrogen as fuel has begun to be studied as an alternative to depletion of petroleum and has attracted attention as a next-generation transportation alternative to fossil-fueled automobiles. It is divided into a method of using hydrogen fuel as the fuel of the internal combustion engine and a method of using electricity generated by reacting hydrogen with oxygen as a power source. Although the energy conversion rate is higher than that of fossil fuels and environmentally friendly, it has drawbacks such as a lack of infrastructure such as a charging system and a high price [6,7].

The purpose of this study is to improve the thermal efficiency and reduce exhaust gas of an LPG engine with hydrogen fuel while maintaining the same heating value in the butane which is widely used as fuel for automobiles. The addition of hydrogen fuel to LPG is advantageous because it can alleviate the backfire problem compared to hydrogen engine, and it is expected that cleaner exhaust conditions can be obtained. This means that the addition of hydrogen to LPG fuels can reduce carbon-to-fuel ratios and reduce carbon emissions.

By adding hydrogen to an LPG engine using butane, the engine power and thermal efficiency can be increased and the exhaust gas can be reduced.

Experimental Apparatus and Test Methods

The engine was selected as a basic experimental device to grasp basic performance and exhaust performance according to the use of gaseous fuel. Table 1 shows the specifications of the engine used in the experiment. The engine type is the overhead valve type and the piston is the bath tub type because the piston shape is compact in the gaseous fuel and the mixture formation is advantageous by the squish effect at the end of compression.

In addition, the existing three way catalytic converter was removed in order to understand the influence of the accurate exhaust gas.

Table 2 compares the characteristics of butane fuel and hydrogen fuel.

A schematic diagram of the experimental setup to understand the basic performance and exhaust characteristics of the engine is shown in Fig. 1. A 130kW dynamometer was connected to the flywheel to control engine speed and load. In addition, a common sensor is attached to the engine to measure the oil temperature, coolant temperature, exhaust temperature, boost pressure, exhaust pressure and so on. A Horiba Ltd, Mexa 9100DEGR exhaust analyzer was used to determine the exhaust characteristics of the engine. The exhaust analyzer measures CO, CO_2, HC, and NOx as the basis. In addition, a crankshaft position sensor (CPS) is installed in the crankshaft pulley of the engine, a Hall sensor is installed in the camshaft pulley, and signals output from these sensors are used in the ignition control device of the Motec Ltd. to supply electric energy to the combustion chamber.

The fuel system makes an appropriate mixture of LPG and hydrogen, and the fuel control unit (duty drive) and the solenoid valve are used. LPG fuel consumption was measured using a weight scale and the resolution of the weight scale was 1 g. In addition, the hydrogen fuel is supplied to the intake pipe via the pressure regulator, the flow meter, the emergency shut-off solenoid valve, and the anti-backfire using high purity hydrogen buffered to 200bar. The surge tank was installed on the intake side to reduce the suction pulsation of the test engine, and the cooling water and oil used external pumps to minimize the power loss of the performance-sensitive engine.

All experiments were carried out at 1400rpm, MBT(Maximum brake torque timing), WOT(Wide open throttle), compression ratio 8. The engine speed and the load have adopted the number of revolutions and the load at which the engine is not overloaded and the maximum torque is generated. Since the compression ratio is 8, it is considered that the bore is large, so that the distance that can reach to the normal flame surface from the spark plug is increased and the abnormal combustion is generated.

Experiments were performed while increasing the relative air-fuel ratio ($\lambda=1/\Phi$) from 0.8 to 1.3, and the ignition timing was adjusted to the ignition timing to become MBT.

Table 1: Specification of test engine

Engine Type	OHV
Number of Cylinder	1
Bore	130mm
Stroke	140mm
Displacement	1,858cc
Range of Compression Ratio	8
Idling rpm	600
Length of Connecting Rod	260mm
Fuel supply method	Mixer

Table 2: Characteristics of butane and hydrogen

	C_4H_{10}	H_2
Theoretical Air-fuel Ratio	15.5	34.3
Lower Heat Value(MJ/kg)	45.8	120
Flammability Limits	0.4 ~ 1.7	0.12 ~ 10.12
Density(kg/m^3)	2.640	0.089
Adiabatic Flame Temperature(℃)	≒ 1990	2384
Turbulent Burning Velocity(m/s)	≒ 0.4	1.7
Auto-ignition Temperature(℃)	585	450

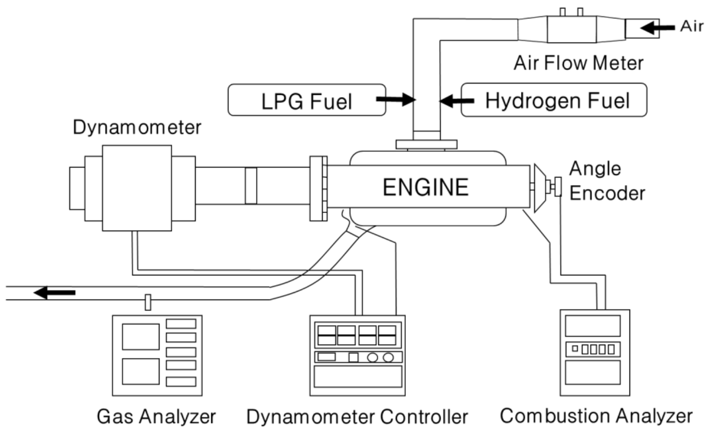

Figure 1: Schematic diagram of experimental apparatus

Results and Discussion

Fig. 2 shows the experimental results of relative air-fuel ratio at 1400rpm, MBT, WOT and compression ratio of 8. The engine performance test was performed while increasing the relative air-fuel ratio (λ=1/Φ) from 0.8 to 1.3.

The fuel was tested with 100% LPG, 95% LPG and 5% hydrogen, and 90% LPG and 10% hydrogen. In Table 2, the lower heat value of hydrogen is about three times higher than butane. Due to the lower heat value of hydrogen, the addition of 10% hydrogen shows about 10% higher engine power than 100% of pure LPG (butane). In case of 5% hydrogen addition, it shows about 5% higher power than pure LPG (butane) 100%. However, if the amount of hydrogen is raised, the cyclic variation becomes high due to the oscillation, and it is considered that there is a problem in the lean region where the relative air-fuel ratio is high. In addition, hydrogen has a faster flame propagation speed than LPG (butane), which is why power is improved.

Fig. 3 shows the thermal efficiency for relative air-fuel ratio.

From the results of the experimental results showing the thermal efficiency of the engine, it is shown that the thermal efficiency is increased during the hydrogen addition as a whole. In particular, the thermal efficiency of the engine in all areas of λ is increased by about 10% when 10% hydrogen is added.

It is also shown that the addition of 5% hydrogen increases about 5% in all regions of relative air-fuel ratio. This hydrogen fuel is thought to bring about an increase in thermal efficiency due to completion of the combustion momentarily.

Fig. 4 shows CO emission characteristics at 1400rpm, MBT and WOT conditions. As the relative air-fuel ratio (λ=1/Φ) increases from 0.8 to 1.3, the CO emissions decrease. Also, the more hydrogen added, the lower the CO emissions. CO shows the maximum in the rich region, that is, near λ=0.8, and λ decreases sharply toward the lean side.

Fig. 5 is a graph showing the change in CO_2 with respect to the relative air-fuel ratio. As a result, CO is generated in large quantities because the rich air-fuel mixture is incompletely combusted because of insufficient oxygen to completely burn all carbon of the fuel into CO_2.

Therefore, the emission of CO is expressed as a function of the air-fuel equivalence ratio, and is considered to be greatly affected by λ. Furthermore, it is thought that the emission of CO, which is a carbon-based component after combustion, decreases with the addition of hydrogen.

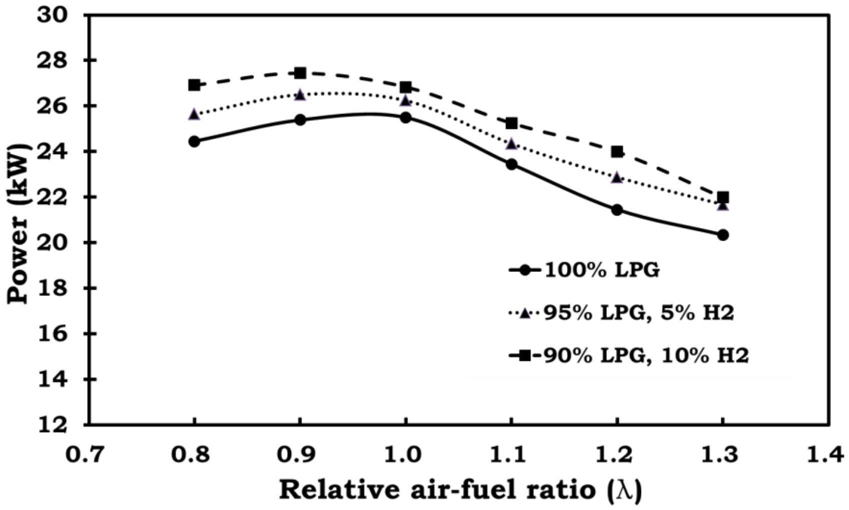

Figure 2: Engine power versus relative air-fuel ratio at the change of various fuels

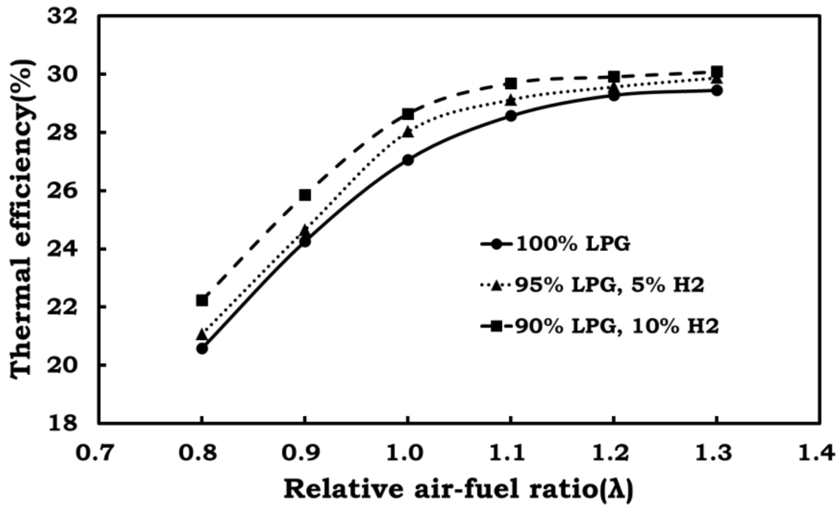

Figure 3: Thermal efficiency versus relative air-fuel ratio at the change of various fuels

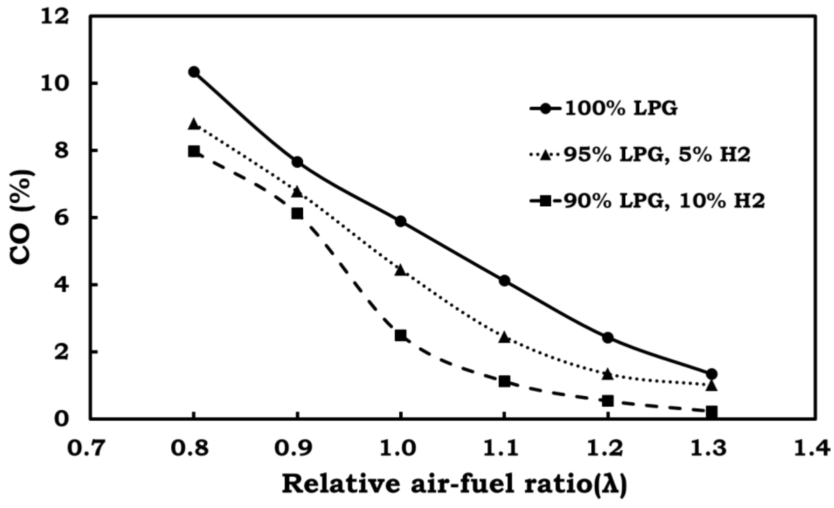

Figure 4: CO versus relative air-fuel ratio at the change of various fuels

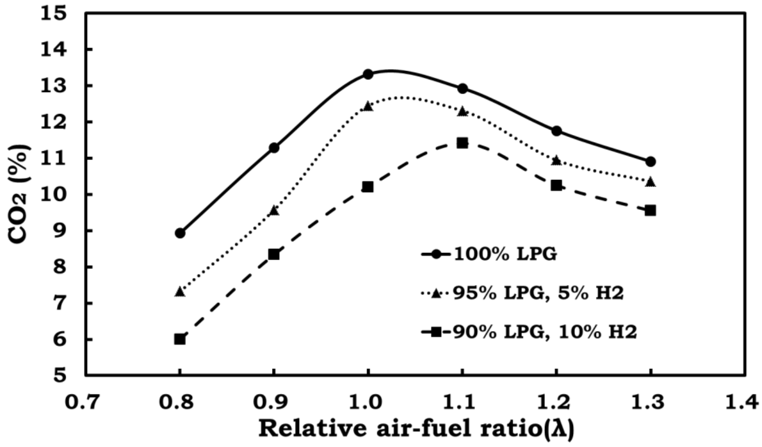

Figure 5: CO_2 versus relative air-fuel ratio at the change of various fuels

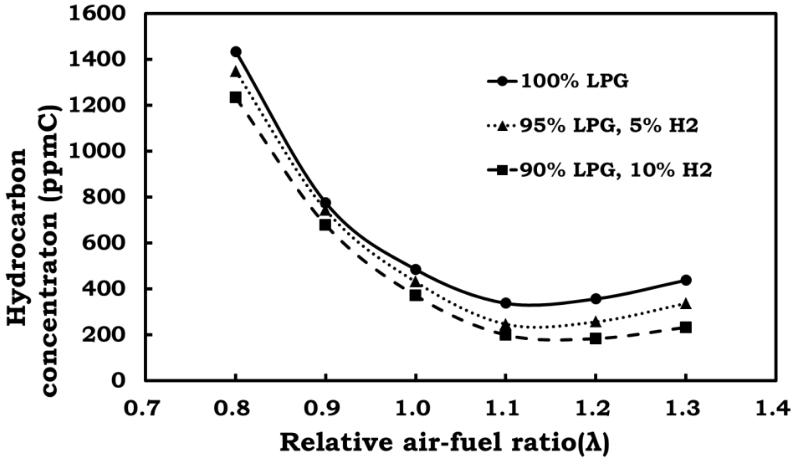

Figure 6: HC concentration versus relative air-fuel ratio at the change of various fuels

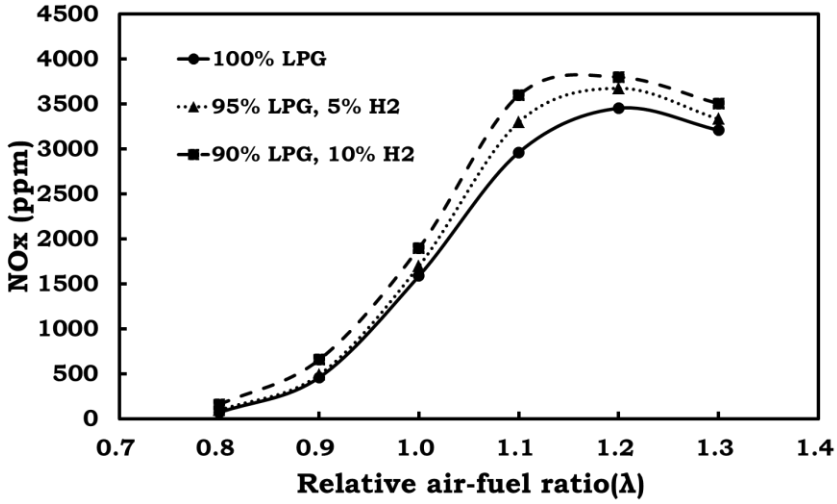

Figure 7: NOx versus relative air-fuel ratio at the change of various fuels

Fig. 6 shows the emission characteristics of hydrocarbon concentration. The unit of the hydrocarbon concentration is expressed in ppmC. As the relative air-fuel ratio ($\lambda=1/\Phi$) is increased from 0.8 to 1.3, the discharge tendency of the hydrocarbon concentration is high in the rich region, but decreases in the lean region. However, it can be seen that HC emissions are rather increased in the too much lean region.

It was also found that the hydrocarbon concentration was reduced by 5% and 10% in all regions depending on the addition of 5% and 10% of hydrogen. The hydrocarbon concentration is such that the unburned fuel air mixture enters the combustion chamber and the flame can not propagate through the gap during the combustion so that the incompletely combusted gas is discharged during the expansion and exhaust stroke. Also, it is considered that the flame propagation is slow and the combustion temperature is low in the lean mixture, so that the flame is turned off when the flame is close to the combustion chamber wall, and the hydrocarbon concentration is increased.

Fig. 7 shows the NOx emission characteristics at the relative air-fuel ratio under the same operating conditions. The overall tendency is maximal at λ=1.15, and at the concentration level of the emissions, 5% and 10% NOx emissions are increased by 5% and 10%, respectively. However, in the rich region, the NOx emissions of about 3% and 5% are increased when the hydrogen addition is 5% and 10%, respectively.

This is because the characteristic of hydrogen fuel is that rapid combustion occurs, and the maximum temperature and pressure in the combustion chamber are higher than when only LPG is combusted.

Conclusions

Experimental results on various performance and exhaust gases were obtained by adding hydrogen fuel to LPG fuel, and the following conclusions were obtained.

1) Due to the lower heat value of hydrogen, 10% hydrogen addition shows about 10% higher power than pure LPG (butane) 100%. In case of 5% hydrogen addition, it shows about 5% higher power than pure LPG (butane) 100%. The thermal efficiency also tends to increase with increasing hydrogen.

2) It was found that CO, CO_2 and HC were decreased by adding 5% and 10% of hydrogen to LPG fuel.

3) However, it was found that NOx is increased by adding 5% and 10% of hydrogen to LPG fuel. It is considered that this is due to the fact that the maximum temperature and pressure of the combustion chamber are increased due to the rapid combustion of hydrogen.

References

[1]. A. Deep, Potential utilization of the blend of orange peel oil methyl ester and isopropyl alcohol in CI Engine, SAE Paper 2014-01-2778, 2014.

[2]. Alexandra Cattelan, Jim Wallace, Exhaust Emission and Energy Consumption Effects from Hydrogen Supplementation of Natural Gas, SAE 952497, pp.155-165, 1995.

[3]. Tomas Kaelblein, Y. I. jeong and K. T. Rhee, Knock Effects on Spark-Ignition Engine Emission and Performance, SAE 900712, 1990.

[4]. Heywood, J. B., Internal Combustion Engine Fundamentals,New York: McGraw Hill, 1988.

[5]. H. C. Watson, L. C. Goldsworthy, and E. E. Milkins, Cycle by Cycle Variations of HC, CO, and NOx, SAE 760753, 1976.

[6]. Edward F. Obert, Internal Combustion Engines and Air Pollution, Intex Educational Publishers, pp.349-367, 1994.

[7]. Robert L. Hoekstra, Peter Van Blarigan, Neal Mulligan, NOx Emission and Efficiency of Hydrogen, Natural Gas, and Hydrogen/Natural Gas Blended Fuels, SAE 961103, pp.1-13, 1996.