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LPi기관에서 수소첨가에 따른 성능특성에 관한 실험적연구

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An Experimental Study on the Performance Characteristics of a Hydrogen Fueled LPI Engine

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ABSTRACT

환경문제와 석유자원의 고갈이 많은 연구자들을 기존 탄화수소연료를 대체할수 있는 재생 가능한 연료를 구하는데 많은 노력을 기울이고 있다. 수소연료는 유해배기물질이 없는 연소와 또한 연소후에 재생 가능한 물성분만 배출하는 속성으로 미래의 청정에너지로 각광을 받고 있다. 이러한 이유로 수소연료는 수송기계의 연료로도 주목을 받고 있다. 따라서 수소연료기관 개발은 21세기에도 지속적으로 진행될 것이다. 이에대한 초기연구로 기체 LPG 연료가 아닌 액체 LPG 연료를 흡기관에 분사하여 기화된 LPG 연료를 엔진으로 흡입하는 LPi엔진에 수소연료를 과급하여 엔진에 성능을 연구하고자 하였다.

주요기술용어 : Compression Ratio(압축비), Maximum Brake Torque Timing(MBT, 최적점화시기), Relative Air-fuel Ratio(공기-연료당량비), Liquid Propane Injection(액상분사), Thermal Efficiency(열효율)

1. Introduction

The automotive engineering has undergone continuous improvements, but at the same time, various global environmental issues related to vehicles are becoming more serious. With the increasing need to both conserve fossil fuel and minimize toxic emissions, much effort is being focused on the advancement of current combustion technology. The pollution levels recorded in large urban areas are rising concerns for public health and substantial reductions in pollutant emissions have become an important issue[1). Hydrogen, as an energy medium, has some distinct benefits for its

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high efficiency and convenience in storage, transportation and conversion[2]. Hydrogen has much wider limits of flammability in air than methane, propane or gasoline and the minimum ignition energy is about an order of magnitude lower than for other combustibles. Because of excellent ignitability and high adiabatic flame temperature of hydrogen fuel, the ignition delay period, flame development angle, rapid burning angle and overall burning angle in hydrogen fueled engines are remarkably short than those of gasoline and diesel engine[3~5].

Thomas et al.[6] described that hydrogen is the primary fuel options under consideration for fuel cell vehicles. The ideal fuel would eliminate local air pollution, substantially reduce greenhouse gas emissions and oil imports, cost no more than current transportation fuels per mile driven, and require little investment in new infrastructure. In addition, the fuel used for future fuel cell vehicles should be suitable for near-term hybrid electric vehicles using internal combustion engines, to avoid the need for introducing more than one new motor fuel in the 21st century. Hydrogen provides the best environmental and oil import improvements, but requires the largest infrastructure investment[7].

From an environmental point of view there is an increasing interest among the supplier's to investigate LPG as a transportation fuel. Currently, liquid-phase LPi system is going to replace vapor-phase system. It can be anticipated that the improve air charge density inherent with liquid-phase LPi system allows engine to aspirate a greater mass of the air and fuel during the intake stroke resulting in high performance than vapor-phase fuel supplement[8]. The LPi system can increase engine power by the decrease of combustion temperature according to vaporization heat and the inertia effect. Comparing the properties of hydrogen and LPG, it is possible to obtain interesting fuel economy and emission reductions. However, today the concept of hydrogen enriched LPG fuel, as fuel for internal combustion engines, has a greater interest than pure hydrogen powered engines because it involves fewer modification to the engines and their fueling systems[9]. In fact, hydrogen and gasoline can be burned together in a wide range of air-fuel mixtures, providing such good performances, as high thermal efficiency and reduced pollutant emissions. The objective of this paper is to clarify the effects of hydrogen enriched LPi fuelled engine on performance characteristics.

2. Experimental Apparatus and Procedure

Figure 1 shows the schematic diagram of experimental apparatus such as test engine, dynamometer controller, exhaust gas analyzer, and combustion analyzer. Oil temperature, coolant temperature, exhaust temperature, inlet pressure and exhaust pressure were measured with various sensors. Signals from the crankshaft position sensor installed on the crankshaft pulley and the hall sensor installed on the cam-shaft pulley are sent to the ignition control device, which then determines the amount of electric energy to be sent to the combustion chamber and controls the ignition timing. In order to determine the ideal compression ratio, the experimental engine was developed. The 6-cylinder, 12 liter diesel engine

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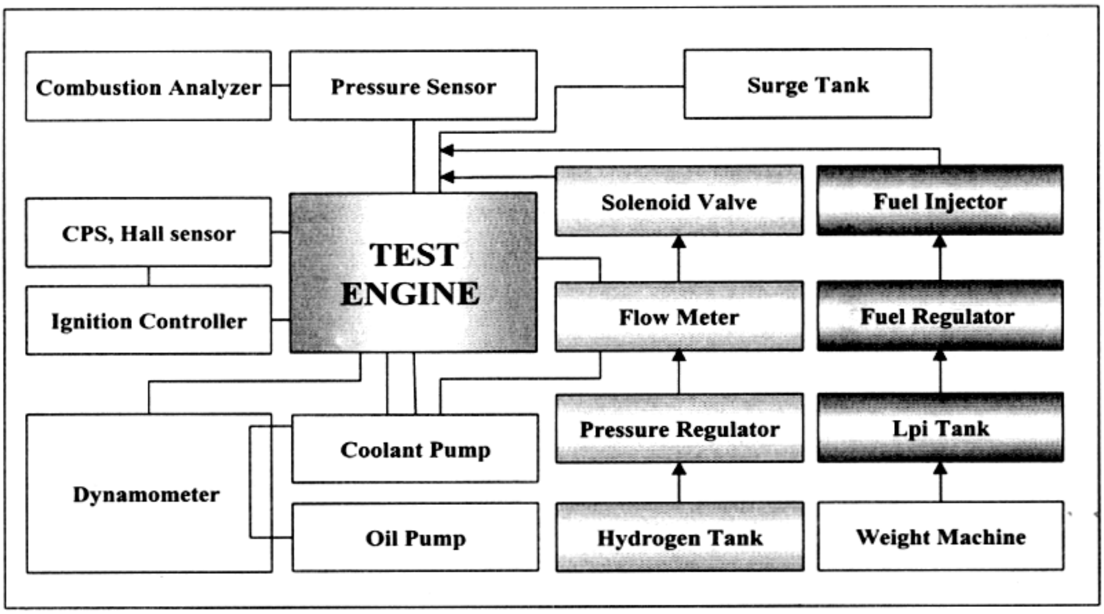

Fig. 1 Schematic diagram of experimental apparatus

has been modified into spark ignition engine. A desired mixture of LPG and hydrogen was used as the fuel, and the fuel flow rate was controlled with a duty drive and a solenoid valve. LPG consumption was measured via a balance scale with a degree of precision of 1g. High purity hydrogen at 200 bar was flown through the pressure controller, the mass flow meter, the solenoid valve, and the flame arrestor on its way to the intake. One of the experimental parameters is dependent of hydrogen supplement rate which is defined as follows:

Hydrogen supplement rate (%) =

$$\frac{m_{H2} \times Q_{HV(H2)}}{m_{C4H10} \times Q_{HV(C4H10)} + m_{H2} \times Q_{HV(H2)}}$$

where mH_2 is the mass flow rate of hydrogen, mC_4H_{10} the mass flow rate of LPG, $QHV(H_2)$ the lower heating value of hydrogen, and $QHV(C_4H_{10})$ the lower heating value of LPG shown in table 1. The 10 percent hydrogen supplement rate per heating value is equal to percent hydrogen per total fuel volume and 20% hydrogen supplement rate per heating value is equal to 85% hydrogen per total fuel volume. The fuel supply system provides LPG/hydrogen mixtures based on the same heating value.

All experiments were conducted at 1400 rpm, MBT, and a compression ratio of 8. To maintain equal heating value, the amount of LPG was decreased, and hydrogen was gradually added. In a similar manner, the relative air-fuel ratio was increased in increments of 0.1, and the ignition timing was controlled to be at MBT each time.

3. Results and Discussion

Table 1 Characteristics of LPG and hydrogen

	C_4H_{10}	H_2
Low heating value, MJ/kg	45.84	120
Theoretical air-fuel ratio	15.5	34.3
lammability limits	0.4~1.7	0.12~10.12
Density, kg/m^3	2.64	0.0899
Adiabatic flame temperature, K	2263	2657
Autoignition temperature, K	858	723
Turbulent burning velocity, m/s	0.4	1.7

Figure 2 shows volumetric efficiency curves as function of relative air-fuel ratio with different LPG fuel systems to find that LPi system supplies more air to the engine than mixer system. Figure with volumetric efficiency is a little bit same tendency as function of relative air-fuel ratio. LPi system is about 16% higher than Mixer system at the volumetric efficiency. It can be deduced that the improved air charge density with liquid-phase LPG injection allows engine to aspirate a greater mass of the mixture during the intake stroke.

Figure 3 shows the engine-out power curves as function of relative air-fuel ratio with different LPG fuel systems. It can be

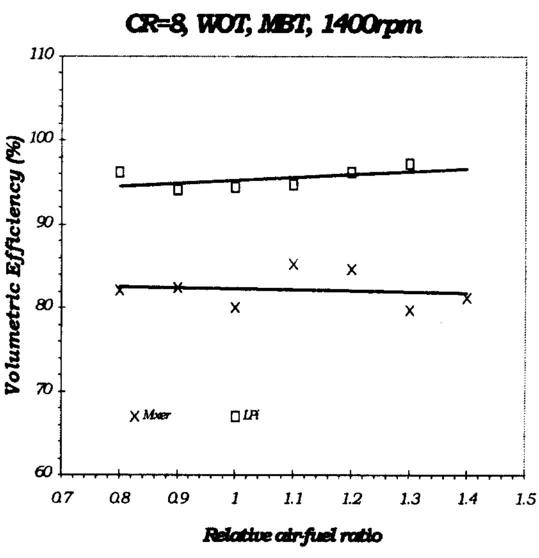

Fig. 2. Volumetric efficiency as a function of relative air-fuel ratio with different LPG systems

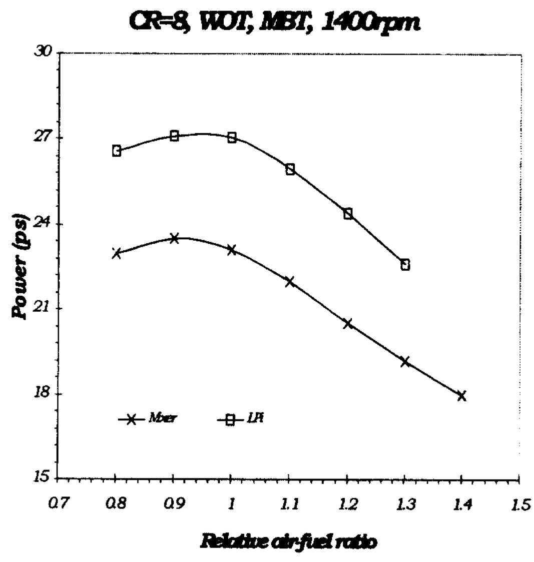

Fig. 3. Engine-out Power as a function of relative air-fuel ratio with different LPG systems

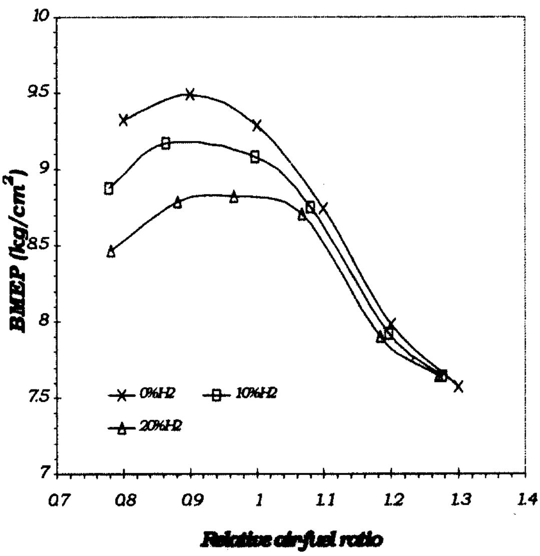

Fig. 4. Variation of brake mean effective pressure with relative air-fuel ratio.

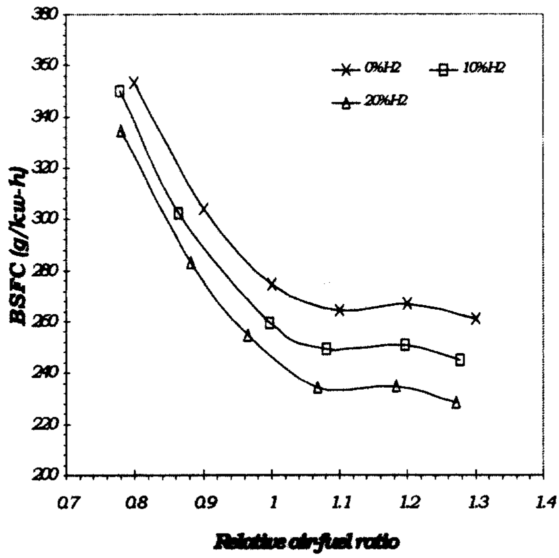

Fig. 6. Variation of brake specific fuel consumption with relative air-fuel ratio.

seen that the power output is the highest at slightly rich of stochiometric condition of fuel and air. Also, it can be known that

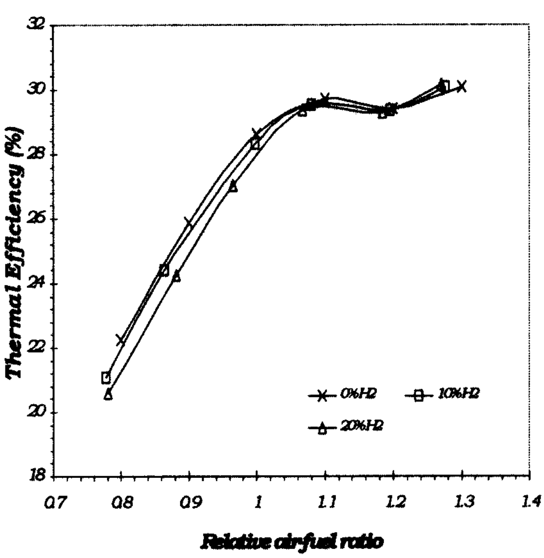

Fig. 5. Variation of thermal efficiency with relative air-fuel ratio.

the power of LPi system with liquid-phase is approximately 17% higher than that of vapor-phase Mixer system due to the increase of volumetric efficiency. Finally, it can be seen Mixer system possible stable running to the value 1.4 because Mixer system has better premixing processes comparing with LPi system.

Figures 4 and 5 indicate some of the test results on the performance characteristics with different hydrogen-LPG mixture such as brake mean effective pressure(BMEP), brake specific fuel consumption(BSFC) and brake thermal efficiency of the test engine. As shown in Figs. 4 and 5, in general, BMEP and thermal efficiency decrease with the increase of hydrogen supplement rate. The reason for the decreases in BMEP and thermal efficiency could be that the lack of oxygen increase with the increase of hydrogen supplement rate in the

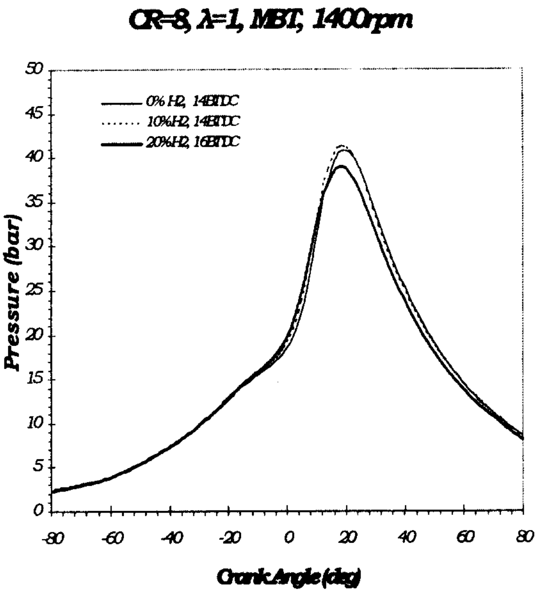

Fig. 7. Variation of cylinder pressure with crank angle.

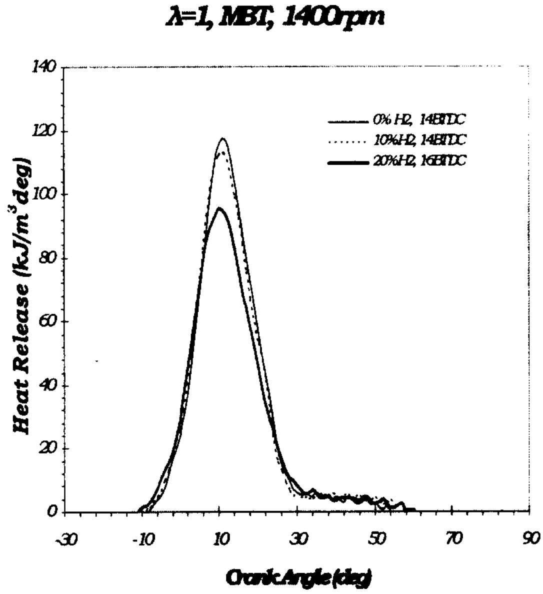

Fig. 8. Variation of heat release with crank angle.

rich mixture zone results in the incomplete combustion. However, there is no difference in power and thermal efficiency in the lean mixture zone. The reason for this result could be that the sufficient oxygen was supplied and hydrogen does much for the fast combustion because hydrogen has four times higher burning velocity than the LPGs. At λ = 1, thermal efficiency shows decrease of about 5 percent with the addition of 20 percent hydrogen. The reason for this decrease in thermal efficiency could be that the hydrogen fuel burns all at once.

Figure 6 shows fuel consumption as a function of relative air-fuel ratio with the addition of 10 percent and 20 percent hydrogen at MBT and a compression ratio of 8. Fuel consumption that depends on thermal efficiency is defined as the mass flow rate per hour, and it may depend on the increase of brake power rather than the increase of fuel quantity. The reason for lower fuel consumption with increased hydrogen additions compared to LPG combustion would be the fast flame propagation velocity of hydrogen.

Figures 7 to 9 show the results of all experiments. Figure 7 shows the measured cylinder pressure versus crank angle. For the calculation the contents of the cylinder were assumed to behave as an ideal gas with the specific heat being dependent on temperature. Figure 8 is the heat release as a function of crank angle. Heat release rate was calculated by making a first law analysis of the average pressure versus crank angle variation for 250 cycles. The cumulative heat release was then calculated shown in Figure 9. The start of combustion was determined from the rate of pressure rise variation. In general, heat release, cylinder pressure and cumulative heat release

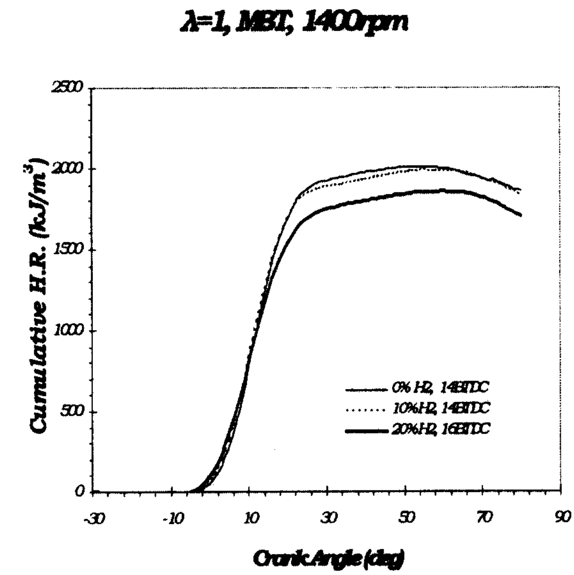

Fig. 9. Variation of cumulative heat release with crank angle

decrease with the increase of hydrogen supplement rate, but the ignition timing decreases with the increase of it.

4. Conclusions

This study is to clarify the effects of a hydrogen enriched LPG fuelled engine on exhaust emission, thermal efficiency and performance. The results obtained are as follows.

1) The power output of LPi system with liquid-phase is approximately 17 percent higher than that of vapor-phase mixer system due to increase of volumetric efficiency. And the MBT spark timing of LPi system is approximately 25 percent more advanced than that of mixer system at stoichiometric condition.
2) BMEP and thermal efficiency decrease with the increase of hydrogen supplement rate. The reason could be that the lack of oxygen increase with the increase of hydrogen supplement rate in the rich mixture zone results in the incomplete combustion
3) Heat release, cylinder pressure and cumulative heat release decrease with the increase of hydrogen supplement rate, but the ignition timing decreases with the increase of it.

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