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Effect of Hydrogen Addition on Combustion and Emissions Performance of a Spark-ignition Gasoline Engine at 800 rpm and Lean Conditions

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1 Introduction

The use of hydrogen as an additive to enhance engine performance has been widely tested. Wang et al. [1] ran an HCNG engine with different hydrogen volumetric fractions at lean conditions. He found that the cyclic variation was decreased with the increase of hydrogen addition. Ma et al. [2] studied the effect of hydrogen addition fraction on the cycle-by-cycle variation, combustion process and emissions characteristics of a CNG engine with hydrogen enrichment. Varde [3] ran a single-cylinder engine with the mixture of hydrogen and gasoline, and he found that the lean burn limit was extended and the flame propagation speed was increased with the addition of hydrogen. Apostolescu and Chiriac [4] studied the effect of hydrogen addition on the combustion process at mid-to-low loads, with the results showing that the cyclic variation and 10% to 90% burn duration were greatly reduced while hydrogen mass fraction varied from 1.5% to 3%. Li et al. [5] investigated the mechanism of toxic emissions foramtion from the gasoline-hydrogen mixture based on chemical dynamics of combustion. He found that the toxic emissions was reduced after hydrogen addition, especially at relatively lean conditions. Lucas and Richards [6] ran an engine with pure hydrogen at idle and found that the engine thermal efficiency increased by at least 10% and CO and NOx emissions were lower than the original one.The engine always suffers low thermal efficiency, high cyclic variation and toxic emissions at idle and low engine speeds, because of the increased charge inhomogeneity and high residual gas fraction. Engines always show high cyclic variation at idle, because of the high residual gas fraction and low fuel burning velocity at low speeds [7].Compared with gasoline, hydrogen has a relatively high flame speed, which is likely to reduce the combustion duration inside the cylinder and ease the cyclic variation.At the same time, only a hydrogen injection system is required to realize the hybrid hydrogen-gasoline engine, reducing the modifiction costs.However, few studies were reported about the effect of hydrogen addition on the performance of a gasoline engine at low operating conditions. In this paper, the test engine was run at three different enrichment levels and four excess air ratios, and the effect of hydrogen addition on engine combustion and emissions performance at 800 rpm and lean conditions was investigated.

2 Experimental

The experiment was carried out on a 1.6L, port fuel injection, four-cylinder, SI engine manufactured by BEIJING HyunDAI Motors. Four hydrogen injectors were mounted near the intake valve of each cylinder while keeping the original gasoline injection system unchanged, so that the injected hydrogen can be introduced into the cylinder faster and the backfire was effectively avoided.The injection timings and durations of hydrogen and gasoline were controlled and adjusted by a self-developed hybrid electronic control unit (HECU). The HECU communicates with the engine original ECU (OECU) to freely adjust injection timings and durations of hydrogen and gasoline via the commands from the calibration computer.This system has accomplished the cold start with pure hydrogen, part-load operation with the hydrogen-gasoline mixture and high load operation with pure gasoline.The spark timing of the engine was kept at TDC during the experiment.The engine is loaded with a GW160 eddy current dynamometer to control and measure engine speed and torque output. A FC2210 fuel mass flow meter is adopted to meter the gasoline mass flow rate.The cylinder pressure acquisition and combustion analysis system consists of a Kistler 2613B optical encoder, a Kistler 6117BFD17 pressure transducer with a spark plug and a combustion analyzer manufactured by Dewetron, Austria. The cylinder pressure transducer with a spark plug is screwed into the cylinder head of the 4^{th} cylinder to detect the combustion cylinder pressure and enforce its ignition.The optical encoder is connected to the front of the crankshaft producing 1800 pulses per rotation for obtaining crank angles and triggering the sampling of combustion pressure.The cylinder pressure transducer and optical encoder are connected to the DEWETRON combustion analyzer via the screened cables.Cylinder pressure and crank angle signals were sampled and treated via DEWE-CA combustion analysis software The exhaust emissions of NOx, HC and CO from the test engine were measured by a Horiba MEXA-7100D emissions analyzer. The air and hydrogen mass flow rates were monitored by a EPI-800 and a D07-19BM thermal mass flowmeters,respectively.

The experiment was conducted after the engine is fully warmed. The idle bypass vavle was 50% opened and the engine speed was 800rpm. Different excess air ratios (1.00, 1.18, 1.43 and 1.67) were acquired by reducing gasoline injection duration with the increase of hydrogen addition. The cylinder pressures of 300 consecutive cycles were sampled for the calculation of coefficient of variation in indicated mean effective pressure COVimep, 0-10% and 10-90% burn durations. The coolant and lubrication temperatures were kept at 90 and 95±1℃,respectively during the experiment to minimize their effects on the test results.

3 Test Results and Discussion

3.1 Brake thermal efficiency

Fig. 1 displays the variation of engine brake thermal efficiency with excess air ratio under various hydrogen addition fractions at 800rpm. It shows that the brake thermal efficiency of the original engine is

reduced sharply with the increase of excess air ratio. This phenomenon demonstrates that the lean combustion technology is not suitable to be applied on the low speed conditions of a pure gasoline fuelled SI engine, since the lean mixture is hard to be burned well under large resodual gas fraction and low combustion temperature. Especially when excess air ratio exceeds 1.43, it can be clearly seen that the original engine thermal efficiency decreased dramatically, which is attributed to the misfire of the mixture in the cylinder.

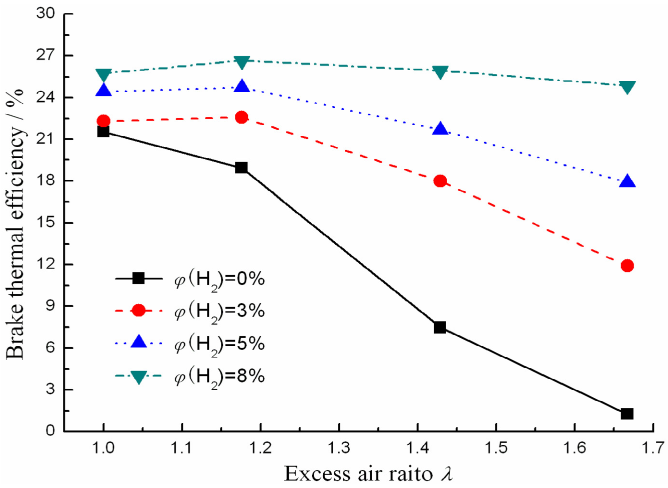

Figure 1: Brake thermal efficiency versus excess air ratio.

3.2 Combustion

The flame development duration CA0-10 and flame propagation duration CA10-90 versus excess air ratio at 800rpm are plotted in Figs. 2 and 3, respectively. CA0-10 and CA10-90 are both shortened with the increase of hydrogen enrichment level. For a specified hydrogen addition fraction, CA0-10 and CA10-90 are prolonged with the increase of excess air ratio. The reason can be attributed to the low combustion temperature caused by lean combustion. The flame velocity is reduced with the decrease of combustion temperature, so that the flame development and propagation durations are both prolonged with the increase of excess air ratio at a certain hydrogen enrichment level.

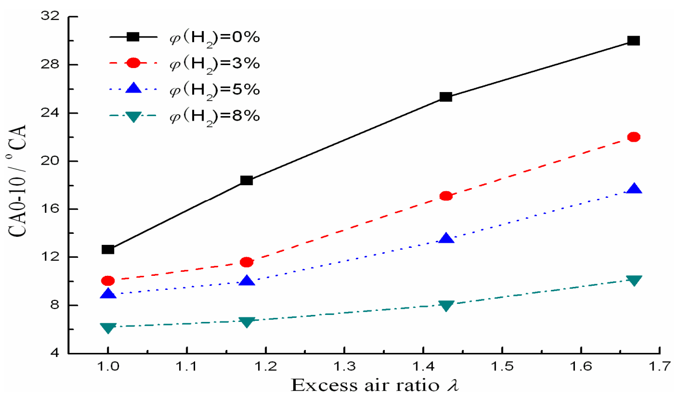

Figure 2: CA0-10 versus excess air ratio.

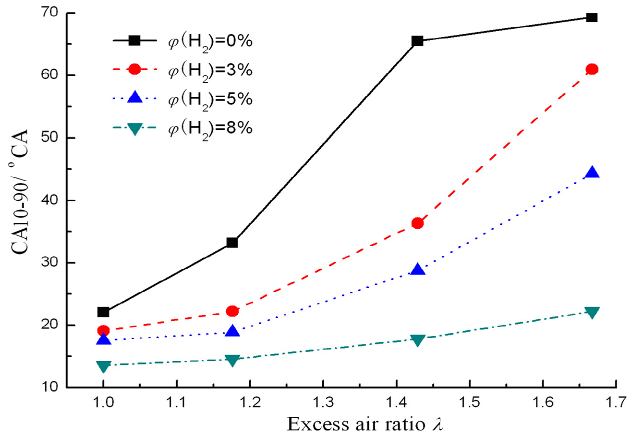

Figure 3: CA10-90 versus excess air ratio.

3.3 Cycle-by-cycle variation

Fig. 4 shows COVimep versus excess air ratio at 800rpm and various hydrogen addition levels.As it can be seen from Fig.4, when excess air ratio exceeds 1.43, COVimep of the pure gasoline engine is sharply increased to 65% due to the severe misfire. The high burning velocity of hydrogen decreases the engine combustion duration which is helpful on reducing the engine cyclic fluctation.When excess air ratio is greater than 1.43, the original engine encountered a serious misfire and caused a dramatical increase in COVimep.However, as the hydrogen-gasoline mixture has a wider flammability,the misfire can be effectively eliminated.

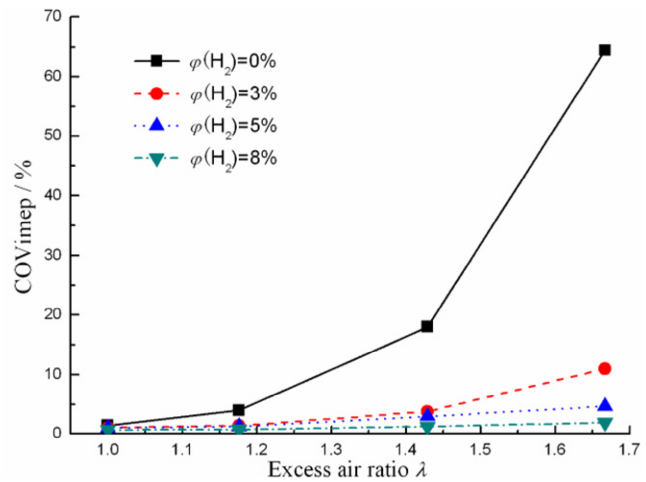

Figure 4: COVimep versus excess air ratio.

3.4 Untreated emissions

The variation of HC emissions with excess air ratio at 800rpm and different hydrogen fractions is shown in Fig.5. It can be seen that HC emissions decrease with the increase of hydrogen addition fraction at the same excess air ratio.For the original engine, HC emissions are obviously increased from 4206 ppm to 14331 ppm when excess air ratio is increased from 1.00 to 1.6 due to the serious partial burning and misfire of the pure gasoline engine at lean conditions.

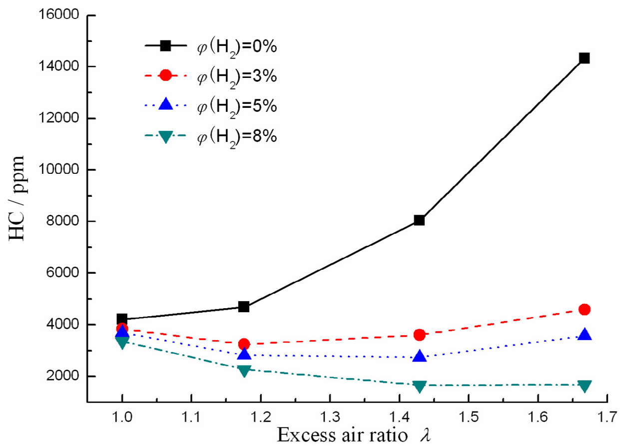

Figure 5: HC emissions versus excess air ratio.

Fig. 6 displays the variations of untreated CO emission with excess air ratio. From Fig. 6 we can see that under lean conditons CO emission dcreases with the increase of hydrogen addition. The decreased gasoline flow rate reduces the amounts of C atoms in the hydrogen-gasoline fuel mixture, and therefore contributes to the decrease of CO emission from the hydrogen-enriched gasoline engine.

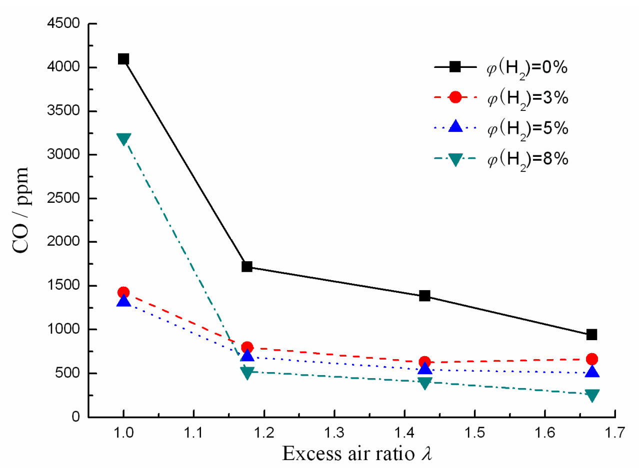

Figure 6: CO emission versus excess air ratio.

In Fig. 7 NOx emissions increase with the addition of hydrogen and decrease with the increase of excess air ratio.Especially at the stoichiometric condition, NOx emissions from the 8% hydrogen-enriched engine are nearly one time higher than those from the original one, because the fast burning velocity and high flame temperature of hydrogen tend to stimulate the formation of NOx.

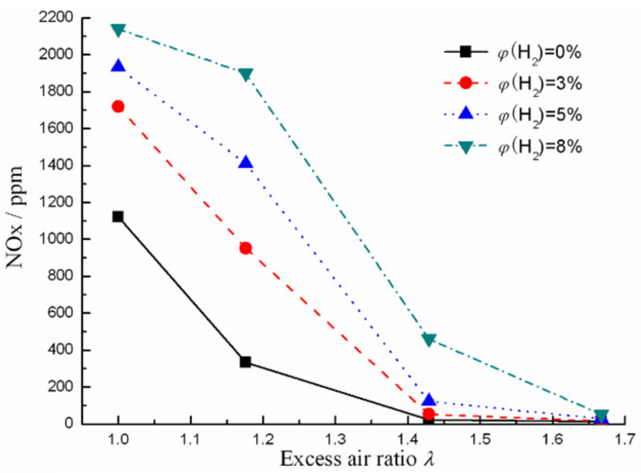

Figure 7: NOx emissions versus excess air ratio.

4 Conclusions

1).The brake thermal efficiency is greatly improved with the addition of hydrogen, especially at lean conditions;2). Hydrogen addition is helpful on decreasing engine flame development and propagation durations;3). The engine cycle-by-cycle variation and misfire is reduced with hydrogen enrichment;4).HC emissions are reduced while NOx emissions are increased with the increase of hydrogen addition for a specified excess air ratio.CO emission decreases with hydrogen enrichment level at lean conditions. However, when the engine runs nearly to the stoichiometric conditions, the 8% hydrogen-rich engine tends to expel more CO than 3 and 6% hydrogen-rich engine, but still lower than the original one.

Acknowledgements

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