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Improving Performance and Reducing Pollution Emissions of a Carburetor Gasoline Engine by Adding HHO Gas into the Intake Manifold

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ABSTRACT

Recently, using hydrogen or hydrogen-rich gas as a supplement fuel for spark ignition and compression ignition engines is one of the potential solutions for improving brake thermal efficiency, reducing fuel consumption and pollution emissions from internal combustion engines. This article investigates the effect of HHO gas addition on engine performance and emission characteristics.

HHO gas was produced by the electrolysis process of distilled water and stored in a high pressure tank before injected into the intake manifold. The experimental study was carried out on a 97 cc SI engine equipped with two injection systems (HHO gas and addition air) on the intake manifold. The tests were divided into two cases: hybrid HHO/gasoline and HHO/gasoline with addition air from second injection. The experiments showed that, of both cases, compared to original engine, the engine performance was improved and the gasoline fuel consumption was declined after enrichment of HHO gas and of HHO gas/addition air mixture,. The NO_x emission was increased; however, HC emission was reduced. The CO and CO_2 emissions displayed different trends between the two cases. When only HHO gas was injected, the CO emission surged due to rich mixture, while it was decreased after the supplying the addition air in the second case. The CO_2 emission trend was in opposite direction of CO. The study demonstrated that the effect of HHO gas addition is most apparent at light loads and lean conditions.

INTRODUCTION

The decline of fossil energy reserves such as petroleum oil, coal, natural gas and the increase of the environmental pollution are now of the world concerns. The significant development of transport vehicles and the personal energy demands lead to tradition energy sources gradually exhausted and produce more greenhouse gas emissions. Hence, engine manufacturers and researchers worldwide are currently encouraging to find out alternative approaches to increase fuel economy and to reduce harmful emissions from internal combustion engines (ICEs) [1]. One of the possible ways to enhance the engine performance, especially for spark ignition (SI) engines is to use an additive gaseous fuels like bio-gas, natural gas, hydrogen and hydrogen-rich gas. Of which, hydrogen and hydrogen-rich gas are mostly used due to the fact that the main component- hydrogen has a number of properties that make it an attractive fuel as an additive or on its own, as shown in Table 1.

Hydrogen is a kind of green renewable fuel, and it's combustion products are mainly water and a little of NO_x emission. Nowadays, hydrogen can be applied for transport as a main fuel (or supplement fuel) for ICEs and for fuel cell; and most of the hydrogen stations on over the world are attending to fuel cell vehicles. However, hydrogen fueled ICEs have some benefits, as the combustion engines have been developed for more than one hundred years and thus have potential to optimize. Using hydrogen as an additive fuel for gasoline engine is often carried out in the research laboratories with the goal to improve the engine performance and to reduce the harmful emissions.

Table 1. The properties of gasoline and hydrogen

Properties	Gasoline	Hydrogen
Molecular weight	107-114	2.02
Density (kg/m^3)	721-785	0.0838
Flammability limits (% vol. in air)	1.4-7.6	4-75
Stoichiometric air/fuel ratio	14.6	34.3
Minimum ignition energy (MJ)	0.24	0.02
Auto-ignition temperature (K)	533-733	858
Flame velocity (cm/s)	41.5	237
Low heating value (MJ/kg)	44	120
Quenching gap in NTP air (cm)	0.2	0.064
Diffusivity in air (cm^2/s)	0.08	0.63
Research Octane Number (RON)	92-98	130

F. Yüksel and M.A. Ceviz [2] evaluated the effects of adding constant quantity of hydrogen to the gasoline-air mixture of an SI engine. The results shown that the addition of hydrogen helped brake specific fuel consumption (BSFC) of gasoline decreased about 11.5%, while the engine thermal efficiency and the air/fuel ratio increased. T. D'Andrea et al. [3] used hydrogen as a part of the air with little modification to the engine. The added hydrogen resulted in the improvement of the output work when operating closer to stoichiometric conditions, little difference in the engine performance was seen. And based on a commercially available on-board electrolysis unit, more energy is required to generate the hydrogen than that gained from the engine. E. Conte and K. Boulouchos [4] used a port fuel injector to supply a small amount of hydrogen in to the intake manifold to create a reactive homogeneous background for the direct injection of gasoline in the cylinder. At lower load, the short spark delay allowed by H_2 addition alone was not enough to compensate the higher NOx production, whereas at higher load, the large spark delay allowed by H_2 enrichment was able alone to limit considerably NOx production. The indicated efficiency increased with H_2 addition; in all conditions, HC emission was substantially lowered by hydrogen addition.

C. Ji and S. Wang et al. [5, 6, 7] investigated the effects of hydrogen addition on combustion and emissions characteristics of a hybrid hydrogen-gasoline engine (HHGE) at lean burn limits and starting conditions. All of these studies were carried out on a four-cylinder 1.6 L engine, which was modified to realize hydrogen port injection by installing four hydrogen injectors in the intake manifolds. At lean conditions, brake mean effective pressure (BMEP) decreased with the increase of hydrogen addition fraction when the excess air ratio was around stoichiometric conditions. However, when the engine ran under lean conditions, the addition of hydrogen helped improve BMEP. The peak brake thermal efficiency increased from 26.37% for the original gasoline engine to 31.56% for the hydrogen enriched gasoline engine at 6% hydrogen addition fraction. HC and CO_2 emissions were obviously reduced, and NO_x emission was certainly increased with the increase of hydrogen blending level. The CO emission increased when the excess air ratio was around stoichiometric, but decreased under lean conditions with the addition of hydrogen [5]. The addition of hydrogen benefited for engine operating at lean conditions. The excess air ratio (λ) at the lean burn limit was extended from 1.45 of the original one to 2.55 of the hydrogen enriched gasoline engine with the hydrogen volume fraction of 4.5%. HC, CO and NO_x emissions at the lean burn limit were obviously reduced for the HHGE [6]. When HHGE started at cold condition, the indicated mean effective pressure (IMEP) in the first cycle was increased significantly after hydrogen addition, the time for the engine to start with hydrogen-gasoline blends was shortened. The HC and CO emissions were decreased markedly with the increase of hydrogen flow rate; the NOx emission in the first 5s after cold start was increased and then declined after 10s [7]. C. Ji, et al. [8] also studied the effect of spark timing on the performance of HHGE at lean conditions. The results showed that IMEP and the engine indicated thermal efficiency first increased and then decreased with the increase of the spark advance. The spark timing did not have much influence on the formation of CO emission, whereas HC and NOx emissions were reduced with the decrease of the spark advance.

Hydrogen-rich gas is a mixture of hydrogen and other gases such as oxygen (HHO gas, hydroxyl, hydroxygen, etc.), carbon monoxide - CO and others (syngas, producer gas). Many researchers studied the effect of the addition of these gases on the performance and emissions in the past several years.

C. Ji et al. [9] used syngas produced by onboard ethanol steam reforming as a supplement fuel for a gasoline engine. When adding syngas into the intake manifold, the engine indicated thermal efficiency was heightened from 34.52% of the original engine to 39.01% of the 2.43% syngas-blended gasoline engine. The HC and NOx emissions were decreased with the increase of syngas volume fraction. But CO emission was increased with the syngas addition.

T. D'Andrea et al. [10] studied the effects of adding small amounts of hydrogen or hydrogen and oxygen to a gasoline fuelled spark ignition engine at part load. The hydrogen and oxygen were added in a ratio of 2:1, mimicking the addition of water electrolysis products. The experimental results showed that, the effects of H_2 addition, while equivalence ratio Φ ≥ 0.85, on torque, IMEP were negligible; the torque and IMEP increased under lean conditions. The effect of adding the extra oxygen which would be produced by water electrolysis had no effect on engine performance. However it did increase NO formation (~500 ppm). The estimated power needed to produce the hydrogen through electrolysis was greater than the power gained from the engine.

Radu Chiriac et al. [11] presented experimental research where gasoline-air mixture was enriched with a Hydrogen Rich Gas (HRG) produced by the electrical dissociation of water. The results showed that brake thermal efficiency, IMEP were improved; the HC and eventually CO emissions concentrations were also reduced, while NO_x was generally increased. The effect of HRG addition was most apparent at light load with lean mixtures. The effect of HRG addition was explained in terms of well known influence of hydrogen, the main component of HRG.

Al-Rousan [12] designed fuel cell for HHO gas production, the generated HHO gas was introduced into the air stream just before entering the carburetor of a Honda G 200 engine. The test results demonstrated that using HHO enhanced combustion efficiency, consequently, reduced fuel consumption.

Musmar and Al-Rousan [13] investigated the effect of HHO gas on combustion emissions on this engine. The results explained that the NO and NO_x average concentrations were reduced to about 50% and 54%, respectively; the average concentration of carbon monoxide had been reduced to almost 20%; HC concentration enlarged when HHO was introduced to the system.

S. Wang et al. [14, 15, 16] modified the intake manifold of a four stroke four cylinder gasoline engine to supply hydrogen and oxygen (hydroxygen) through two injectors. When adding hydroxygen with the ratio of hydrogen to oxygen of 2:1 by mole fraction, the same with water electrolysis product, BMEP of the engine enriched by hydroxygen was generally higher than that of the original gasoline engine for all excess air ratios. The addition of hydroxygen helped decrease the engine HC and CO emissions. But the NO_x emission was adversely increased after the hydroxygen blending [14]. Compared with the performance of HHGE, thermal efficiency of hydroxygen-blended gasoline engine was higher at low blending fractions. But at high blending fractions, it was lower. The hydroxygen-blended gasoline engine produced lower CO emission than the hydrogen-enriched gasoline engine. At low blending fractions, the addition of hydroxygen was more effective on reducing HC emissions; NO_x emission, however, increased [15]. To explain the influence of hydrogen volume fractions of hydroxygen on performance of the engine, the injection durations of the hydrogen and the oxygen injectors were changed to obtained hydrogen volume fraction raised from 0% to 100%. The results demonstrated that the increased of hydrogen volume fraction in the hydroxygen leaded to the increase of the engine indicated thermal efficiency. The HC, CO and NO_x emissions were decreased, but NOx emission was increased after the hydroxygen addition with the increase of hydrogen volume fraction [16]. According to the simulation results of Tuan Le Anh et al. [17], thermal efficiency and engine power were surged, BSFC was declined. NO_x and CO emissions over the lambda ranging from 0.8 to 1.4 were increased, while HC emission was reduced. However, at lean conditions, the CO deteriorated slightly. The effect of HHO gas addition was most obvious at lean conditions.

Due to the fact that, the lambda range of the carburetor gasoline engine is around the stoichiometric value (lambda ~ 1), at these conditions, CO and NO_x emissions are increased, the effect of HHO gas on engine performance is not clearly as that at lean conditions. Hence, the authors carried out experimental study based on the original engine set-up conditions and the modified conditions with the addition of HHO gas alone and with the HHO gas and lean mixture. The simulation study was used to explain the combustion characteristics of the engine in cases with/without HHO gas addition.

EXPERIMENTAL SET-UP AND PROCEDURE

Experimental Set-Up

Fig. 1 shows the schematic diagram of the experimental system.

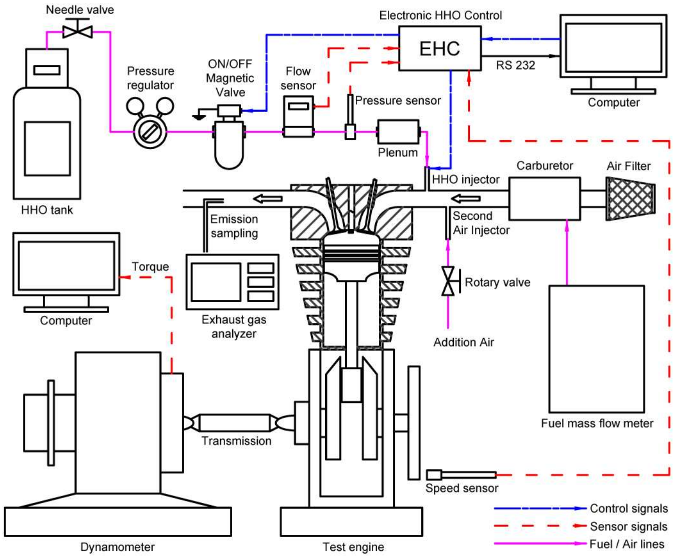

Figure 1. The schematics of the experimental system

The experiment was conducted on a 97 cc SI engine using carburetor system. Specifications of the engine are listed in

Table 2. Technical specifications of the engine

Description	Specifications
Engine Type	Single cylinder Spark Ignition
Fuel system	Carburetor
Bore x Stroke (mm)	50 x 49.5
Displacement (cm^3)	97
Compression ratio	9.0:1
Spark ignition timing (^{0}CA BTDC)	12 (at idle speed) and adjusted by DC-CDI
Valve type	DOHC x 2 valves

Table 3. The test lambda matrix

Throttle position	Mixture	Engine speed (rpm)									
		3600	4000	4400	4800	5200	5600	6000	6400	6800	7200
30%	Case 1	1.01	1.00	1.00	0.98	1.00					
	Case 2	1.02	0.98	0.99	0.97	1.00					
	Case 3	1.08	1.03	1.03	1.01	1.01					
50%	Case 1				0.95	0.96	0.97	0.99	1.00		
	Case 2				0.94	0.95	0.98	0.99	0.99		
	Case 3				0.98	1.02	1.00	1.02	1.02		
70%	Case 1						1.02	1.04	1.07	1.05	1.04
	Case 2						1.01	1.01	1.01	1.01	1.01
	Case 3						1.05	1.06	1.11	1.10	1.10

Table 2. The engine was coupled to a Didacta T101D water brake dynamometer in order to load the engine and to monitor the torque and speed. The gasoline fuel (RON 92) consumption was measured by AVL Fuel Balance 733S. The exhaust emissions (CO_2, CO, NO_x and HC) were measured by exhaust gas analyzers (AVL CEB II). NO_x emission was measured by the chemiluminescen detector (CLD), HC emission was determined by the hydrogen flame ionization detection (FID), CO and CO_2 emissions were detected by the non dispersive infrared detector (NDIR).

HHO gas produced by water electrolysis process was compressed to a tank with the pressure of 3.5 bars. The HHO supplying pressure was adjusted by a pressure regulator. The pressure sensor was used to get a more sensitive signal for Electronic HHO Control (EHC) unit. The HHO mass flow was determined by a flow sensor - called TF-4000, with the range from 0 to 30 liters/min and the measurement uncertainty less than 2%. The HHO gas was injected into the intake manifold downstream of the carburetor by an injector controlled by the EHC unit (as shown in Fig. 2) and an ON/OFF magnetic valve. The addition air was controlled by a rotary valve locating in a 10cm diameter pipe while the ambient air was aspirated naturally.

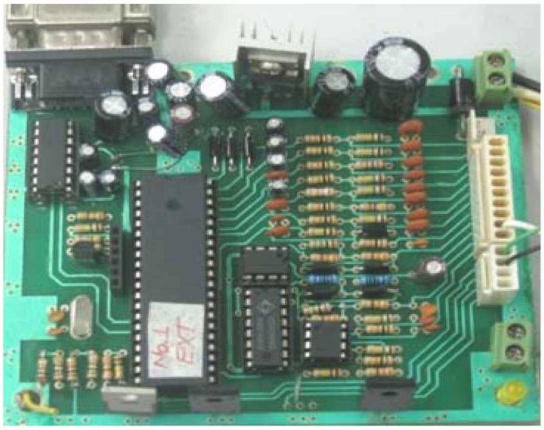

Figure 2. Photograph of the EHC unit

According to researchers on over the world [10,11,17], the addition of hydrogen-rich gas have strong effect at lean conditions, so the authors operated the engine with the addition of the ambient air into the gasoline-HHO gas mixture to obtain the leaner mixture than the traditional engine (case3). In addition, no addition adjustment of the spark timing was made during the experiments except it was tuned automatically by DC-CDI.

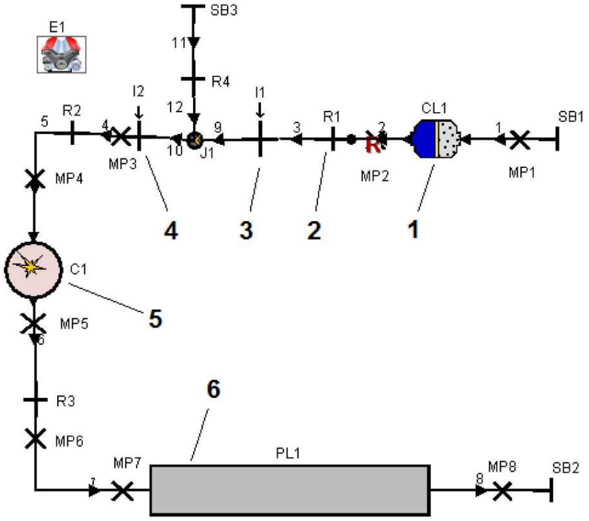

Figure 3. Simulation model based on AVL Boost 1. Air Cleaner, 2. Restriction (throttle), 3. Carburetor, 4. HHO gas injector, 5. Cylinder, 6. Plenum (muffler)

Experimental Procedure

The experimental studies were carried out on modified engine at three positions of throttle, 30%, 50% and 70% with the different speed range, as shown in Table 3 for test lambda matrix. The engine speed was adjusted by the level of water in the brake. The flow rates of HHO gas were controlled by the injection pressure and the injection duration to obtain the ratios of HHO gas in the mixture about 1.95% by mass over all of considered throttle positions. The global lambda of gasoline and HHO gas mixture can be calculated as follow:

$$\lambda = \frac{(dm/dt)_{Air}}{(dm/dt)_{Gasoline}.(A/F)_{Gasoline} + (dm/dt)_{HHO}.(A/F)_{HHO}} \qquad (1)$$

In Equation (1), $(dm/dt)_{Air}$, $(dm/dt)_{Gasoline}$ and $(dm/dt)_{HHO}$ represent the measured mass flow rates of the intake air, gasoline and the HHO gas, respectively. $(A/F)_{Gasoline}$ and $(A/F)_{HHO}$ symbolize the stoichiometric air to fuel ratios of gasoline (14.6) and HHO gas, respectively. Because of HHO gas is water electrolysis product, so the volume of oxygen in this gas is enough for hydrogen combustion process; therefore $(A/F)_{HHO} = 0$ (in theory condition).

For each position of the throttle and the engine speed, the engine was fueled with three mixtures, gasoline with intake air (case 1), gasoline with intake air + HHO gas (case 2), and gasoline with intake air + HHO gas + addition air (case 3).

PREDICTION OF COMBUSTION CHARACTERISTICS

Model Set-Up

One-dimension model of the test engine has been built on AVL Boost version 2010 software to estimate the combustion characteristics of the gasoline engine enriched by HHO gas. The simulation model data requirements such as cylinder, air cleaner, piping parameters, gasoline mass flow and HHO gas flow rates, etc. were obtained from the experimental study. HHO gas input was delivered by the gas injector (I2 in Fig. 3) and it was considered that the mass fractions of the two gases are 0.889 for oxygen (O2) and 0.111 for hydrogen (H2). The mass flow rate of addition air was controlled by the flow coefficient element R4. The Fractal combustion model [18] was chosen in this study for the prediction of combustion characteristics. The simulation procedures were the same as experimental conditions.

Simulation Results

Fig.4 displays the results of the engine power and the specific fuel consumption measured and simulated at 30% throttle opening position and different engine speeds of the original engine. The maximum difference of the simulated and experimented data of 2.88% can ensure the accuracy of the simulation model.

The in-cylinder combustion pressure and the mass fraction burn of three cases at the engine speed of 4000rpm and 30% throttle opening conditions are shown in Fig. 5.

Because of the high flame velocity of hydrogen, main component of HHO gas, the burned fraction of gasoline with HHO gas is higher than that of gasoline alone. The flame development in case 2 is fastest, leading to combustion pressure and the pressure rise rate increasing rapidly. When adding more air into the intake manifold by second air injector, due to the dilution effect, the burning rate in case 3 is slower than that in the case 2.

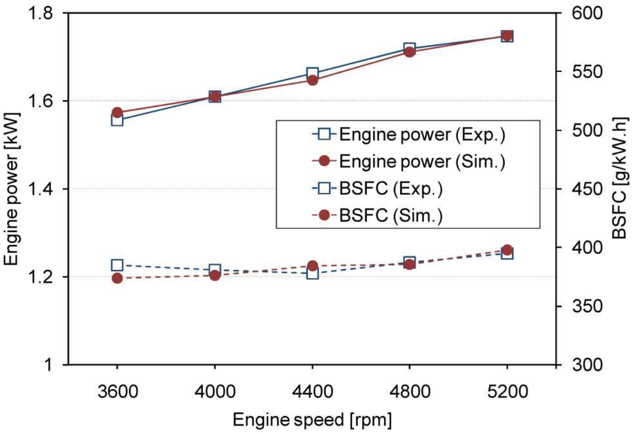

Figure 4. Measured and simulated engine power and specific fuel consumption at 30% throttle opening of the original engine

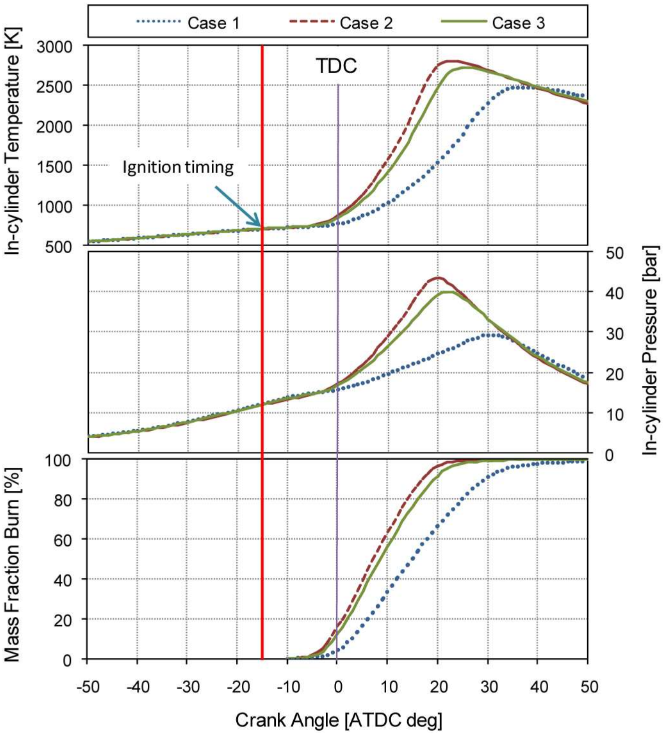

Figure 5. Simulation combustion characteristics in three cases at engine speed of 4000 rpm and 30% throttle opening

According to the mass fraction burn profiles of these mixtures, the total heat release from the combustion process can be calculated. As a result of high burning rate, the total utilizable heat release of the mixture enriched with HHO gas is higher than that of the traditional mixture and the high unburned hydrocarbon is expected in the later case. The variations of in-cylinder combustion temperature are similar to those of the combustion pressure.

EXPERIMENTAL RESULTS

Engine Performance

Fig. 6 shows the measured gasoline mass flow rates in three cases.

In the carburetor system, the fuel is aspirated by the vacuum at the throat of the carburetor, which produced by the motion of the charge air. The fuel mass flow rate is controlled directly by the volume of ambient air moved into the cylinder and the cross section area of the orifice. This cross section area is determined by the diameter of the orifice and the position of the throttle needle. For each test condition, the throttle needle position (or throttle position) is fixed. Thus, when adding HHO gas and mixture of HHO gas+addition air, the mass flow rate of gasoline is reduced due to the reduction of the ambient air volume passing through the carburetor's orifice.

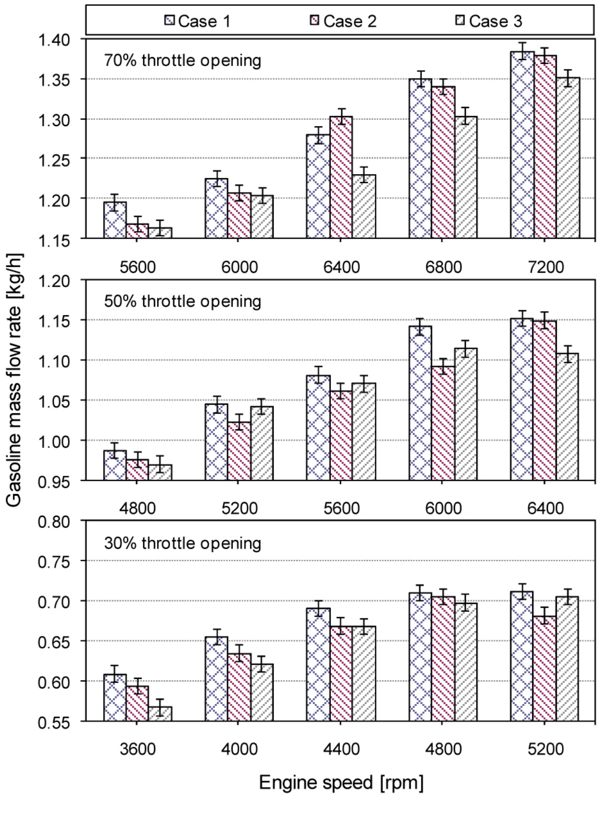

Figure 6. The measured gasoline mass flow rates in three cases at different engine speeds and throttle positions

Over the considered engine speeds and throttle positions, the average gasoline mass low rate declined around 1.74% and 2.74% in case 2 and case 3 (relative to case 1), respectively. The volume of the ambient air reduces about 1.95%, so the global excess air ratio (λ) declines in the case 2, however, λ surges in the case 3. Similar to other research, the gasoline saved from case 2 and case 3 compared to case 1 is not balanced with the energy needed for HHO gas production. However, the efficient use of gasoline and the reduced exhaust emissions are important targets of the research.

Fig. 7 presents the average percentage increase of the engine power output when the original engine is enriched by HHO gas and by the mixture of HHO gas/addition air. According the indicated pressure curve shown in Fig. 5, the IMEP of the test engine in case 2 is larger than that in case 3 due to the dilution of the addition air which causes the combustion velocity collapsed in this later case, the improvement of the engine power in the case 2 is better than that in the case 3. At light load (30% throttle opening), HHO gas addition has a strong effect on the engine power, the average percentage increases of the engine power are 4.45% and 3.57% in case 2 and in case 3, respectively. At middle load (50% throttle opening) and high load (70% throttle opening), this effect is decreased. As the spark ignition timing is automatically adjusted by DC-CDI around the basic angle, the advanced ignition angle is increased together with the engine speed. Thus, at lower engine speeds, the advanced ignition angles are small which better match with high combustion velocity in cases of hydrogen availability. The high advanced ignition angles can lead to earlier combustion of the mixture with the presence of hydrogen and may reduce the engine thermal efficiency compared to the optimum value. Thus the retarded spark timing is necessary when adding HHO gas to obtain more engine efficiency in the next research.

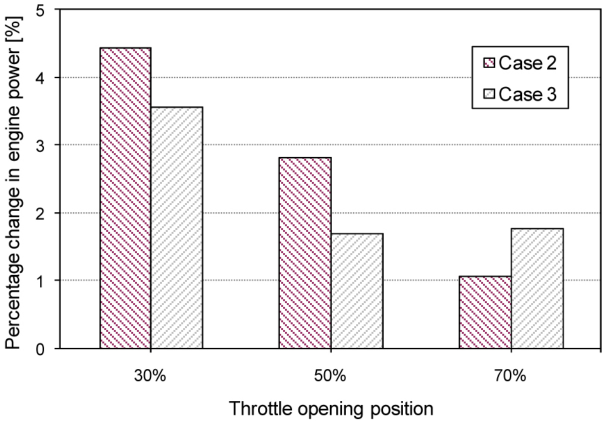

Figure 7. Average percent increase of engine power relative to case 1 over the considered engine speeds

On the other hand, the air/fuel ratio or the excess air ratio also shows the influence on the engine power. Theoretically the higher the excess air ratio, the slower the combustion velocity. However at higher load, this effect can be compensated by higher temperature of the engine. At the throttle opening of 70%, the engine power output in case 3 is larger than that in case 2.

Exhaust Emissions

Fig. 8 demonstrates the variations of NO_x emission in case 2 and case 3 relative to case 1. Over all throttle positions, the NO_x concentration in case 3 is higher than that in case 2 due to the excess air ratio in case 3 closer to the stoichiometric value. In case 2, the NO_x concentration is declined with the widening of throttle positions, because of the time for NO_x formation reactions is shortened. However, in case 3, the NO_x concentration changing is climbed dramatically at 70% throttle opening due to more completed combustion as mentioned at this condition. Over the considered engine speeds and throttle positions, the average NO_x emission climbed about 29.16% in case 2 and 47.42% in case 3.

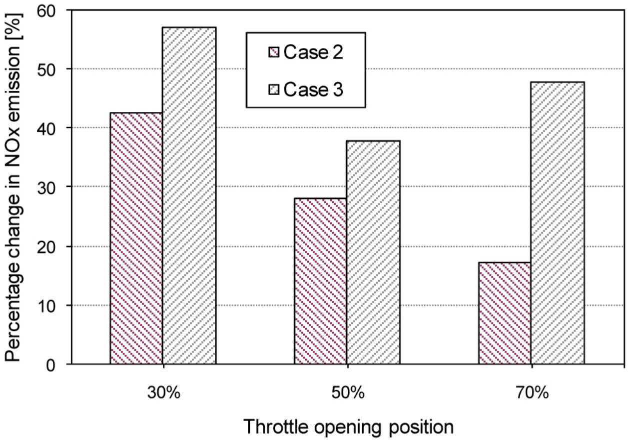

Figure 8. Average percent increase of NO_x emission relative to case 1 over the considered engine speeds

Fig. 9 presents information about the percentage change in CO emission in case 2 and case 3 relative to case 1.

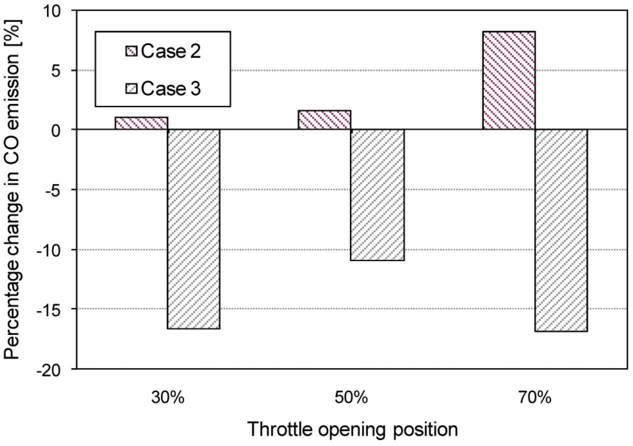

Figure 9. Average percent increase of CO emission relative to case 1 over the considered engine speeds

When adding only HHO gas into the mixture of gasoline/intake air (case 2), CO emission is increased, whereas it is collapsed with the supply of HHO gas and addition air into the gasoline/intake air mixture (case 3). These could be explained by the quality of the mixture. In case 2, the mixture is richer than that of case 1, leading to insufficient oxygen for completed hydrocarbon combustion. However, in case 3, thanks to the addition of the intake air, the oxygen concentration in the mixture is enough for more complete combustion of hydrocarbon and oxidation of CO into CO_2. In addition, the effect of the lambda on CO emission is clearly shown in case 3. At higher lambda values of 30% and 70% throttle positions, the CO concentration in the exhaust gas is obviously lower than that of 50% throttle case.

Fig. 10 displays the average percentage change of HC emission over engine speeds at different throttle positions in two cases (case 2 and case 3) compared with case 1.

It is also seen from Fig. 10 that, the HC emission is reduced with the addition of HHO gas in case 2 because of the higher combustion temperature and short quenching distance of the hydrogen. In case 3, with the supplement of the addition air from the ambient, the mixture is leaner, that means the concentration of oxygen in the mixture is higher, enough to oxidize more hydrocarbon, the lower HC emission is obtained. Average percentage decreases of HC emission over the engine speeds and throttle positions are about 4.88% and 6.16% in case 2 and case 3 compared to original engine, respectively. Furthermore, as mentioned, the leaner mixture at 30% and 70% throttle positions make HC emission reduction more relative to that at 50% throttle position.

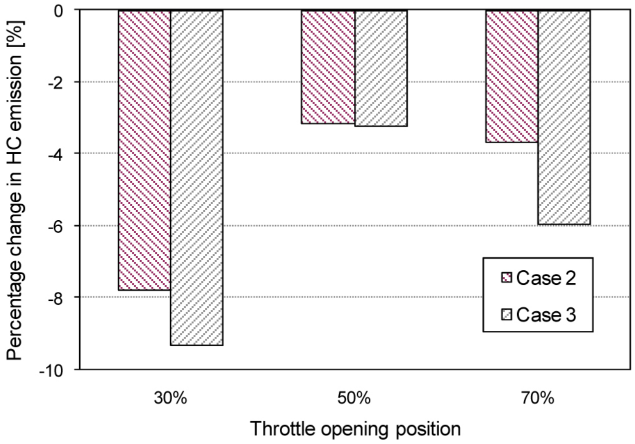

Figure 10. Average percent increase of HC emission relative to case 1 over the considered engine speeds

Fig. 11 shows the variations of CO_2 emissions in case 2 and case 3 relative to case 1 at different engine loads over the considered engine speeds.

It can be found that the CO_2 emission is lightly declined with the addition of HHO gas in case 2. Although the combustion is improved with the addition of the HHO gas, which is proved by the reduction of the HC emission and the increase of the NO_x emission, the fuel consumption is declined as lambda is lower in case 2 compared to that in case 1. When the supplement air is added in case 3, the mixture is leaner, the more completed combustion is achieved, which results in more CO_2 emission formation in the exhaust gas. In case 2, averaged CO_2 emission dropped about 1.17%, whereas in case 3, this emission surged around 5.18% relative to that in the case 1.

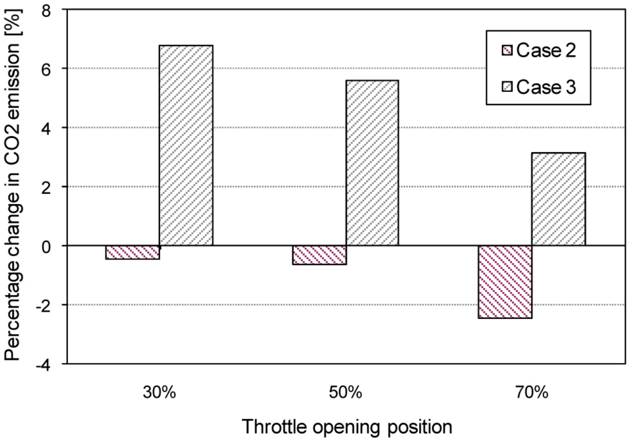

Figure 11. Average percent increase of CO_2 emission relative to case 1 over the considered engine speeds

CONCLUSIONS

This paper introduced the simulation and experimental studies to investigate the engine performance and the exhaust emissions when supplying the HHO gas and mixture of HHO gas/addition air into the intake manifold of a carbureted gasoline motorcycle engine. The experiments were carried out on a modified carburetor gasoline engine with the position of HHO gas and addition air injectors at downstream the carburetor. The experimental results showed that engine performance was improved with the addition of HHO gas and the addition of the HHO gas/supplement air mixture. The engine power increased nearby 2.35% and 2.78% when adding only HHO gas and the mixture of HHO gas/addition air, respectively. The change of the exhaust emissions from the test engine in case 2 and case 3 displayed similar trend in NO_x and HC emissions. Of which, NO_x emission increased gradually and HC emission reduced after adding HHO gas and HHO gas/addition air enriched. However, CO and CO_2 emissions showed an opposed trend between case 2 and case 3; CO emission climbed when HHO gas introduced into the intake manifold but it deteriorated after the addition air injected thanks to leaner mixture.

This article also demonstrated that the effect of HHO gas addition is most apparent at light loads and lean conditions. Furthermore, the addition of HHO gas alone makes the mixture richer which can bring a negative effect to the CO emission, however the addition of HHO gas together with a secondary air injection can help the mixture leaner and the lower CO emission is resulted. Finally, the consideration of retarded spark timing in case of HHO gas addition is important especially at high engine speed due to high flame velocity of hydrogen.

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DEFINITIONS/ABBREVIATIONS

SI - Spark Ignition

CI - Compression Ignition

ICEs - Internal Combustion Engines

NO_x - Nitrogen Oxide

HC - Hydrocarbon
CO - Carbon Monoxide
CO_2 - Carbon Dioxide
RON - Research Octane Number
BSFC - Brake Specific Fuel Consumption
HHGE - Hybrid Hydrogen-Gasoline Engine
IMEP - Indicated Mean Effective Pressure
BMEP - Brake Mean Effective Pressure
HRG - Hydrogen Rich Gas
°CA - Crank Angle degree
BTDC - Before Top Dead Center
DC-CDI - Direct Current- Capacitor Discharge Ignition
DOHC - Double Over Head Camshaft
CLD - Chemiluminescen Detector
FID - Flame Ionization Detection
NDIR - Non Dispersive Infrared Detector
EHC - Electronic HHO Control

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