Fuel 90 (2011) 3066–3070

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Effect of HHO gas on combustion emissions in gasoline engines

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ARTICLE INFO

Article history:
Received 16 February 2011
Received in revised form 11 May 2011
Accepted 17 May 2011
Available online 1 June 2011

Keywords:
Auto emissions
Brown's gas (HHO)
Fuel cell (FC)
Nitrogen monoxide (NO)
Nitrogen oxides (NO_X)

ABSTRACT

Reducing the emission pollution associated with oil combustion is gaining an increasing interest worldwide. Recently, Brown's gas (HHO gas) has been introduced as an alternative clean source of energy. A system to generate HHO gas has been built and integrated with Honda G 200 (197 cc single cylinder engine). The results show that a mixture of HHO, air, and gasoline cause a reduction in the concentration of emission pollutant constituents and an enhancement in engine efficiency. The emission tests have been done with varying the engine speed. The results show that nitrogen monoxide (NO) and nitrogen oxides (NO_X) have been reduced to about 50% when a mixture of HHO, air, and fuel was used. Moreover, the carbon monoxide concentration has been reduced to about 20%. Also a reduction in fuel consumption has been noticed and it ranges between 20% and 30%.

1. Introduction

Global warming is considered one of the major problems the scientific community has to face. Many theories refer to the increase of exhaust gases concentration in the atmosphere as one of the major causes of the global warming [1]. Industrial plants and automobiles are the major source of the exhaust gases. Since they utilize the power associated with oil combustion as energy source. Emissions are simply the exhaust or leftovers of combustion coming out of an engine. An emissions test is normally done with a probe placed into the exhaust stream. Every road going vehicle has certain clean requirements that it is required to meet.

The emission sampler, which is known as gas analyzers, measures five types of gases. These gases are HC, NO_X, O_2, CO, and CO_2 [2]. HC which refers to hydrocarbons, are simply another term for unburned fuel that makes it way through the engine and out the exhaust. Smog intensity is proportional to the amount of HC's in the exhaust [3]. HC's is also considered hazardous when inhaled. NO_X refers to oxides of Nitrogen. High NO_X emission is usually noticed with highly heated and compressed air that has nitrogen in it [2,4]. NO_X is another bad emission to breath at high levels. O_2 which is unburned oxygen in the exhaust is also measured. Although O_2 is obviously not bad, it is tested to better understand the combustion characteristics [4]. Knowing the percentage of oxygen in the exhaust one may estimate the air/fuel ratio of the engine as it runs. CO and CO_2 refer to carbon monoxide and carbon dioxide respectively. Odorless CO causes headaches and eventually death by hold up O_2 from the human body, if it exists in high quantities. CO_2 is present in the air in large amounts contribute to green house effect and consequently global warming. HC's are usually the worst problem for vehicle engines [3].

Many things can produce high HC's such as advanced timing, and bad catalytic converter. NO_X is generally worse on higher compression engines. All engines produce NO_X but the use of Exhaust Gas Recirculation Valve (EGR) valves will cool and slow down the combustion rate of the engine. This considerably lowers NO_X values [4].

CO has to do with the efficiency of the combustion in the engine and also is highly affected by the fuel to air ratio of the engine. CO_2 is also an indicator of the engines set up. The HC's and NO_X are by far the largest problem areas [2,4]. Catalytic converters clean the majority of the emissions and need to be replaced when they break internally causing a loss in power and no longer effective [4].

A shift in scientist's interests, recently observed, toward lower fuel consumption and emission engines take place. This encourages researchers to seek for alternative solutions to be used in engines without the need for a dramatic change in the vehicle design. Among those using H_2 as an alternative fuel which enhances the engine efficiency and runs with almost zero pollution effect [5]. However, this is not a viable solution from a commercial point view. Building a system that generates H_2 and integrated it with the engine system makes the manufacturing cost too expensive [6], which reflects on the vehicle market price. Other researchers use a blend

Abbreviations: HHO, Brown's gas; FC, fuel cell; NO, nitrogen monoxide; NO_X, nitrogen oxides; EGR valve, Exhaust Gas Recirculation Valve; $1/\varnothing$:relative air/fuel ratio, lambda λ; $\varnothing$:$A/F_{actual}/A/F_{theoretical}$, air–fuel ratio equivalence ratio.

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doi:10.1016/j.fuel.2011.05.013

of H_2 mixed with natural gas to enhance the combustion efficiency [7–16]. Fanhua Ma et al. show that mixing H_2 with natural gas enhances the combustion efficiency and reduces the emissions level. They refer this to the shorter flame development and propagation periods associated with the case where H_2 was used [7]. Ali Can Yilmaz et al. studied the effect of HHO gas addition on compression ignition engines. His results showed significant enhancements in the engine performance due to the presence of HHO [17].

The main objective of the present study is to introduce some of the hydrogen advantages and maintain the original specifications of the engine. This may be attained by introducing HHO cell to the fuel supplying system. So, the fuel becomes a mixture of gasoline and HHO gas. A compact unit for generating HHO gas has been designed to fit the engine requirement and to be installed in the engine room.

2. Experimental setup

2.1. Fuel cell

FC is a fuel supply device containing several parts that demonstrate the real possibility of how hydrogen can be used as a 100% clean fuel for cars in future. Yull Brown patent, in 1977, a technique to generate HHO gas based on electrolysis process [18]. Research on FC is currently going on with main target is to enhance the fuel cell performance and/or reduce the fuel size [18–30]. The fuel cell used in this research is basically an electrolyte cell which decomposes distilled water (H_2O) into HHO. Heat is generated due to this electrolysis process so a sodium bicarbonate may be added gradually to accelerate the decomposing of H_2O into HHO and assure control of the heat generation. HHO gas generated, in electrolysis process, due to the separation to water molecules H–HO. It has high potential energy, the caloric value of HHO gas is three times that of gasoline.

Plates of stainless steel-grade 316-L are used as the cell plates. The cell plates have an anode and cathode. Both of them made of the same materials. As a result of experience stainless steel grade 302 and 304 for the cathode (the minus volt wire) may be used but grade 316-L is essential for the anode. The electric current entered the anode and then passes to the cathode through the electrolyte. The cell plates are arranged inside a Plexiglas box supplied by the required fittings and piping. The input of the cell is distilled water and sodium bicarbonate which is used as an electrolyte. The output gas (HHO) can easily be injected into the combustion chambers in order to spark and burn. This cell has

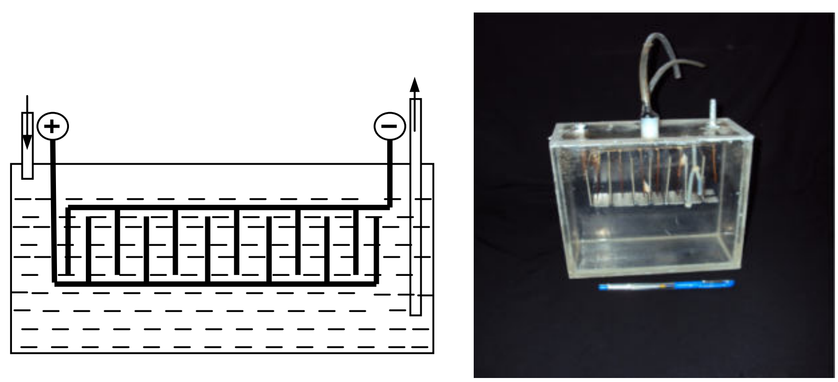

Fig. 1. Photograph and a schematic diagram of HHO fuel cell.

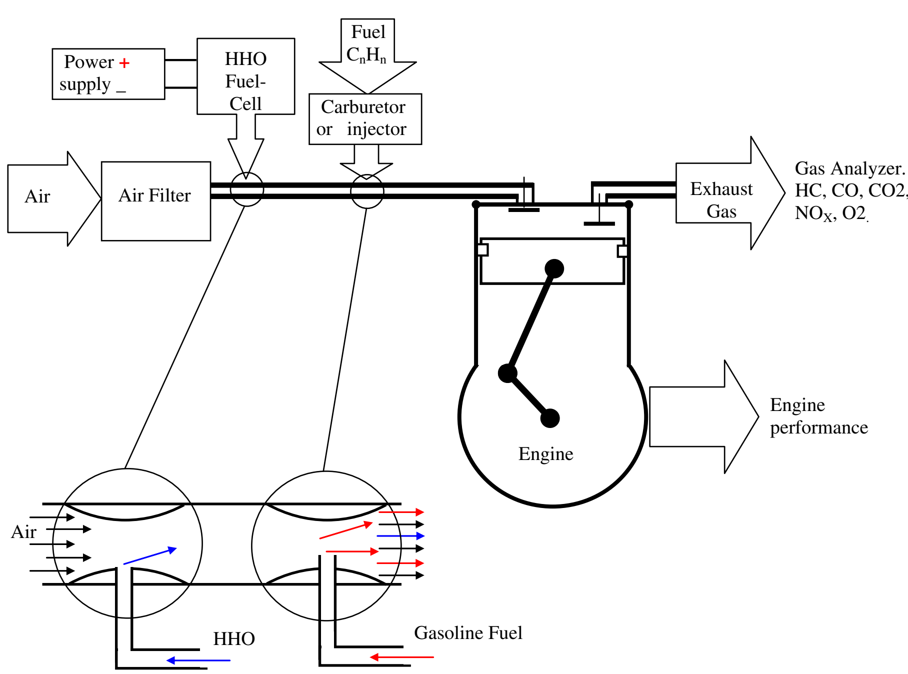

Fig. 2. Schematic experimental setup.

Table 1
G200 engine specifications (after [25]).

Bore stroke	67 × 56
Displacement	197 cm
Compression power ratio	6:5:1
Maximum torque	1.06 kg m/2500 rpm
Fuel tank capacity	3.5 l
Oil capacity	.7 l
Diminution (L × W × H)	337 × 375 × 425 mm
Dry weight	15 kg

been designed and built at Mutah University workshops with a volume capacity of 2.8 l. Fig. 1 shows a photograph to the HHO cell used in this study. The experimental setup is shown in Fig. 2.

2.2. Description of the experimental rig and measurements techniques

A single cylinder, air cooled spark ignition engine (Honda G 200 engine [30]) is used for testing purpose. The motor specification is shown in Table 1 below. A constant load test and variable speed (1000–2300 rpm) has been performed on this motor. A gas analyzer has been used to estimate the concentrations of NO_X, HC, CO, CO_2, and O_2 in the exhaust stream. Tachometer was used to measure the engine speed.

2.3. HHO injection inside engine system (see Fig. 3)

Adding HHO gas to the fuel/air mixture has the immediate effect of increasing the octane rating of any fuel. "Octane Rating" means how much that fuel can be compressed before it ignites [31]. More efficient combustion translates to less fuel being consumed [31]. An earlier study by Al-Rousan demonstrates the enhancements associated with the use of a blend of HHO gas on both the break efficiency and fuel consumption [31].

2.4. Emission parameters

The effect of adding HHO gas to the air/fuel mixture on the carbon monoxide concentration is presented in Fig. 4. Using a blend of HHO gas reduces significantly the presence of carbon monoxide in the exhaust. CO has to do with the efficiency of the combustion in the engine and also is highly affected by the fuel to air ratio of the engine. It has been shown that introducing HHO gas to the combustion enhances the combustion efficiency and enhancement in thermal efficiency and specific fuel consumption will be evident (as shown in Fig. 3). HHO is extremely efficient in terms of fuel configuration; its hydrogen and oxygen exist as tiny independent

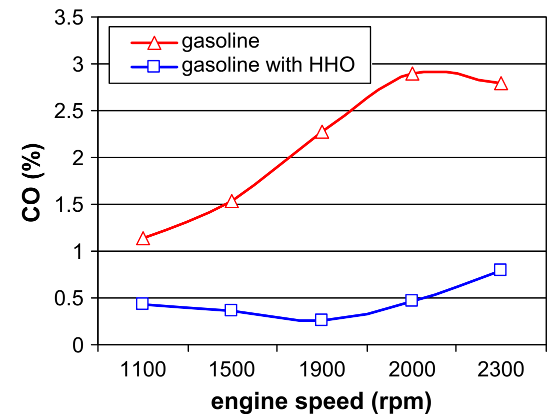

Fig. 4. Variation of carbon monoxide concentration with engine speed.

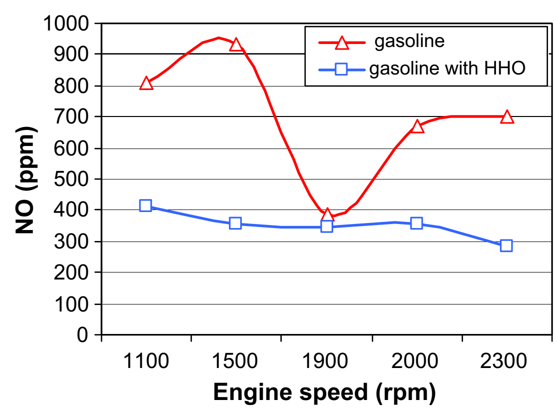

Fig. 5. Variation of nitrogen oxide concentration with engine speed.

clusters of no more than two atoms per combustible unit. Comparatively, a gasoline droplet consist many thousands of large hydrocarbon molecules. This diatomic configuration of HHO gas (H_2, O_2) results in efficient combustion because the hydrogen and oxygen atoms interact directly without any ignition propagation delays due to surface travel time of the reaction. On ignition, its flame front flashes through the cylinder at a much higher velocity than in ordinary gasoline/air combustion [7]. The heat and pressure wave HHO generates crushes and fragments the gasoline droplets, exposing fuel from their interior to oxygen and the combustion reaction. This effectively enriches the air/fuel ratio since more fuel is now available to burn. Simultaneously, the HHO flame front

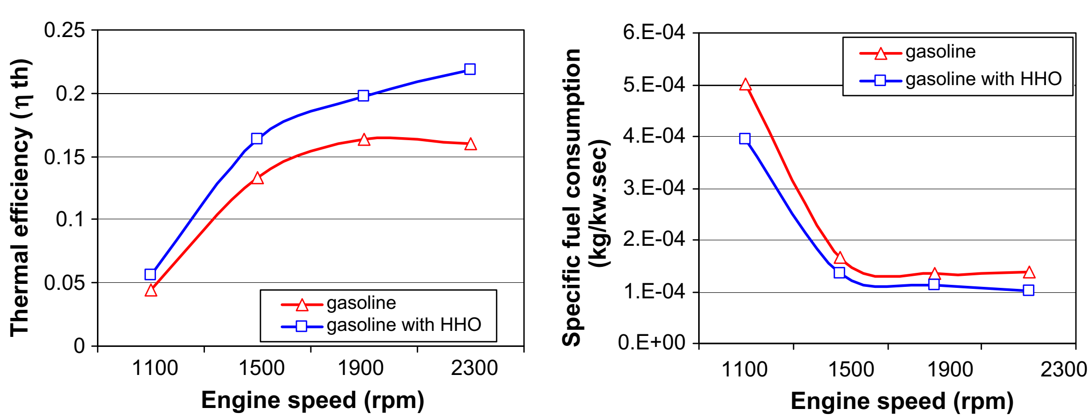

Fig. 3. Effect of HHO gas on break efficiency and fuel consumption [31].

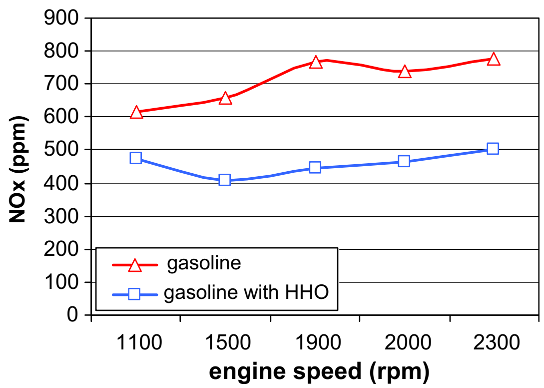

Fig. 6. Variation of nitrogen oxides (other than NO) concentration with engine speed.

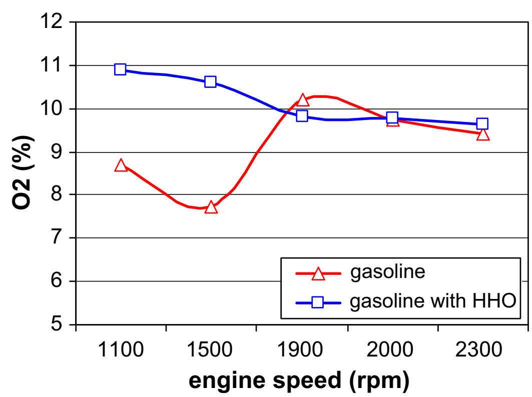

Fig. 7. Variation of oxygen concentration in the exhaust with engine speed.

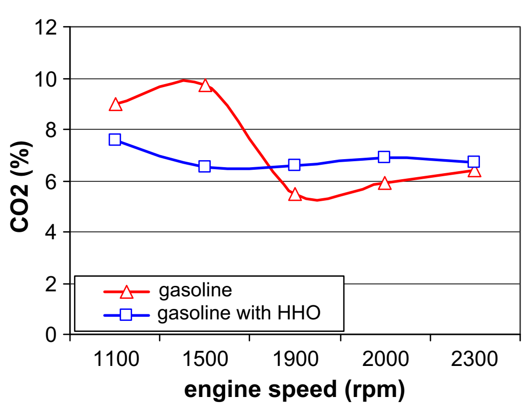

Fig. 8. Variation of carbon dioxide concentration in the exhaust with engine speed.

ignites the crushed fragments thereby releasing more of their energy, more quickly. Fig. 5 shows the reduction in nitrogen oxide emission due to the existence of HHO in the combustion chamber. As well as Fig. 6 shows the reduction in NO_X concentration in exhaust. High NO_X emission is usually noticed with highly heated and compressed air that has nitrogen in it. Adding HHO to gasoline increases the octane ratting. This fact causes the gasoline to ignite before TDC (Top Dead Center, the point where the piston is at the highest point of its motion), making it less efficient because the explosion of gas fumes pushes the piston down and out of sequence (it is too early so it goes a bit in reverse) and therefore the "pinging" noise and less power from regular gasoline. Brown's

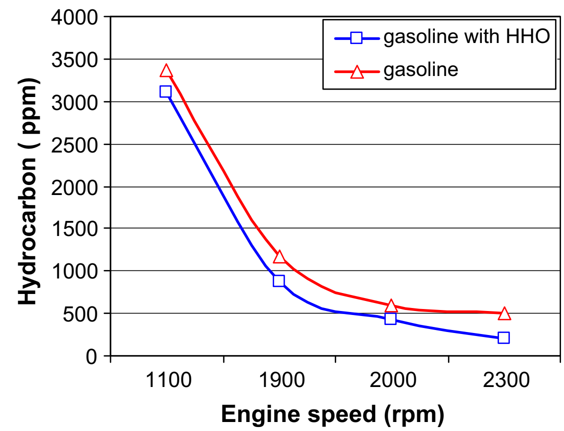

Fig. 9. Plot showing the effect of using HHO on hydrocarbon concentration in exhaust gas with variable engine speed (rpm).

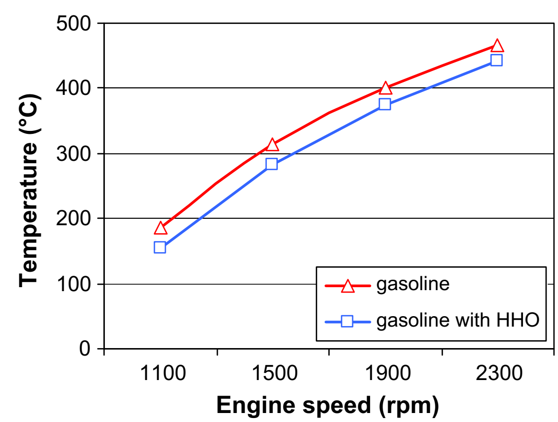

Fig. 10. Plot showing the effect of using HHO on exhaust gas temperature with variable engine speed (rpm).

gas or water vapor causes regular low-grade fuel to ignite more slowly, making it perform like a high octane gasoline. A higher octane rating means stronger horse power due to combustion occurring much closer to TDC, where it has a chance to turn into mechanical torque (rotary push) the right way and without pinging. Each piston transfers more energy during its combustion cycle, so combustion becomes more efficient as well as. More efficient combustion translates to less fuel being consumed.

The variation of oxygen concentration and carbon dioxide concentration in the exhaust with engine speed is presented in Figs. 7 and 8 respectively. One can notice that the result shows two segments. The first is up to 1900 rpm engine speed, oxygen presence increased by about 20% when HHO gas has been introduced to the system, whereas carbon dioxide is reduced by 40%. The second segment shows no significant difference in either oxygen or carbon dioxide concentrations. This is related to the time available to combustion reactions to take place; higher engine speed is directly related to shorter combustion time.

HC's are usually the worst problem for vehicle engines. HC which refers to hydrocarbons, are simply another term for unburned fuel that makes it way through the engine and out the exhaust. The variation of hydrocarbon concentration with engine speed is shown in Fig. 9. One can notice that HC concentration in the exhaust is reversely related to the engine speed. This is due to an increase in turbulence intensity mixing process of burnt and unburnt gases which increases oxidation rate of HC. Also a reduction in HC concentration in the exhaust as a result of

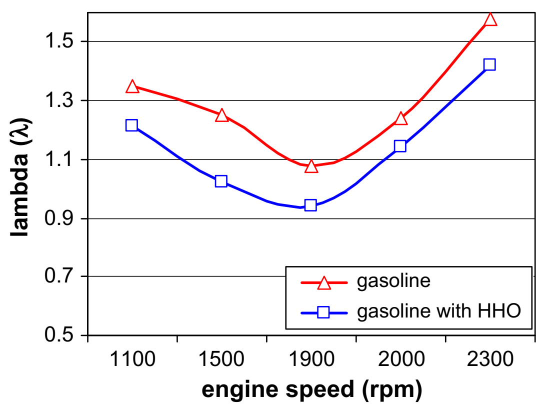

Fig. 11. Plot showing the effect of using HHO on lambda with variable engine speed (rpm).

introducing HHO is noticed. This reduction in HC emission is increased with engine speed. At 2300 rpm engine speed, Fig. 9 reveals a reduction in HC concentration to about 40% due to the presence of HHO in the fuel mixture.

Fig. 10 shows the variation of exhaust gas temperature with engine speed. The exhaust gas temperature is almost directly related to the engine speed. Introducing HHO to the intake manifold reduces the exhaust gas temperature. This leads to lower NO_X emissions as shown in Figs. 5 and 6. The variation of λ ($A/F_{theoretical}/A/F_{actual}$) with engine speed is shown in Fig. 11. The results reveals that introducing HHO gas shifts the curve downward, since it enhances the combustion characteristics and consequently reduces the fuel consumption at any speed.

3. Conclusion

Experimental tests to investigate the effect of HHO gas on the emission parameters of a Honda G 200 engine have been carried out. HHO gas has been generated by an electrolysis process in a Plexiglas box (fuel cell). The generated gas is mixed with a fresh air just before entering the carburettor. The exhaust is sampled by a gas analyser and the exhaust constituents have been identified and their concentrations have been evaluated. The following conclusions can be drawn.

1. HHO cell may be integrated easily with existing engine systems.
2. The combustion efficiency has been enhanced when HHO gas has been introduced to the air/fuel mixture, consequently reducing fuel consumption.
3. The concentration of nitrogen oxide has been reduced to almost 50% on average when HHO is introduced to the system.
4. When HHO is introduced to the system, the average concentration of carbon monoxide has been reduced to almost 20% of the case where air/fuel mixture was used (no HHO).
5. The NO_X average concentration has been reduced to about 54% of the case where HHO was not introduced.
6. HC concentration is highly affected by the engine speed and the presence of HHO gas.

References

[1] Ishida H, Kawasaki S. On-board and roadside monitoring of NO_X and SPM emission from vehicles. Eastern Asia Soc Transp Stud 2003;5:2398–407.
[2] Heywood JB. Internal combustion engine fundamentals. McGraw Hill; 1988.
[3] Kanazawa T, Sakurai K. Development of the automotive exhaust hydrocarbon adsorbent. SAE technical paper 2001-01-0660; 2001.
[4] Shehata M, Abdel-Razek S. Engine performance parameters and emissions reduction methods for spark ignition engines. Eng Res J 2008;120:M32–57.
[5] Boretti A. Comparison of fuel economies of high efficiency diesel and hydrogen engines powering a compact car with a flywheel based kinetic energy recovery systems. Int J Hydrogen Energy 2010;35(16):8417–24.
[6] Whiete CM, Steeper RR, Lutz A E. The hydrogen-fueled internal combustion engine: a technical review. Int J Hydrogen Energy 2006;31(10):1292–305.
[7] Fanhua Ma, Mingyue Wang. Performance and emission characteristics of a turbocharged spark-ignition hydrogen-enriched compressed natural gas engine under wide open. Int J Hydrogen Energy 2010;35:12502–9.
[8] Fanhua Ma, Mingyue Wang. Performance and emission characteristics of turbocharged CNG engine fueled by hydrogen-enriched compressed natural gas with high hydrogen ratio. Int J Hydrogen Energy 2010;35:6438–47.
[9] Fanhua Ma, Yefu Wang, Shangfen Ding, Long Jiang. Twenty percent hydrogen-enriched natural gas transient performance research. Int J Hydrogen Energy 2009;34:6523–31.
[10] Fanhua Ma, Shangfen Ding, Yefu Wang, Mingyue Wang, Long Jiang, Nashay Naeve, et al. Performance and emission characteristics of a spark-ignition (SI) hydrogen-enriched compressed natural gas (HCNG) engine under various operating conditions including idle conditions. Energy Fuel 2009;23:3113–8.
[11] Fanhua Ma, Haiquan Liu, Yu Wang, Yong Li, Junjun Wang, Shuli Zhao. Combustion and emission characteristics of a port-injection HCNG engine under various ignition timings. Int J Hydrogen Energy 2008;33(2):816–22.
[12] Fanhua Ma, Yu Wang, Haiquan Liu, Yong Li, Junjun Wang, Shangfen Ding. Effects of hydrogen addition on cycle-by-cycle variations in a lean burn natural gas spark-ignition engines. Int J Hydrogen Energy 2008;33(2):823–31.
[13] Fanhua Ma, Wang Yu, Haiquan Liu, Yong Li, Wang Junjun, Shuli Zhao. Experimental study on thermal efficiency and emission characteristics of a lean burn hydrogen enriched natural gas engine. Int J Hydrogen Energy 2007;32(18):5067–75.
[14] Fanhua Ma, Yu Wang. Study on the extension of lean operation limit through hydrogen enrichment in a natural gas spark-ignition engine. Int J Hydrogen Energy 2008;33(4):1416–24.
[15] Fanhua Ma, Junjun Wang, Yu Wang, Yefu Wang, Yong Li, Haiquan Liu, et al. Influence of different volume percent hydrogen/natural gas mixtures on idle performance of a CNG engine. Energy Fuel 2008;22(3):1880–7.
[16] Fanhua Ma, Yu Wang, Mingyue Wang, Haiquan Liu, Junjun Wang, Shangfen Ding, et al. Development and validation of a quasi-dimensional combustion model for SI engine fuelled by HCNG with variable hydrogen fractions. Int J Hydrogen Energy 2008;33(18):4863–75.
[17] Yilmaz AC, Uludamar E, Aydin K. Effect of hydroxy (HHO) gas addition on performance and exhaust emissions in compression ignition engines. Int J Hydrogen Energy 2010;35:11366–72.
[18] Brown Y. Brown's gas. United States Patent. US Patent 4014,777; March 28, 1978.
[19] Bacon FT. The high pressure hydrogen oxygen cell. J Ind Eng Chem 1960;52(4):301–3.
[20] Akikusa J, Adachi K, Hoshino K, Ishihara T, Takita Y. Development of a low temperature operation solid oxide fuel cell. J Electrochem Soc 2001;148:A1275–8.
[21] Appleby AJ. Fuel cell electrolytes: evolution properties and future prospects. J Power Sources 1994:15–34.
[22] Bacon FT. Fuel cells, past, present and future. Electrochim Acta 1969;14:569–85.
[23] Badwal SPS, Foger K, Zheng XG, Jaffrey DH. Fuel cell Interconnect device. United States patent WO 96/28855 A1; September 19, 1996.
[24] Bance P, Brandon NP, Girvan B, Holbeche P, O'Dea S, Steele BCH. Spinning out a fuel cell company from a UK university 2 years of progress at ceres power. J Power Sources 2004;131(1-2):86–90.
[25] Baozhen Li, Ruka JR, Singhal CS. Solid oxide fuel cell operable over wide temperature range. United States patent. US patent 6207,311. 03/27/2001.
[26] Barclay FJ. Fundamental thermodynamics of fuel cell, engine, and combined heat and power system efficiencies. P I Mech Eng A-J Powder 2002;216:407–17.
[27] Batawi E. High temperature fuel cell. United States Patent. 04/30/1996. US patent 5691075.
[28] Bockris JO'M, Srinivasan S. Fuel cells: their electrochemistry. New York: McGraw-Hill; 1969.
[29] Hoogers G. Fuel cell technology handbook. Birkenfeld, Germany: CRC Press; 2003.
[30] Haughton Honda, power equipment sales service and spares. Australia: The Association; c2001–2006. <http://www.haughton.com.au/product/engines/indpethor/HO0017.html>.
[31] Al-Rousan AA. Reduction of fuel consumption in gasoline engines by introducing HHO gas into intake manifold . Int J Hydrogen Energy 2010;35(23):12930–5.