Application of Hydrogen as Fuel Supplement in Internal Combustion Engines-A Brief Review

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Abstract— Faced with the ever increasing cost of conventional fossil fuels and the severe environmental pollution, researchers worldwide are working to cost effectively improve internal combustion engines fuel economy and emission characteristics. Recently, use of hydrogen or hydrogen-rich gas as fuel supplement for SI and CI engines is considered to be one of the potential solutions to these problems. Hydrogen has many excellent combustion properties that can be used for improving hydrocarbon combustion and emissions performance of both SI and CI engines. This article presents a brief review on the recent progress in the application of hydrogen as a fuel additive to improve the efficiencies and emissions of modern IC engines.

Key words: Hydrogen Enrichment, Brown's Gas, Spark Ignition, Compression Ignition, Performance, Emissions

I. INTRODUCTION

Hydrocarbon fuels provide the primary source of energy used in the world. These fuels are used for applications such as electrical power generation, heating and transportation. Although hydrocarbon fuels provide energy for our world they have several very serious side effects. These negative side effects include harmful polluting emissions, increased level of greenhouse gases and catastrophic disasters such as large scale oil spills. Due to the widespread dependence on hydrocarbon fuels and the difficulty of their replacement, it is not economically feasible to completely eliminate their use in the near future. Hence, methods are needed to significantly reduce the harmful emissions and consumption of hydrocarbon fuels. With the depletion of fossil fuel and the adverse effect it has on the environment, researchers worldwide are working overtime to cost effectively improve internal combustion engine (ICE) fuel economy and emission characteristics. It is in this context that many are looking into hydrogen technologies as part of a sustainable energy solution.

Hydrogen is the lightest chemical element with the symbol H and having molecular formula H2. Among all fuels, hydrogen is a long term renewable, recyclable and non-polluting fuel. It is carbon-free and the combustion of hydrogen gas produce water only. It is the most abundant resource in the universe. However the biggest problems in the use of hydrogen as a fuel are (i) the high cost of hydrogen gas processing from production to compression and (ii) the danger involved in carrying compressed hydrogen gas and (iii) increase emission of nitrogen oxides (NOx).

One recent approach in tackling the above mentioned problems is the use of hydrogen as fuel supplement in fossil fuel combustion systems. Hydrogen holds significant promise as a supplemental fuel to improve the performance and emissions of spark ignition (SI) and compression ignition (CI) engines. Example of SI and CI engines are gasoline and diesel engines respectively.

Hydrogen fuel enhancement is the process of using a mixture of hydrogen and conventional hydrocarbon fuel in an internal combustion engine, typically in a car or truck, in an attempt to improve fuel economy, power output, or both. This kind of hydrogen energy application is more feasible at our present stage than trying to use hydrogen as total replacement for fossil fuel due to the high cost of hydrogen production and safety measures. Therefore the present article is intended to give a brief review on the recent application of hydrogen as fuel supplement in modern ICEs.

II. HYDROGEN PRODUCTION AND APPLICATION

The setup for introducing hydrogen into the engine involves a hydrogen source or tanks on-board. Currently, there are three main options for on-board production of hydrogen for fuel enrichment- (i) water electrolysis [1] (i) carrying compressed hydrogen gas on the vehicle as a second fuel [2] (iii) or reforming conventional fuel into hydrogen with a catalyst [3]. Among these, electrolysis of water isconsidered to be the simplest and a convenient method for on-board generation of hydrogen. By the process of electrolysis hydrogen can be generated on demand basis avoiding the potential danger of storing the gas. The most common type of electrolyzer design used in this application has multi-electrodes structure and, the gas output is the 2:1 stoichiometric mixture of H2 and O2 commonly known as Brown's gas or oxy-hydrogen (HHO) gas. This system can be used for both SI and CI internal combustion engines.

Generally hydrogen or Brown's gas is applied to the engine by direct injection to the air intake manifold [1,4]. This method does not require any major modification to the engine hardware and software. However, to obtain best results additional electronic control systems are required to be integrated with the engine that will vary hydrogen percentage depending on fuel air equivalence ratio, engine speed and load [4]. An important point to note in on-board water electrolysis is that part of the vehicle alternator electrical output will be used to run the electrolyzer unit. Therefore, the feasibility of generating hydrogen gas on-board by water electrolysis has to carefully examine first, to avoid overloading of the engine electrical source. A few options are there to make room for water electrolysis in terms of energy demand: (a) alternator update (b) use of LED in Head light system or (c) increasing water electrolysis efficiency. As far as the water electrolysis is concerned our recent study had shown that an 11 plate HHO dry cell under direct DC electrolysis has the efficiency of about 60% and consumed about 131 Watt of electrical energy to continuously produced about 1 LPM of HHO gas [5]. According to other studies further improvement in effeciency can be achieved using circular cell structure, pulse width modulator (PWM) or ultra-short pulse power supply instead of direct DC [6,7].

III. EFFECTS OF HYDROGEN GAS ON ENGINE PERFORMANCES

A number of research reports have now appeared studying the effects of hydrogen or Brown gas as fuel supplement in hydrocarbon combustion engines. The parameters used to define the engine performances are mainly engine torque, specific fuel consumption, brake thermal efficiency and exhaust emissions. These studies show that presence of only small quantity hydrogen or Brown gas can have significant improvement in the performances and emission characteristics of both spark ignition (SI) and compression ignition (CI) engines. However the amount of improvements achieved varies widely depending on the type of engine, fuel and method of engine optimization. Reduction in fuel consumption from 20% to 40% had been obtained in gasoline SI engines [1,8] while for diesel operated engines the improvement in fuel consumption is around 13% after hydrogen enrichment [4,9]. Apart from this, increase in brake thermal efficiency and engine torque are observed [4,10].

Significant improvements in engine emissions are also noticed as a result of hydrogen addition in both types of engines. In general, the emission of air pollutants decrease by 5-9.5% for HCs, 7-20% for CO and 19.3% for particulate matter [4,10]. However for NOx, while a reduction by 50% on the average has been reported by Musmar and Al-Rousan [8], other studies showed increased emission level of the gases [2,9]. This is due to the dependence of NOx formation on different factors such as engine compression ratio, hydrogen enrichment level and engine load. In general, NOx emission is found to increase with higher engine compression ratio, high concentration of hydrogen and high engine load [2,9].

The ability of hydrogen blended fuels to burn more cleanly and efficiently is owed to its unique combustion characteristics such as high flame speed, the high diffusivity, low ignition energy and wide flammability limits [4]. The properties of hydrogen in comparison to hydrocarbon fuels are given in Table I [10]. When hydrogen is used as additional fuel, the high diffusivity of hydrogen makes the combustible mixture better premixed with air and more uniform [4]. On ignition by spark plug or compression, its flame front flashes through the engine cylinder at a much higher velocity than in ordinary fuel/air combustion. Because of its very high combustion velocity, hydrogen detonates all the fuel virtually at once. This applies more pressure on the piston in a shorter time interval and most importantly, burns and extracts power from the fuel that previously would have been thrown away through the exhaust. Therefore, hydrogen increases combustion efficiency by forcing the engine to burn hydrocarbon fuel more completely and efficiently. Moreover the wide flammability range of hydrogen allows ultra-lean combustion which dramatically reduces specific fuel consumption [2]. However, in this application, hydrogen contributes an insignificant amount of direct kinetic energy toward moving the engine's pistons. In other words, HHO delivers its primary benefit by modifying the car's fuel, not by acting as the car's fuel.

Hydrogen gas is also found to have similar beneficial effects in the combustion of other fuels. Senthil et al reported an increase in the brake thermal efficiency from 27.3% to a maximum of 29.3% in a compression ignition engine primarily powered by a vegetable oil, namely Jatropha oil [11]. They also noticed significant smoke reduction by 20% and a reduction in UBHC and CO emissions from 130 to 100 ppm and 0.26-0.17% (by volume), respectively, at maximum power output .

Tunestal et al. [12] experimentally proved that addition of hydrogen to natural gas increase the efficiency of the combustion engine as well as.

Properties	Hydrogen	Unleaded gasoline	Diesel
Autoignition Temperature (K)	858	533-733	530
Minimum ignition energy (mJ)	0.02	0.24	-
Flammability limits (volume % in air)	4-75	1.4-7.6	0.7-5
Stoichiometric air fuel ratio (by mass)	34.3	14.6	14.5
Net heating value (MJ/Kg)	119.93	43.9	42.5
Flame velocity (cm/s)	265-325	37-43	30
Diffusivity (cm2/s)	0.63	0.08	-
Octane number	130	92-98	30

Table 1: Properties Of Hydrogen

Lowered HCs emission [12]. The increase in efficiency is due to increase in burn rate and combustion efficiency. The increased in burn rate allowed retarded ignition timing which decreases heat loss, lower maximum temperature and thus, lower Nitrogen oxides (NOx) emissions.

IV. CONCLUSION

Hydrogen or hydrogen rich gas is a potential fuel supplement in both SI and CI engines to enhance engine performance and improve emission characteristics. Generation of hydrogen in a form called Brown's gas by electrolysis of water on-board vehicle appears to be a convenient and low cost method. The high burning velocity, wide flammability range, high diffusivity and low ignition energy are the main characteristics that make hydrogen a potential additive for different type of hydrocarbon fuels.

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