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Review Paper

A Review on the Application of Hydrogen Rich Gas as Fuel Supplement in CI and SI Internal Combustion Engine

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Abstract

With the rapid increase in consumption of fossil fuels and its high contribution to environmental pollution, researchers all over the world works to improve internal combustion enginesemission characteristics and reduce the consumption of fuel. The application of hydrogen or hydrogen-rich gas as fuel supplement for SI and CI engines is considered to be one of the most desirable methods 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.

Keywords: Hydrogen enrichment, Brown's gas, spark ignition, compression ignition, performance, emissions.

Introduction

Hydrogen is the lightest chemical element with the symbol H and having molecular formula H_2. Hydrogen is a renewable, carbon free and non-polluting fuel, producing only water during combustion. It is the most abundant resource in the universe. The ability of hydrogen blended fuels to burn more effectively is due to its special combustion factors such as low ignition, the high diffusivity, energy high flame speed and wide flammability limits[1]. The properties of hydrogen in comparison to hydrocarbon fuels are given in Table-1[2]. When hydrogen is used as additional fuel, because of its high diffusivity it easily combines with both the fuel and air, forming a highly uniform combustible mixture[1]. On ignition by spark plug or compression, combustion occurs inside the engine cylinder at a much higher velocity than in ordinary fuel/air combustion. The high combustion velocity enables the fuel mixture to burns more efficiently. The combustion of the hydrogen fuel mixture provides more force to the piston by enabling the fuel mixture to burn completely from inside out and at the same time reduces the release of unburnt hydrocarbons in the atmosphere. 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[3].

Ricardo (1920) and Burstall (1925) experimented on the use of hydrogen as fuel supplement and both reported increased in thermal efficiencies of more than 40%. They reported the problem of firing back or backflash, which of course limited the performance. About the same time, Rudolph Erren from Germany devised a method called "Errenizing" to overcome the problem of backflash. In Errenizing meant injecting slightly pressurized hydrogen into air or oxygen inside the combustion chamber rather than feeding the air fuel mixture via a carburetor into the engine that result in violent backfiring[4].

However the biggest problems in using hydrogen as a fuel supplement 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).

Methodology

The simplest and most conventional method for on-board generation of hydrogen is water electrolysis[5]. With this process, hydrogen can be generated on demand basis avoiding the potential danger of storing the gas. KOH and NaCl are often used as electrolytes. 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 H_2 and O_2 commonly known as Brown's gas or oxy-hydrogen (HHO) gas. The HHO gas produced from electrolysis is directly injected into the combustion engine. This system can be used for both SI and CI internal combustion engines.

Results and Discussion

The concept of using an electrolysis unit on-board a vehicle to improve combustion is almost 100 years old. The first ever known popular work on hydrogen as fuel was conducted by Reverend Cecil in 1820. His main idea was to develop an engine in which hydrogen gas when mixed with atmospheric pressure produce a large imperfect vacuum on explosion during ignition enough to provide a moving force. However, it was only after the production of Stuart electrolyzers at around 1920 that the method of injecting hydrogen into combustion engine becomes possible[4].

Many reports have shown that the electrodes material, the space between the electrodes, the type of electrolytes used contribute a significant role in increasing the electrolysis efficiency. Platinum (Pt) and gold, even though they highly increase the efficiency, are not suitable for both industrial and commercial purposes because of their high price. The most commonly used electrodes are aluminum, cobalt and nickel. These materials have high resistance to corrosion, high chemical stability and suitable cost and greatly increase the efficiency[6].

The efficiency is also influence by the nature of the reaction between the electrodes and the electrolytes. Pt reacts much better with KOH electrolyte than Molybdenum (Mo), while 1-butyl-3-methylimidazolium tetrafluoroborate (BMI.BF4) reacts better with Mo than Pt at temperature below ca.333K[7]. Kandah reported that higher production of HHO gas is seen with potassium hydroxide (KOH) electrolyte when compared with sodium carbonate[8].

When the electrodes are place close to each other at low current density, the electrical resistance and the formation of bubbles called void fraction decreases, thereby increasing the efficiency. However at higher current density, the void fraction increases which caused the efficiency of electrolysis to decreases[9,10]. Moreover, since bubbles formation occurs in upper parts of electrodes, greater height of electrode causes more power dissipation in a cell[7]. The formation of bubbles also increases when using a separator in a cell causing the electrical resistance to increase three to five times when used without a seperator[10,11].

Hydroxy gas has been widely reported to increase the performance of both petrol and diesel engine, at the same time reduce the emissions of unburnt hydrocarbons. 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. The application of hydrogen energy in the form of Brown's gas or Hydroxy gas has been report to improve the combustion speed, lean burn ability and flame quenching distance of hydrocarbon combustion in the cylinder[3,12].

Hydrogen blended fuel have been reported to decrease fuel consumption. Reduction in fuel consumption from 20% to 40% had been obtained in gasoline SI engines[5,13,] while for diesel operated engines the improvement in fuel consumption is around 13% after hydrogen enrichment[2,14,15]. With increase in H_2/O_2, the air –fuel ratio increases as more air is being continuously displaced by H_2/O_2[14,16]. Increase in brake thermal efficiency was also reported which varied depending on the type of engine, electrolytes used and other conditions[16,17,18,19]. The heat release rate is higher with hydrogen rich gas fuel as compared to neat fuel, due to higher combustion rate of hydrogen, resulting in higher release of energy thereby increasing the efficiency of engine[18].

Significant improvements in engine emissions are also noticed as a result of hydrogen addition in both types of engines. Many reports shows that experiments done so far on hydrogen rich fuel results in decreased in CO and HC emissions. The decrease in CO emission is about 7%-20% percent. This high reduction rate can be attributed to the absence of carbon in HHO gas[1,14,18]. The reduction in HC emissions is found to be 5-9.5% and 19.3% for particulate matter[9,12,18]. However for NOx, while a reduction by 50% on the average has been reported by Musmar and Al-Rousan[13], other studies showed increased emission level of the gases. 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[3, 20,21].

Table-1
Properties of Hydrogen

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

Conclusion

Hydrogen is applicable to be used as fuel supplement in both SI and CI engines to enhance engine performance. 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. Optimum spacing between the electrodes increase the efficiency of electrolysis. 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. Brown's Gas reduce the emissions of CO and HC gases, however, emissions of NO_x needs further investigation.

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