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Performance analysis of hydrogen oxygen mixture with gasoline fuel in 4-stroke single cylinder SI engine - Review study

Sandipkumar K. Patel[1], Prof. Arvind S. Sorathiya[2], Prof. Manish K. Mistry[3]

[1]I.C. Engine and Automobile Engineering, Government Engineering College-Bhuj
[2] I.C. Engine and Automobile Engineeringe, Government Engineering College-Bhuj
[3] Mechanical Engineering, Shree Swami Atmanand Saraswati Institute of Technology-Surat

Abstract

Review is made for the positive features and the current limitations associated with the use of hydrogen as a SI engine fuel. Literature shows that hydrogen has excellent prospects to achieve very satisfactory performance in engine applications that may be superior in many aspects to those with conventional fuels. Using hydrogen as supplementary fuel along with petrol increases fuel economy and emission performance except NOx emission. Change in design and operational parameter is needed to affect the full potential of hydrogen as an engine fuel. The only limiting factor to hydrogen widespread use as an S.I. engine fuel is economical production of it.

Keywords- *HHO, hydroxygen, hydrogen oxygen enrichment, performance, SI engine*

I. INTRODUCTION

All Hydrogen has long been recognized as a fuel having some unique and highly desirable properties, for application as a fuel in engines. The main feature of hydrogen as a fuel is that it does not occur in its free state naturally. The gas must be manufactured from a wide variety of possible sources while requiring much energy and capital resources.[1]

Hydrogen can be produced by reforming, partial oxidation, water electrolysis and other advance techniques. Hydrogen can be stored by compressing hydrogen gas in the cylinders, liquefying hydrogen in a cryogenic vessel or tank, using metal hydrides and slush hydrogen storage. While on board production of hydrogen eliminates storage requirement but continues and in sufficient quantity production is limitation for this approach.

Many researches have been done on hydrogen as alone and also as supplementary fuel with gasoline. Results show improvement in break power, thermal efficiency and specific fuel consumption. Improvement in CO, CO2 and HC (hydrocarbon) are conformed while NOx emission marginally increases due to increment in temperature and pressure inside cylinder while using hydrogen as fuel. Also with small changes design and operational parameter benefit of usage of hydrogen fuel can be increase.

Some of the key overall properties of hydrogen that are relevant to its employment as an engine fuel are listed in Table 1. These are compared to the corresponding values of Methane and gasoline. [1]

Table 2 lists some combustion properties that have much influence on potential behavior of hydrogen as a fuel. The corresponding values for methane and commercial gasoline are also shown for comparison. [1]

II. HHO KIT

Approximately 4% hydrogen produces from water electrolysis [11]. However water electrolysis remain a very minor contributor to the total production of Hydrogen because it uses electricity which considered as high grade energy and can be directly supplied to power production. However, recently and due to exploring expansion in renewable energy production which require in many cases energy storage methods , the interest in water electrolysis has increased[11]. Hydrogen can be produced in sufficiently high purity for fuel cell applications through the electrolysis of water with thermal efficiency ranging from 60% to 75% [1]. Electrolysis production has many advantages which are simplicity of the process, high purity of hydrogen and oxygen, environmental friendly and avaibility of water sources.

A. Hydrogen production and fuel system :

An alkaline water electrolyser generates hydrogen and oxygen as supplementary fuel. The main units of an electrolyser are: an anode, a cathode, and an electrolyte which transmits the ions between anode and cathode (electrodes). When the power is turned on, water decomposes into positively charged hydrogen ions and negatively charged oxygen ions. The positive hydrogen ions move to the negatively charged electrode (cathode) and form as hydrogen gas (H_2) and the negative oxygen ions move to the positively charged electrode (anode) and form as oxygen gas (O_2). The fundamental reactions at the electrodes of an alkaline electrolyser are as follows [5]:

Cathode Reaction : $4H_2O(l) + 4e^- \rightarrow 4H2(g) + 4OH^-(aq)$ (1)

Anode Reaction : $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$ (2)

Overall Reaction : $2H_2O(l) \rightarrow 4H_2(g) + O_2(g)$ (3)

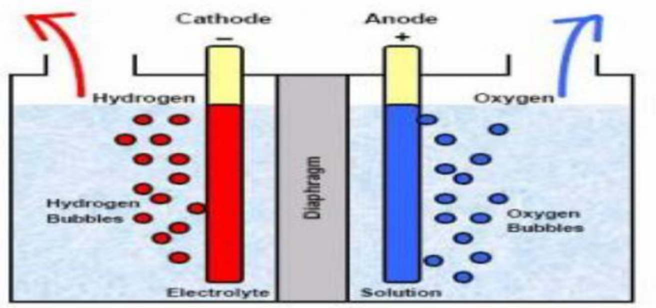

Figure 1 Water electrolysis principal [8]

Theoretical and experimental findings showed that electrode spacing between 2.5 mm was optimum when concentration of 8.5 by weight % of KOH and 3.5 V [5].

Table 1 Some comparative properties of hydrogen, methane and iso-octane

Property	*Hydrogen*	*Methane*	*Gasoline*
Density at 1 atm and 300 K (kg/m3)	*0.082*	*0.717*	*5.11*
Stoich. composition in air(% by volume)	*29.53*	*9.48*	*1.65*
Stoich. fuel/air mass ratio	*0.029*	*0.058*	*0.0664*
No. of moles after combustion to before	*0.85*	*1.00*	*1.058*
Heating values			
HHV (MJ/kg)	*141.7*	*52.68*	*48.29*
LHV (MJ/kg)	*119.7*	*46.72*	*44.79*
HHV (MJ/m3)	*12.10*	*37.71*	*233.29*
LHV (MJ/m3)	*10.22*	*33.95*	*216.38*
Combustion energy per kg of stoich mixt. (MJ)	*3.37*	*2.56*	*2.79*
Kinematic viscosity at 300 K (mm^2/s)	*110*	*17.2*	*1.18*
Thermal conductivity at 300 K (mW/m K)	*182.*	*0 34.0*	*11.2*
Diffusion coeffcient into air at NTP (cm^2/s)	*0.61*	*0.189*	*0.05*

Table 2 Some comparative combustion properties of hydrogen with methane and gasoline

Flammability limits (% by volume)	*4–75*	*5.3–15.0*	*1.2– 6.0*
Minimum ignition energy (mJ)	*0.02*	*0.28*	*0.25*
Laminar flame speed at NTP (m/s)	*1.90*	*0.38*	*0.37–0.43*
Adiabatic flame temp (K)	*2318*	*2190*	*~ 2470*
Auto ignition temperature (K)	*858*	*813*	*~ 500–750*
Quenching gap at NTP (mm)	*0.64*	*2.03*	*~ 2.0*

B. HHO measurement technique

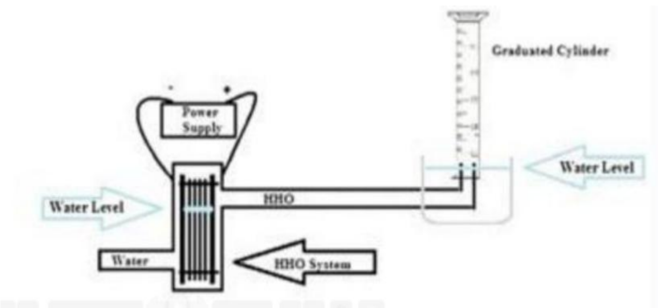

Figure 2 Measurement of HHO ($\dot{m}_{HHO}$) [11]

The gas produce from the generator can be collected in upside down, water filed graduated cylinder in water bath. The time to fill for particular volume of graduated cylinder is noted. Here to insure the gas collected is pure HHO gas no water steam, the gas should pass through cold water bath. The bubbler unit can be work as water bath and collect all water streams.

III. LITERATURE REVIEW

Ghazi A. Karim[1] made review about the positive features and the current limitations associated with the use of hydrogen as a spark ignition engine fuel. According to him Hydrogen can be produced in sufficiently high purity for fuel cell applications through the electrolysis of water with thermal efficiency ranging from 60% to 75%. He listed high flame propagation rates, lean operational limit mixture in a spark ignition engine, less undesirable exhaust emissions, fast burning characteristics, less cyclic variations, high effective octane number, excellent cold starting, less heat loss as positive features of hydrogen. He also noted that hydrogen has some limitation as a fuel : It reduces power output, due mainly to the very low heating value of hydrogen on volume basis, uncontrolled pre-ignition and backfiring, excessively high cylinder pressure, temperature and knock, need for higher safety, undesirable corrosion and lubricating oil contamination etc. He suggest some measures for improving the operational features of SI hydrogen engines as with wide-open throttle, variation in spark timing in controlling the combustion process, higher engine rotational speeds to increase the power output, higher compression ratios to increase the power output and efficiency, hotter water jacket temperatures than normally employed for gasoline operation for lean operation.

Maher A.R. Sadiq Al-Baghdadi[2] studied the effect of compression ratio, equivalence ratio and engine speed on the engine performance and emissions of a spark ignition engine operating on hydrogen fuel. He also used analytical model to verify the experimental data of the engine**.** According to result the high useful compression ratio (HUCR), which gives the highest power, occurred at the compression ratio (CR) of 11:1 and further increase in compression ratio, the engine power decreases due to unstable combustion. He show the optimum spark timing decreases as the compression ratio is increased. Experimental results show that the indicated thermal efficiency is improved as the compression ratio is increased, reaching maximum at compression ratios between 10:1 and 11:1. According to their result compression ratio and equivalence ratio have a significant effect on both performance and emission characteristics of the engine. He suggests higher engine rotational speeds at lean mixtures to increase the power output. He found NOx emission increased up to 0.8 equivalence ratio then reduce due to less avaibility of N_2.

Changwei Ji et al [3] studied performance of a hybrid hydrogen–gasoline engine under various operating conditions like cold starting, idle and part load. They converted gasoline engine into a hybrid hydrogen–gasoline engine (HHGE) by adding a hydrogen injection system and a hybrid electronic control unit. HHGE fueled with the pure hydrogen at cold start, hydrogen–gasoline blends at idle and part loads and the pure gasoline at high loads. They found HC and CO emissions are reduced by 94.7% and 99.5% for the HHGE at cold start, compared with those from the original engine. Experimental results show HHGE gains higher thermal efficiency and lower cyclic variation than the original gasoline engine. HHGE expels fewer amounts of NOx emissions than the original gasoline engine only at cold start and idle conditions.

T. D'Andreaa et al [4] experimentaly investigate the addition of hydrogen to a gasoline-fuelled SI engine. They use a 20 HP, four-stroke, V-twin Briggs & Stratton SI engine for experiment. Hydrogen was supplied to the engine with air by using compressed gas cylinders that contained 98% air and 2% H2. They tested supplement of 0%, 1% and 2% hydrogen fraction as percentage of fuel as volume. Results show increment in torque by 1Nm when equivalence ratio lowers than 0.85 and 5Nm when equivalence ratio greater than 0.85. They found the period necessary to burn 2–10% of the mass, was decreased with the addition of hydrogen. With hydrogen addition the cyclic variability apparently decreased at lower equivalence ratio also NO_x emissions increased.

Y. Karagoz et al [5] designed and manufactured a practical alkaline water electrolyser to produce hydrogen from water and used in ICE as a supplementary fuel. 0 and 20 l/min hydrogen and oxygen mixture as supplementary fuel was introduced into intake manifold of engine. According to their test results, 2mm gap between plates, 28 weight% KOH solution and 3.5 V voltage were the best conditions in terms of energy efficiency (76.7% energy efficiency).In result it is found that the engine brake power value increased by 3.2% to 5% with hydrogen addition at all engine speeds compared to only gasoline fuel operating condition and bsfc value decreased by 3.2% to 9.4% with H2/O2 addition at all engine operating gaps. They found that Total Hydrocarbon emissions improved by 9.2% to 24.7% with H_2-O_2 addition at all engine cycles and CO emissions decreased by 3.5% to 16.4% with H_2-O_2 addition at all engine speeds. where NO_x emission increased by 36.2% to 15.4% based on engine speed..

Shuofeng Wang et al [6] investigated the effect of hydrogen oxygen blends (hydroxygen) addition on the performance of a gasoline engine at different hydrogen volume fractions in the hydroxygen. They use hybrid electronic control unit to control the spark timing and the injection timings and durations of hydrogen, oxygen and gasoline. The overall volume fraction of the hydroxygen in the total intake gas was fixed at 3% and the hydrogen volume fraction in the hydroxygen was raised from 0% to 100% by changing the injection durations of hydrogen and oxygen. Their results shows that thermal efficiency is increased after adding 3% hydroxygen in the total intake gas for nearly all hydrogen volume fractions in the hydroxygen. The maximum cylinder temperature and the cylinder temperature at exhaust valve opening are decreased with the increase of hydrogen volume fraction in the hydroxygen due to the decreased fuel energy flow rate. They found HC, CO and NOx emissions were decreased with the increase of hydrogen volume fraction in the hydroxygen but NOx emissions of the hydroxygen-blended engine were higher than those of the original engine for all hydrogen volume fractions in the hydroxygen.

Jianbiao Zhao et al [7] done experimental study on the effects of compression ratio (i.e. 10:1, 12:1) on the combustion and emission of a hydrogen enriched natural gas engine under different excess air ratio. To get different compression ratio they use different piston. They conclude from results that increase in the compression ratio can reduce the flame development period and, the lean limit drops from 2.34 to 2.23 correspondingly as the compression ratio increases from 10 to 12. Results show that when the excess air ratio is beyond the certain value, the advantage of increasing compression ratio is lost totally. They found that emissions are not improved with the increase of the compression ratio. Oppositely, both THC emission and NOx emission rise at different degree. They conclude from experiment that increasing the compression ratio can improve the engine's fuel consumption and power performance within the normal operation range (excess air ratio less than 1.8) instead of the extremely lean operation.

Pranay N. Patel et al [8] experimentally investigate Hydrogen Port Fuel as a part of supplement in 4-Stroke SI Engine. For production of hydrogen they use HHO cell and hydrogen and oxygen along with air supplied to intake manifold. Experimental results shows 9.2-14 % increment in break power, 10-25% increment in specific fuel consumption and 5-20 % increment in break thermal efficiency. They found upto 80% reduction in CO emissioin, up to 50% reduction in CO_2 and up to 80 % reduction in HC.

Yasin Karagoz et al [9] investigated the effect of hydrogen addition in various hydrogen energy fractions such as 0%, 5%, 8%, 10% and 15% on coefficient of variation in the engine speed, coefficient of variation in the indicated mean effective pressure, peak in-cylinder temperature, energy flow rate, indicated thermal efficiency, indicated specific fuel consumption, THC, CO, and NOx emissions. Results show that coefficient of variation in the engine speed and the indicated mean effective pressure increased up to 32.1% and 25.6% respectively. They found energy flow rate value reduced between 5.1% and 9.8% with hydrogen addition and improvement on indicated specific fuel consumption between 5.1% and 9.8% with the hydrogen addition. Also, the indicated thermal efficiency value increased between 5.4% and 10.9%. They found CO and THC emission reduce while there is dramatic increase in NOx emissions.

Shuofeng Wang et al [10] focused on performance of a hydrogen-blended gasoline engine at lean and the wide open throttle conditions. They run engine at 1400 rpm and two hydrogen blending levels of 0% and 3% and the excess air ratio was raised from 1.00 to about 1.45 for a given hydrogen addition fraction. Results showed that Break mean effective pressure of the engine blended with 0% and 3% hydrogen are reduced with the enhancement of excess ratio due to the dropped fuel energy supplement but with hydrogen blending decrement was slower due to high flamibility range of hydrogen. They found Break Thermal Efficiency was increased after the hydrogen blending, because the quick combustion of the fuel–air mixtures is achieved due to the enhanced flame speed with hydrogen blending. Combustion analysis of their results concludes that the gasoline–air mixtures with hydrogen blending are much easier to be ignited. They found that because of the enhanced combustion, the hydrogen blending contributed to the reduced HC, CO and particulate emissions from the gasoline engine. However, NOx emissions were increased after the hydrogen addition due to the raised cylinder temperature.

IV. CONCLUSION

All the literates' shows common facts and that can be listed in general as follows:

1. Hydrogen as alone or with supplement with petrol improves break power, specific fuel consumption, thermal efficiency.
2. Hydrogen can be produce in sufficient quantity by water electrolysis with efficiency up to 76.7%.
3. Compression ratio and equivalence ratio have a significant effect on both performance and emission characteristics of the engine when hydrogen as fuel.
4. Due to high octane number of hydrogen increase in Compression Ratio improve power output but CR can be increase up to optimum level after that increase in CR reduce power output.
5. Hydrogen blending with gasoline increases lean burn limit of hybrid engine.

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