Evaluation of Emission Characteristics of Hydrogen as a Boosting Fuel in a Four Stroke Single Cylinder Gasoline Engine

Mr. Satheeshkumar. C
Dept. of Mechanical Engineering
LBS College of Engineering
Kasaragod, India

Dr. Mohammed Shekoor. T
Dept. of Mechanical Engineering
LBS College of Engineering
Kasaragod, India

***Abstract*— It is well known that hydrogen addition to spark-ignited (SI) engines can reduce exhaust emissions and increase efficiency. Based on the spark ignition experiments, the main conclusion is that hydrogen added to gasoline, influences the flame propagation speed. At constant excess air ratio, the flame speed of hydrogen/ gasoline/air mixtures are greater than the gasoline/air mixtures. With hydrogen supplement to gasoline, spark ignited(SI) engines can run very lean resulting in a large reduction in nitrogen oxides (NOx) emissions relative to stoichiometric combustion without hydrogen.. It was observed that the heat release rate increases when hydrogen mixes in gasoline. By adding hydrogen, the combustion increases which is not only by the flame propagation speed of the hydrogen mixture but also the auto ignition of the charge at different locations simultaneously. Certain remedies to overcome the backfire phenomena are attempted in this experiment. This paper presents results of experiments for a single cylinder four stroke variable speed hydrogen boosted internal combustion engine. In general, very good agreement between predictions and experimental results was obtained in the entire experimental range.**

Keywords*— *Emission, Hydrogen, Spark ignition, Hydrocarbon, Carbon monoxide, NOx, Carbon dioxide

I. INTRODUCTION

The world is presently confronted with the twin crisis of fossil fuel depletion and environmental degradation. Indiscriminate extraction and lavish consumption of fossil fuels have led to reduction in underground based carbon resources. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, management, efficiency, and environmental preservation, has become highly pronounced in the present context. The power used in the agricultural and transportation sector is essentially based on hydrocarbon fuels and it is, therefore, essential that alternatives to fossil fuels be developed. Hydrogen is an obvious alternative to hydrocarbon fuels such as gasoline. It has many potential uses, is safe to manufacture, and is environment friendly. Today many technologies can use hydrogen to power cars, trucks, electric plants, and buildings – yet the absence of an infrastructure for producing, transporting, and storing large quantities of hydrogen prevents its practical use.

The two principal combustible elements common in coal and petroleum are carbon and hydrogen, of the two, hydrogen being more efficient. The value of a fuel depends mainly in its calorific value. Pure carbon has less calorific value while hydrogen has a high calorific value which is showed in the table 1. The higher the proportion hydrogen in a fuel, the more energy it will provide. The hydrogen content of liquid and gaseous fuels ranges from 10 to 50% by weight. They provide far more heat than solid fuels, which ranges from 5% to 12% by weight. Hydrogen is carbon free fuel; hence on burning produce only water. It is non-toxic, non-odorant and also results in complete combustion

$$2H_2 + O_2 \rightarrow 2H_2O$$

Due to these beneficial characteristics of hydrogen, now a day, lot of research are progressing in this area of alternative fuels; especially with hydrogen usage in internal combustion engine and also in the development of fuel cell powered vehicles.

TABLE I Comparison of calorific value of carbon and hydrogen

Fuel	Symbol	BTU/lb	HHV MJ/Kg
Carbon	C	14,100	32.8
Hydrogen	H_2	61,000	141.80

Hydrogen is a high quality carrier which can be used with a high efficiency and zero emissions at the point of use. It has technically demonstrated that hydrogen can be used for transportation, heating, and power generation, Hydrogen has very low density both as gas and as liquid. Hydrogen is also a potential fuel for internal combustion engines. Hydrogen is an attractive alternative fuel due to the fact that it can be produced from fossil fuels. Alternative fuels are available in the form of solid, liquid, and gas. Although these fuels are used, they generate considerable pollutants from the internal combustion engines. Hydrogen is largely available and renewable in nature. Hydrogen is clean burning fuel among all other alternative fuels. Hydrogen has high auto ignition temperature and energy density. The higher auto ignition temperature of hydrogen limits its use as a sole fuel in diesel engines.

Hydrogen has wide flammability limits which make it to burn in an internal combustion engine over a wide range of air-fuel mixtures. Hydrogen can burn on lean mixture and it is possible to achieve greater fuel economy. Hydrogen also has higher flame speed and mass diffusivity compared to other gaseous fuels. Hydrogen mixed in the intake air in small quantities improves the thermal efficiency and reduce the smoke emissions of a petrol engine.

TABLE II Comparison of Hydrogen with Gasoline

Property	**Hydrogen**	**Petrol**
Formula	H_2	C5-H12
Density at 1 atm and 300 K(kg/m^3)	0.082	5.11
Lower Heating Value (MJ/kg)	119.7	44.79
Kinematic viscosity at 300 K(mm^2/s)	110	3.292
Thermal conductivity at 300 K (W/mK)	182.0	0.1768
Boiling point(K)	20.27	436-672
Octane number	-	40-55
Molecular weight(g/mole)	2.015	170
Combustion energy per kg of stoich. mixture (MJ)	3.37	2.79
Flammability limits (% by volume)	4-75	1.2-6.0
Laminar flame speed at NTP (m/s)	1.90	0.37-0.43
Max deflagration speed (m/sec)	3.5	0.3
Minimum ignition energy (MJ)	0.02	-
Adiabatic flame temperature (K)	2318	2200
Auto ignition temperature (K)	858	530

II. EXPERIMENTAL SETUP AND PROCEDURE

The engine used for the present investigation is a single cylinder, four strokes, air cooled, direct injection, variable speed Petrol engine. The schematic diagram of the experimental setup is shown in Figure and the engine specification is given in Table. Initially the engine was operated with gasoline and the performance, emission parameters were evaluated. Then the engine was allowed to run with a Hydrogen gas was introduced by induction technique through the intake manifold. The performance, combustion and emission parameters were measured and compared with that of gasoline baseline readings. The hydrogen gas was introduced in two different flow rates like 2lpm and 3lpm

Hydrogen fuel, at a constant flow rate of 2lpm and 3lpm were supplied through a flame arrester and flame trap and finally it was admitted into the intake pipe (at a distance of 10 cms from the intake manifold) where it mixed with air and this hydrogen-air mixture was inducted into the engine cylinder. Hydrogen fuel from a high pressure cylinder was inducted through an intake pipe. A double stage diffusion pressure regulator was employed over the high pressure cylinder. The regulator was used to control the outlet pressure. Then engine was allowed to run for two or three different loads and with hydrogen at two different flow rates 2lpm and 3lpm. The performance and combustion parameter is obtained by computer provided into data acquisition system. An exhaust gas analyzer is used to calculate the emission parameter.

Make	Honda
Model	GK200
Type of engine	4 stroke, Air Cooled, Single Cylinder, Horizontal Shaft Displacement 197 c.c.
Engine Net Power	2.6 kW at 3,600 rpm
Engine Max. Net Torque	7.9 Nm at 2,500 rpm
Bore	87.5
Stroke	110
Compression ratio	11.5
Injection timing	13deg before TDC

Fig.1. Photographic view of experimental setup

III. EXPERIMENTAL RESULTS

In the present work, hydrogen gas- air mixture is used in the spark ignition engine where petrol is used as a main fuel in the operation. The emission characteristics of gasoline with hydrogen enrichment of different flow rate compared with baseline petrol operation. Experiments are conducted to obtain variation in emission of NO, HC, CO2 and CO at rated speed at varying load is also identified. The variation of above mentioned parameters are identified at conditions without supply of hydrogen and with three various flow rate of hydrogen. The obtained variations are plotted.

A. Emission Parameters

The hydro carbon emission of gasoline engine with hydrogen is lower compared without hydrogen. Some HC emission is found because of carbon present in lubricating oil and also because of high cylinder temperature the carbon particles, present in lubricating oil and main fuel, gets oxidizes and converted into CO2.

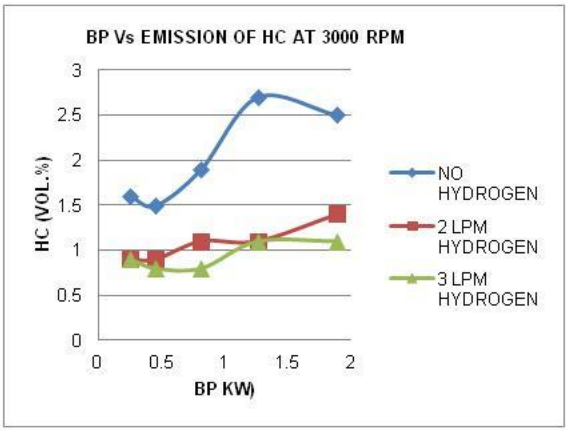

Fig.2. Variation of hydrocarbon emission with brake power

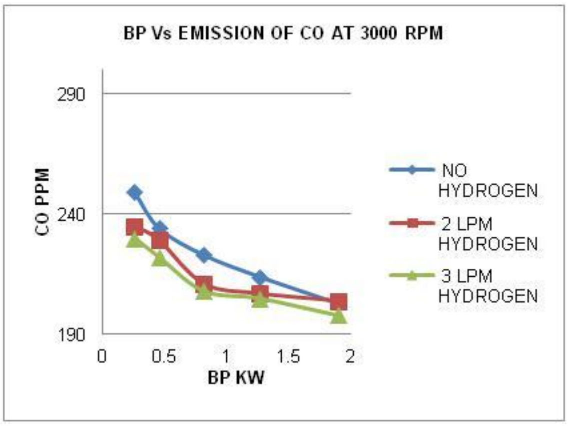

Fig.3. Variation of Carbon monoxide emission with brake power

Variation of the carbon monoxide with hydrogen enrichment decreased with increase in hydrogen addition. The reason for lower CO emission is due to absence of carbon atoms in the hydrogen structure.

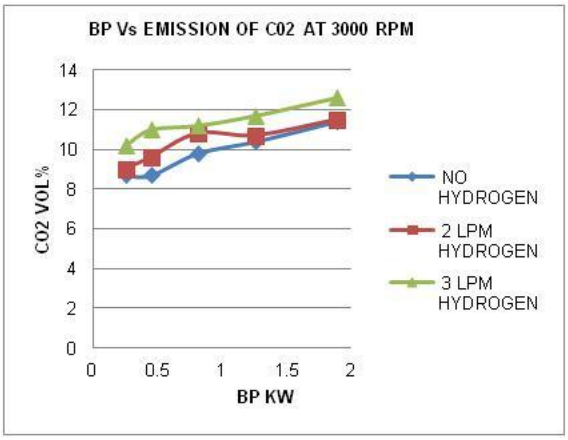

Fig.4. Variation of carbon dioxide emission with brake power

While using hydrogen, due to high temperature achieved during combustion, the CO get oxidized and converted into CO2. Therefore the carbon dioxide emission increases with increase in hydrogen flow rate because all CO gets oxidizes and converted into CO2 after utilizing the heat of hydrogen.

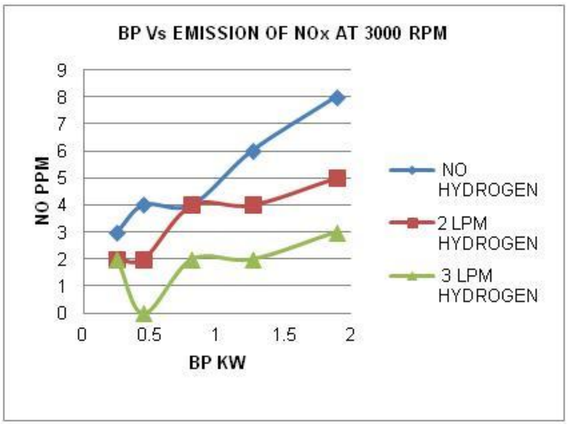

Fig.5. Variation of oxides of nitrogen emission with brake power

Significant decrease in NOx emission is observed with hydrogen operation. Almost 4 times decrease in NOx can be noted. Operating the engine with a lean mixture is kept NOx levels low. The combustion of hydrogen with oxygen produces water at its only product: The combustion of hydrogen with air however can also produce oxides of nitrogen. The oxides of nitrogen are created due to the high temperatures generated within the combustion chamber during combustion. This high temperature causes some of the nitrogen in the air to combine with the oxygen in the air.

The formation of oxides of nitrogen is due to the following reasons

- The peak combustion temperature.
- The oxygen concentration in the combustion chamber.
- The residence time of high temperature gas in the cylinder.

IV. CONCLUSION

From the results analysis, the following conclusions can be formulated:

NOx emission of hydrogen fuelled engine is about 2-4 times lower than gasoline fuelled engine. Emission of CO, HC and CO2 of hydrogen is very less so hydrogen is environment friendly. On medium term hydrogen application in use can be developed in order to replace the fossil fuels into engine combustion processes. This becomes an efficient solution for pollutant emissions level decrease and hydrocarbons fuels dependency reduction. Due to its properties hydrogen has proved to be an excellent fuel for internal combustion engines and signifies a reliable option to the fossil fuels replacement, providing also the benefit of maintaining the main principles of the existing engines design.

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