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Experimental investigation on the effect of hydrogen blending on performance and emssion of four stroke single cylinder spark ignition engine

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ABSTRACT

World is presently facing two major problems of energy crisis and environmental pollution. In order to conserve petroleum fuels for future and to eliminate the above limitations stated there is a need of an alternative and innovative fuel. Recently, using hydrogen, CNG, LPG, methane as additional sources fuels for spark ignition and compression ignition engines are the best solutions in improving performance characteristics and emissions of an internal combustion engines. Expert studies indicate hydrogen is one of the most promising energy carriers for the future due to its superior combustion qualities, eco-friendly nature and availability. This work investigates the effect of hydrogen gas blending on engine performance and emission characteristics. This work also provides a comprehensive overview of hydrogen as a fuel for Spark Ignition (SI) Internal Combustion engine. Hydrogen gas was manufactured by the process of electrolysis of distilled water and directly injected into the intake manifold without being stored. The experimental study was performed on 133 cc single cylinder four stroke spark ignition engine. The test was subdivided into two cases: gasoline and mixture of hydrogen + gasoline. On comparison it was viewed that the engine performance is improved and the gasoline fuel consumption was declined after enrichment of hydrogen gas. Moreover, the HC and CO emissions were all decreased considerably after the hydrogen enrichment taken place. The NO_x emission was increased with addition of hydrogen.

Keywords— **Emission Characteristics, Hydrogen, Internal Combustion Engine, Performance parameter, Spark Ignition Engine.**

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I. Introduction

The downfall of petroleum reserves such as oil, coal, natural gas, petrol, diesel and the escalation of the environmental pollution are now the major world concerns. Recently, India is facing the ever increasing cost of petroleum fuels. The transportation sector is mainly dependant on petroleum fuels. The denoting development of transport vehicles and the personal energy demands lead to conventional sources gradually exhausted and produce more emissions, which is very harmful for the human beings [1]. All petroleum fuels contain carbon atoms in addition to hydrogen atoms, carbon dioxide (CO_2) is a major harmful gas product formed during the conversion of petroleum fuel to thermal energy in an internal combustion engine. The main pollutants from the internal combustion engines are hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO_2), which are produced due to an unburned combustion of petroleum fuels [2]. It is very important to reduce exhaust emissions and to increase performance characteristics of an internal combustion engines. The higher thermal efficiency of petrol engines certainly has advantages for conserving conventional petroleum energy and solving in problems related to harmful emissions [3]. One of the possible ways to reduce engine emissions and to enhance the engine performance, especially of spark ignition engines is of use additives gaseous fuels like bio-gas, natural gas, hydrogen gas etc. [4]. Among all fuels, hydrogen fuel is used as additive fuel because it has certain advantages over hydrocarbon fuels; the most important thing is the absence of carbon atoms. Hydrogen has very high burning velocity, which increases rapid combustion and wide flammability range. Hydrogen is renewable and non-polluting in nature. Properties of hydrogen are summarized in the Table 1 [5]. Due to low injection energy and wide flammability range of hydrogen, hydrogen engines are quite suitable to run at lean conditions, which is helpful for the enhancement of engine performance and reduction of harmful exhaust emissions [6]. The self ignition temperature of hydrogen is 858K, so it is not intended to use directly IC engine with spark plug and thus hydrogen is used as additive in a petrol engine [7, 8].

Shivaprasad K V et al. [1] investigated the effect of hydrogen addition on a high speed gasoline engine performance at various engine speeds. They reported that, the thermal efficiency and emissions of engine were improved after hydrogen enrichment, except for that NO_x emission was increased.

Ali Khan Yilmaz et al. [2] found that the engine torque output, BSFC, CO and HC emissions of the hydrogen enriched compression engine were lower than the original diesel engine.

Tuan Le Anh et al. [3] used HHO gas for gasoline engine. When adding HHO gas into the intake manifold, the engine power increased nearby 2.35% to 2.78%. The HC and CO emissions were decreased after HHO gas enrichment. However NO_x emission was increased by adding HHO gas.

Ammar A Al-Rousan [4] designed fuel cell for HHO gas production, the generated HHO gas was introduced into the air stream just before entering the carburettor of a197cc engine. The test results showed enhancement in combustion efficiency and consequently reduction in fuel consumption.

Satheeshkumar C [5] evaluated the effect of hydrogen gas on combustion emissions of gasoline engine. The results explained that the NO_x emission of hydrogen fuelled engine is about 2-4 times lower than gasoline fuelled engine. Emission of CO, CO_2 and HC of hydrogen was very less.

Tyagi R K et al. [6] checked effect of hydrogen + gasoline blend on the performance of SI engine. They found that the output power, torque, brake mean effective pressure and thermal efficiency were increased considerably.

Jiwak G Suryawanshi et al. [7] noted reduction in the exhaust gases of SI engine after enrichment of hydrogen + CNG blends.

Eugen RUSU et al. [8] studied a SI engine fuelled with gasoline and hydrogen in addition. They found the stable engine operation at lean mixtures and noted higher engine output comparative to the gasoline engine. They also noted reduction in Bsfc, HC emission and CO emission over the gasoline engine.

Table 1 Properties of hydrogen compared with gasoline

Property	Hydrogen	Gasoline
Formula	H_2	C_5H_{12}
Calorific Value	141780	44500
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 mixture (MJ)	3.37	2.79
Flammability limit (% by volume)	4-75	1.2-6.0
Laminar flame speed at NTP (m/s)	1.90	0.37-0.43
Max deflection speed (m/s)	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

A. Experimental Setup

The engine used for the present experimental investigation was a single cylinder, four stroke, air cooled, direct injection, variable speed, spark ignition gasoline type. The figure 2.1 illustrates the schematic view of the experimental setup and figure 2.2 is the photographic view of actual experimental setup. The experimental setup involved in assembly of dynamometer, exhaust gas analyzer, gasoline tank and hydrogen generation kit on the top of the engine. The dynamometer is attached with the engine shaft for the measurement of engine torque. The exhaust gas analyzer is mounted at end of exhaust manifold for measuring the level of different exhaust gas emissions emerge out from the combustion. The rotameter is mounted next to hydrogen generation kit for fuel controlling and measuring purpose.

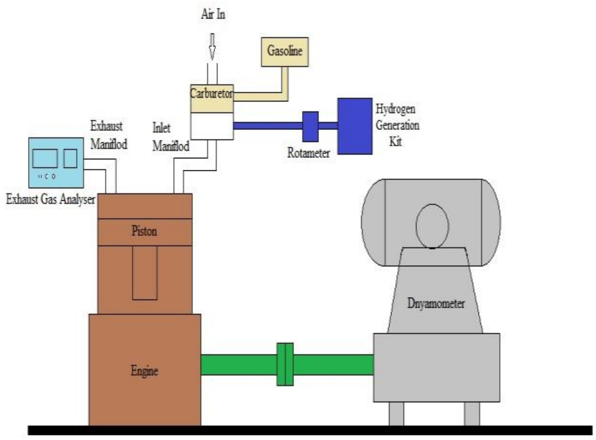

Fig 2.1 Schematic diagram of experimental setup

Fig. 2.2 Photographic view of engine setup

1. The hydrogen generation kit: Figure 2.3 illustrates the hydrogen generation kit which is used the experimental setup for hydrogen production. In the present work of investigation, the electrolysis process was used for hydrogen generation depends on various available resources. As the various elements required for hydrogen production are available in market. The hydrogen is generated by using electrolysis of distilled water. The KOH powder was added in to the water as a catalyst which enhances the rate of production of the hydrogen.

Fig. 2.3 Hydrogen production unit

1.1 Chemical reactions occurred inside hydrogen generation kit is expressed as follows:

$2Al + 2KOH + 6H_2O \rightarrow 2KAl(OH)_4 + 3H_2\uparrow$ (4)

$KAl(OH)_4 \rightarrow KOH + Al(OH)_3\downarrow$

1.2 Technical specifications of hydrogen production unit: The technical specifications are summarized in the table given below.

Table 2 Technical Specifications of hydrogen Production Unit

Maximum gas supply capacity	1 liter per minute
Electrodes (Anode and Cathode)	Stainless steel plates
Maximum electrolysis voltage and current	12V , 9A
Electrolysis voltage and current required	5.2 V, 4.2 A
Electrolyte (1-2 % by mass)	KOH (1m)
Reactor container volume	0.500 L
Water level control	Periodic check for every change of load
Water temperature	$25^{o}C$ to $45^{o}C$
Overall Dimensions	320 X 50 mm
Weight	350

2. Acrylic body rotameter: The acrylic body rotameter regulates the flow of hydrogen supplied to engine and the amount of hydrogen flow can be measured.

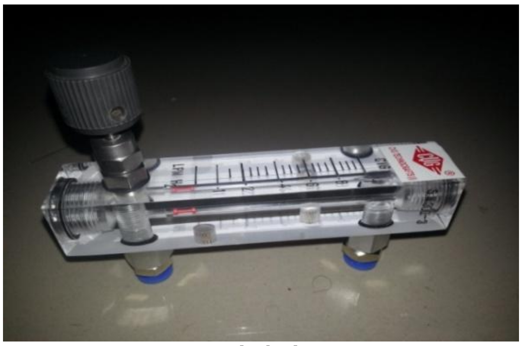

Fig. 2.4 Acrylic body rotameter

2.1 Technical specifications of rotameter: The technical specifications of rotameter are summarized in the table below.

Table 3 Technical specifications of rotameter

Make	CVG
Model	CVG-PB-V
Range	0.1-1 lpm
Service	H_2
End Connection	Bsp(M) at rear with valve
Float	PVC
Wetted Part	S.S.
Mounting	Panel
In & Out	Back/Back
Body	Acrylic
Packing	Neoprene
Scale	Engraved on body
Operating Pressure	Atmosphere
Operating Temperature	Ambient
Accuracy	+/- 2%Fsd

3. Engine: The engine used in the present work of investigation is a single cylinder, four strokes, air cooled, direct injection, variable speed gasoline engine.

Fig. 2.5 A single cylinder gasoline engine

3.1 Technical specifications of a single cylinder gasoline engine: Technical specification of Engine is given in the table below.

Table 4 Engine Specifications

Make	Hero Honda
Model	Ambition
Displacement	133.00 cc
Type	Single cylinder,4 stroke, Air cooled
Power	14.0 bhp @8000 rpm
Torque	10.5 Nm @4500 rpm
Speed	5 Speed

B. Experimental Procedure

The hydrogen gas was added to the engine without any modification done in to the present engine. The hydrogen gas was generated in the hydrogen generation kit by the process of electrolysis. The first test was conducted by introducing individual gasoline into the engine, the performance and emission parameters were recorded for this case. The second test was conducted by introducing mixture of gasoline + hydrogen gas mixture into the engine, the performance and emission parameters were recorded for this condition attempt made again. The data was recorded for both the tests and compared. The current experimental investigation is aimed at analyzing the effect of hydrogen enriched SI engine on the performance and emission characteristics of the engine.

III. RESULTS AND DISCUSSIONS

A. Performance characteristics

The test is performed on the test SI gasoline test engine before and after introducing the hydrogen gas. The calculations have been performed according to the standard equations that can be referred from any standard textbooks published on engine study.

1. Brake Thermal Efficiency: The fig. 3.1 shows the variations of brake thermal efficiency with different engine speed with hydrogen addition made in for. From the graph it can be concluded that, the brake thermal efficiency of the engine increases with gasoline + hydrogen mixture in the comparison of pure gasoline engine operation. This is because; hydrogen has wide flammable range, high flame speed and higher flame temperature over the gasoline, which helps to accelerate the combustion of gasoline + hydrogen + air mixtures. Another reason behind is shorter burning time and a more complete combustion.

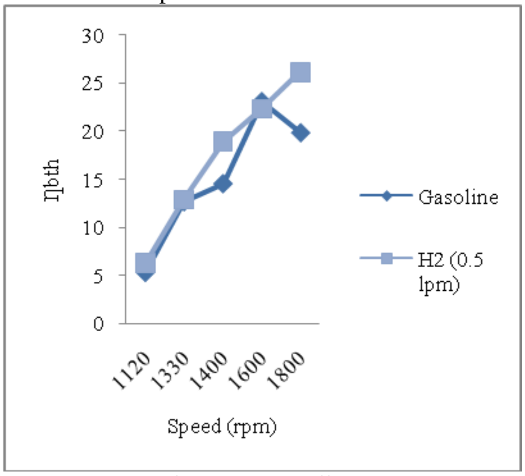

Fig. 3.1 Variation of brake thermal efficiency with the speed

2. Brake Specific fuel consumption (Bsfc): The fig. 3.2 shows the variations of Bsfc with different engine speed. From the graph it can be viewed that, the Bsfc decreases as the gasoline + hydrogen + air mixtures compared with the pure gasoline engine operation. The reduction in Bsfc is due to high diffusivity of hydrogen as well as high oxygen index of hydrogen gas which helps gasoline during combustion process and produces better combustion. Since hydrogen gas is having a high flame speed and wide flammability, the addition of hydrogen gas would assist the gasoline fuel to be burned faster and more complete at high speed condition. An average gain of 14% is achieved on Bsfc by addition of hydrogen gas with the gasoline fuel.

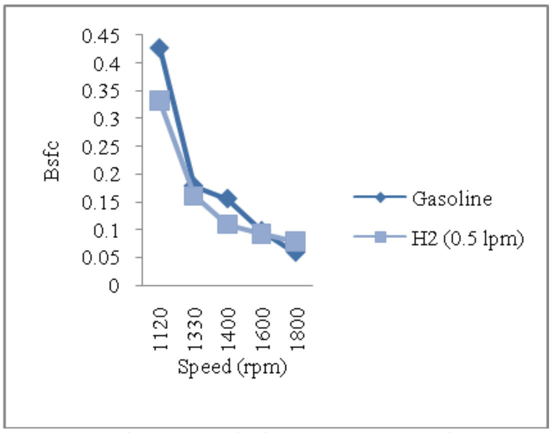

Fig. 3.2 Variation of brake specific fuel consumption (Bsfc) with the speed

3. Brake Power (BP): The Fig.3.3 shows the variation of brake power with engine speed. From the graph it can be concluded that, the brake power increases as the engine speed increases and this is because of

oxygen concentration of hydrogen gas and better mixing of hydrogen with air. The high speed of hydrogen decreases ignition delay and combustion period that provides lower heat losses from the engine. The high burning velocity of hydrogen gas provides faster rise in pressure and temperature.

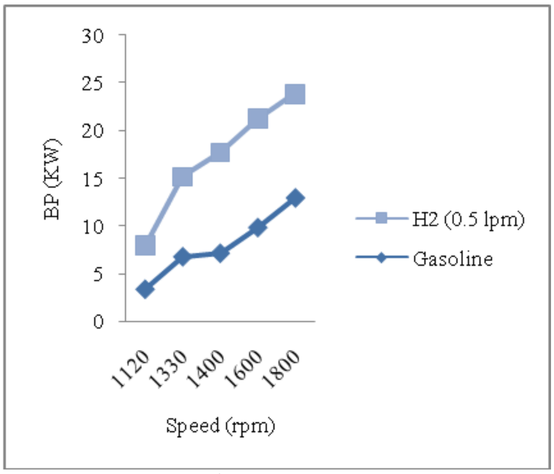

Fig. 3.3 Variation of brake Power (BP) with the speed

B. Emission Parameters

At the end of exhaust manifold of the engine exhaust gas analyzer is attached to measure engine exhaust parameters.

1. Carbon Monoxide (CO) Emission: The effect of hydrogen blends on CO emission at various engine speeds are shown in the fig. From the figure it can be concluded that CO emission decreases as the hydrogen added with gasoline. This is because the enhanced combustion caused by hydrogen addition and sufficient oxygen available for the post oxidation of CO emission. This due to the properly increased hydrogen enrichment helps to increase the formation of O and OH radicals which extend the complete combustion. The fast combustion produces shorter post combustion period than gasoline, so that the time and temperature for CO oxidation reaction decreases causing slow reaction of CO into CO_2. The CO emission decreases due to wide range flammability of hydrogen.

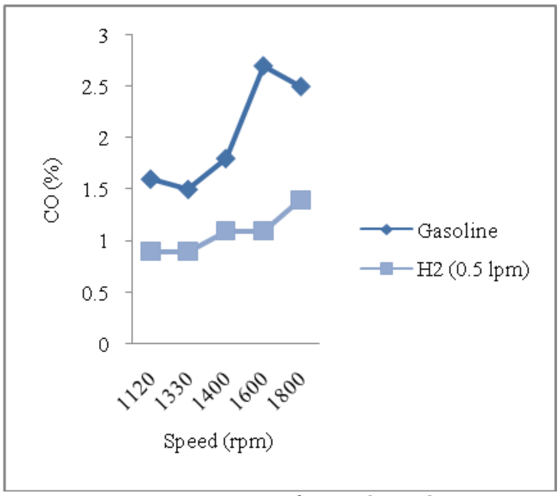

Fig. 3.4 Variation of HC with speed

2. Hydrocarbons (HC) Emission: The fig. 3.5 shows the variation of HC emissions with engine speeds with hydrogen blending. The hydrogen blending increases the formation of OH radicals, so that gasoline-hydrogen mixture can be more fully burnt and emits less HC emissions than gasoline. The another reason for the less HC emission is less quenching distance which facilities complete combustion of gasoline-hydrogen mixture.

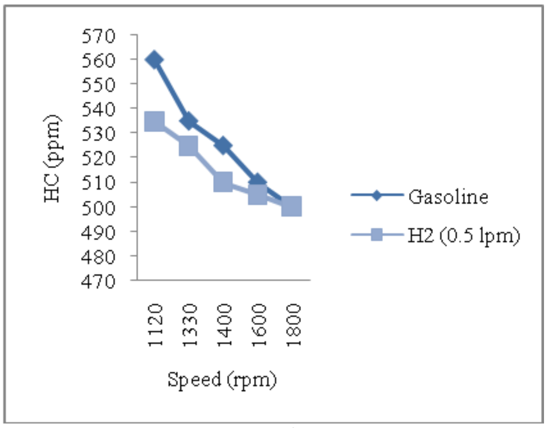

Fig. 3.5 Variation of HC with speed

3. Nitrogen Oxide (NO_x) Emission: The fig. 3.6 shows the variation of NO_x emissions with engine speeds with addition of hydrogen into gasoline. From fig. it can be concluded that the NO_x emission increases with the addition of hydrogen into gasoline. This is due to high pressure and temperature in the combustion chamber of an engine. At high temperature N_2 breaks down to N which is very reactive. The water vapor and other gases also break down at very high temperature, at high temperature more dissociation takes place leading to the formation of more NO_x.

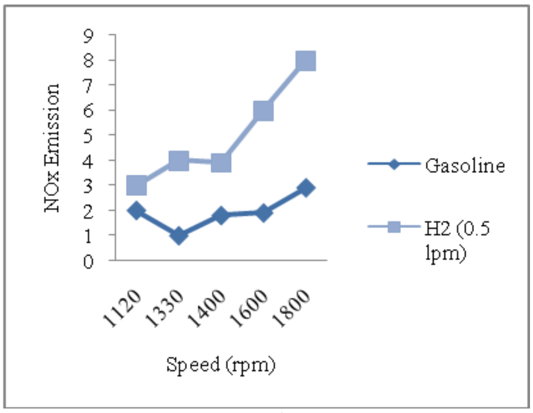

Fig. 3.6 Variation of NO_x with speed

IV. CONCLUSIONS

An experimental investigation was carried out to determine the effect of hydrogen addition on improving gasoline engine performance. The following are the main conclusions drawn after an experimental investigation.

- The brake thermal efficiency increases by addition of hydrogen gas. This is due to high burning velocity and wide flammability range of gasoline-hydrogen-air mixture compared to pure gasoline.

- The brake specific fuel consumption decreases with addition of hydrogen gas. Uniform and better mixing of gasoline-hydrogen-air has a major effect on Bsfc.
- The brake power increases with addition of hydrogen. Gasoline-hydrogen-air mixture has shorter combustion period and ignition delay which leads to less hest losses from the engine.
- An HC and CO emission reduces with addition of hydrogen mainly due to complete combustion of fuel and high temperature of combustion chamber.
- The NO_x emission increases with addition of hydrogen due to higher combustion temperature.

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