Experimental investigation on the effect of hydrogen blending on performance and emission 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 NOx emission was increased with addition of hydrogen.


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 (CO2) 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 (CO2), nitrogen oxide (NOx), 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 NOx 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 NOx 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 NOx emission of hydrogen fuelled engine is about 2-4 times lower than gasoline fuelled engine. Emission of CO, CO2 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.


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>
<thead>
<tr>
<th>Property</th>
<th>Hydrogen</th>
<th>Gasoline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formula</td>
<td>H₂</td>
<td>C₇H₁₆</td>
</tr>
<tr>
<td>Calorific Value</td>
<td>141780</td>
<td>44500</td>
</tr>
<tr>
<td>Density at 1 atm and 300 K</td>
<td>0.082</td>
<td>5.11</td>
</tr>
<tr>
<td>Lower heating Value (MJ/kg)</td>
<td>119.7</td>
<td>44.79</td>
</tr>
</tbody>
</table>

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

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

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

\[
2\text{Al} + 2\text{KOH} + 6\text{H}_2\text{O} \rightarrow 2\text{KAl} (\text{OH})_4 + 3\text{H}_2↑
\]

\[
\text{KAl} (\text{OH})_4 \rightarrow \text{KOH} + \text{Al} (\text{OH})_3↓
\]

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

<table>
<thead>
<tr>
<th>Maximum gas supply capacity</th>
<th>1 liter per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodes (Anode and Cathode)</td>
<td>Stainless steel plates</td>
</tr>
</tbody>
</table>
3.1 Technical specifications of a single cylinder gasoline engine: Technical specification of Engine is given in the table below.

Table 4 Engine Specifications

<table>
<thead>
<tr>
<th>Make</th>
<th>Hero Honda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Ambition</td>
</tr>
<tr>
<td>Displacement</td>
<td>133.00 cc</td>
</tr>
<tr>
<td>Type</td>
<td>Single cylinder, 4 stroke, Air cooled</td>
</tr>
<tr>
<td>Power</td>
<td>14.0 bhp @8000 rpm</td>
</tr>
<tr>
<td>Torque</td>
<td>10.5 Nm @4500 rpm</td>
</tr>
<tr>
<td>Speed</td>
<td>5 Speed</td>
</tr>
</tbody>
</table>

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.

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.

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.

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.

3. Nitrogen Oxide (NOx) Emission: The fig. 3.6 shows the variation of NOx emissions with engine speeds with addition of hydrogen into gasoline. From fig. it can be concluded that the NOx 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 N2 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 NOx.

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 heat 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 NOx emission increases with addition of hydrogen due to higher combustion temperature.

REFERENCES


