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# Generation of oxy-hydrogen gas and its effect on performance of spark ignition engine

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**Abstract:** Considering the current scenario of petroleum fuels, it has been observed that, they will last for few years from now. On the other hand, the ever increasing cost of a gasoline fuels and their related adverse effects on environment caught the attention of researchers to find a supplementary source. For commercial fuels, supplementary source is not about replacing the entire fuel, instead enhancing efficiency by simply making use of it in lesser amount. From the recent research that has been carried out, focus on the use of Hydrogen rich gas as a supplementary source of fuel has increased. But the problem related to the storage of hydrogen gas confines the application of pure hydrogen in petrol engine. Using oxy-hydrogen gas (HHO) generator the difficulties of storing the hydrogen have overcome up to a certain limit. The present study highlights on performance evaluation of conventional petrol engine by using HHO gas as a supplementary fuel. HHO gas was generated from the electrolysis of water. KOH solution of 3 Molar concentration was used which act as a catalyst and accelerates the rate of generation of HHO gas. Quantity of gas to be supplied to the engine was controlled by varying amount of current. It was observed that, engine performance was improved on the introduction of HHO gas.

## 1. Introduction

A leaning concern regarding the reduction in emissions and reducing the fuel consumption has brought researchers attention to find different alternatives which can be used in an engine without having much modifications. Automotive sector is considered as the largest consumer of fossil fuels. And if these fuels are not utilized in a proper way then they may last hardly for next 100 years [1]. Also decreasing the sources of fossil fuels and constantly increasing the concentrations of atmospheric pollutants are some of the major challenges to the society.

In general, fuel economy is better and the combustion reaction is more complete only when an IC engine runs on a lean mixture. Hydrogen has a wide range of flammability when compared with all other fuels. Hence, hydrogen can be burned in an IC engine over a wide range of air-fuel mixtures. So advantage of this is that hydrogen can run on a leaner air-fuel mixture which ensures prompt ignition [2]. Also, from well-to-wheel analysis it has been observed that hydrogen powered vehicles have low consumption of fuel and emit few greenhouse gases



throughout the cycle [3]. Also it has been observed that, HHO gas can be used as an additive along with petrol to reduce the emissions [4]. Among the different probable alternative fuels, hydrogen is said to be the most promising due to its clean burning along with better combustion properties [5, 6]. Common duct water electrolyzers that can generate a hydrogen oxygen mixture which is used for injection into IC engines is mostly promoted as a technique for improving the brake thermal efficiency as well as fuel consumption and reducing emissions [7].

Presence of oxy-hydrogen gas at the time of combustion process was found to reduce the brake specific fuel consumption and improve the brake thermal efficiency. It also reduces HC, CO<sub>2</sub> and CO emissions but considerable increase in the NO<sub>x</sub> emissions [8, 9].

## 2. Literature review:

Budhesh K. Jambukiya et al. [10], in this paper HHO gas was generated by water electrolysis process with KOH as an electrolyte. Four stroke, single cylinder gasoline engine was used for performance analysis with HHO gas as a complementary fuel which was supplied along with intake air. Performance was done with variable compression ratio on gasoline engine. 2.57 %, 2.60% and 2.74 % of HHO gas was used with intake air in petrol engine with compression ratio varied as 7, 8 and 9. From the analysis it was found that, amount of fuel consumption decreased with increase in % of HHO gas and compression ratio. Also brake thermal efficiency increased with increase in % of HHO gas and compression ratio.

Shivaprasad K V et al. [11], investigation was done on single cylinder high speed petrol engine with various blends of hydrogen and gasoline. The effect of hydrogen enrichment on volumetric efficiency, brake thermal efficiency and emission characteristics was investigated. Compressed hydrogen was supplied from steel gas tank which was controlled by regulator valve. The engine was modified with addition of hydrogen continuous injection system with unchanged injection system of petrol. Exhaust emissions were analyzed by exhaust gas analyzer. The tests were performed at speed range of 2000 to 4000 rpm with constant increment of 500 rpm. With the help of regulator 5%, 10%, 15%, 20% and 25% by volume of hydrogen was adjusted. From the test results it was observed that, with increased hydrogen % the combustion performance and fuel consumption was improved. Also with increased hydrogen fraction, the brake thermal efficiency increased. Volumetric efficiency was found to be decreased with increased hydrogen % as amount of air was replaced by hydrogen. HC and CO emissions found to be decreased with increased hydrogen % due to overall increased temperature inside the cylinder but NO<sub>x</sub> was increased. From the overall results it was concluded that blends with 20% hydrogen were suitable as a fuel for optimum performance of the engine.

Shashikant Jadhav et al. [12], in this paper, HHO gas was generated by electrolysis process and the generator integrated to the petrol engine. The experimentation was done on single cylinder 250 cc SI engine at a constant speed. Load was varied along with HHO gas. HHO gas was varied by varying the current supplied to the generator. Amperes used were 1, 2 and 3 amperes with DC supply of 12 volts. HHO gas was supplied along with air through intake manifold. From the results it was observed that, at full load and at 3 ampere current total

reduction in fuel consumption was about 18.87% compared with normal petrol engine. This was due to better combustion. After hydrogen enrichment at full load and at 3 ampere, brake thermal efficiency was increased by 3.72%. Also HC was decreased by 28.33% at full load. CO was reduced to 1.42% from 1.7% by volume at 3 ampere current supply. The main reason was presence of oxygen which came along with hydrogen fuel enhances complete combustion.

Shrikant Bhardwaj et al. [13], HHO gas was obtained by water electrolysis process. The tests were carried out on four stroke, four cylinder petrol engine. Different performance parameters along with emissions were investigated verses load. From the results it was concluded that, indicated thermal efficiency increased with the enrichment of HHO gas. Tendency to knock was reduced due to increased octane number. Also it was observed that, levels of CO, CO<sub>2</sub> and HC were reduced with increased HHO% but NO<sub>x</sub> was found to be increased because of increased temperature inside the combustion chamber.

Nikhil Narayan et al. [14], Oxy-hydrogen gas was generated by electrolysis process with KOH solution as an electrolyte. The performance and emission tests were carried out on three cylinder four stroke gasoline engine. It is observed that, addition of HHO gas as supplementary fuel reduced brake specific fuel consumption and increased brake thermal efficiency. Also decrease in the values of HC and CO was observed.

Daniel M. Madyira et al. [15] in this paper, HHO generator was installed into the compartment of the engine. Four stroke SI engine was used for experimentation. The generated HHO gas was supplied through intake manifold up to 0.45% by volume. Tests were conducted for a range of speed from 1000 to 3500 rpm and maximum load applied was 30% of full load. It was found that, addition of HHO enhanced power and torque and a significant reduction in CO and HC was observed. Also improved combustion was observed especially a low loads.

### **3. HHO generation:**

Different methods of generation of HHO gas: Yadav M.S. et al [9] has investigated different methods for the generation of Oxy-Hydrogen gas in this paper. There are two different methods for the generation of HHO gas and those are as follows:

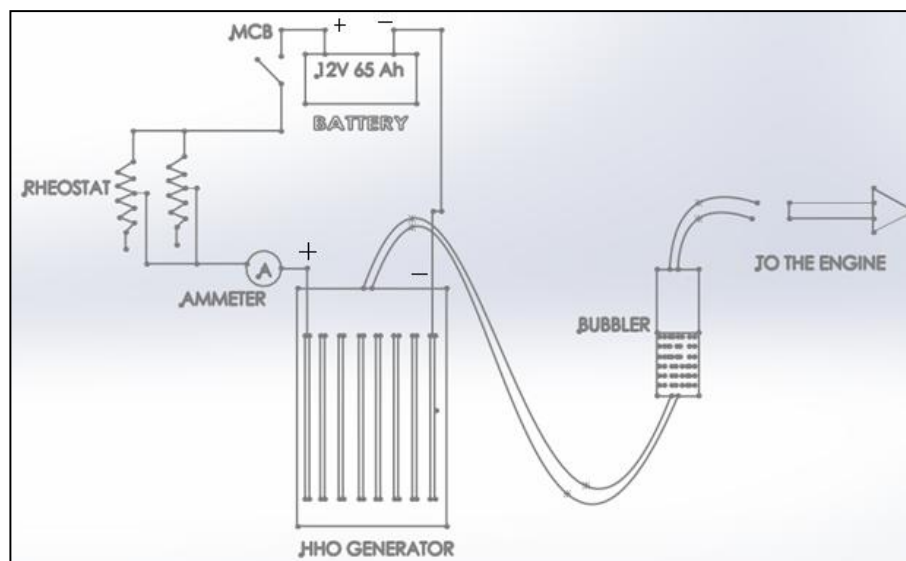
1. First method is depending on the Faradays law. Whenever a supply is given to the two electrodes or plates which are made up of same material for e.g. Stainless steel, it leads to dissociation of water into hydrogen and oxygen ions. Hydrogen appears at cathode which is negatively charged electrode while oxygen appears at anode which is positively charged electrode. With the consideration of ideal faraday efficiency, the generation of moles of hydrogen is twice that of oxygen.

2. In second method, use of DC pulses is made (particularly square wave output). By the use of these DC pulses, vibrations are made in the water to achieve condition of resonance. The variation in natural frequency of water leads to the generation of large electrical force which is used to break the bond between hydrogen and oxygen which results into freed gas molecules

which are magnetically coupled to each other. And then it is used for further applications. But this method has limitations due to its complex design, bulky structure and large space which is required for its installation [18].

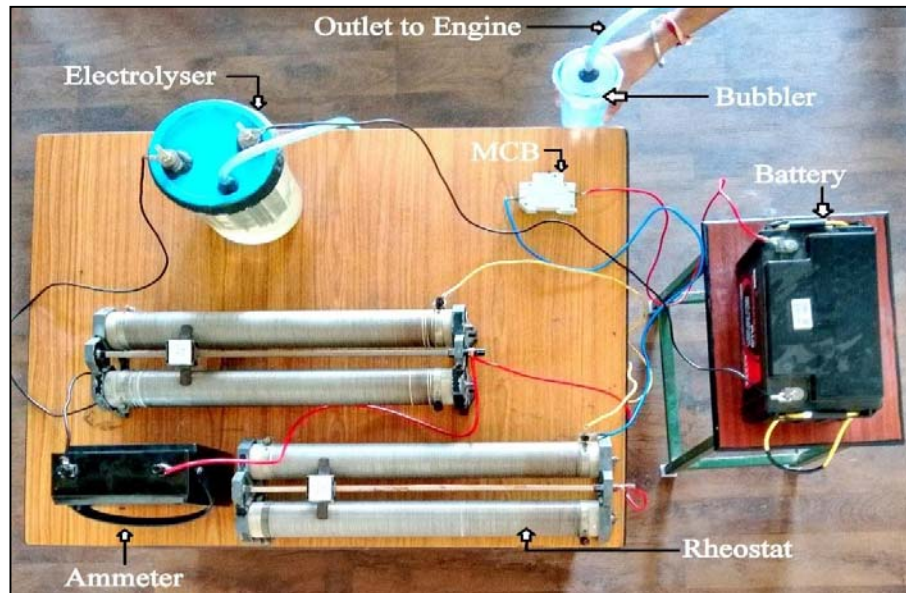
#### 4. Experimental setup:

##### 4.1 HHO generator:



**Figure 1.** Schematic diagram of HHO gas generation system

The method of electrolysis is used in this study for the generation of HHO gas. The HHO generation system is as shown in figure above. It consists of an electrolytic cell which is also called as electrolyser. This generator used in this experiment is a plastic container in which stainless steel plates of grade 304 were used since this grade can sustain ordinary corrosion in architecture and can resist most chemicals. [16] These plates are bolted together in a group of 4 closely spaced pairs. Spacing between these two plates was maintained as 1.6mm because the space less than this may result in blast of the electrolyser due to possibility of jumping of current across the different electrode plates which might result in production of spark. Also if the space between the plates is less than 1.6mm, the gas generation rate decreases. [9] Different types of catalysts are used in various research and from those potassium hydroxide (KOH) was found to be the best for this application because of its ability to remain unchanged during the process of electrolysis [17]. Since the rate of generation of gas is mainly depends on the concentration of electrolyte KOH solution with 3 molar concentration was used as an electrolyte.



**Figure 2.** Experimental setup for HHO generation

#### 4.2 Working of HHO generator:

A 12V-65Ah battery was used as a power supply for the electrolyser. When the current starts flowing through the electrodes, the process of electrolysis starts. In this process, dissociation of water molecules takes place leading to the formation of oxygen and hydrogen gas on positive and negative electrode respectively. Specifically, it is a mixture formed containing 1/3rd of oxygen and 2/3rd of hydrogen which are bonded together. These hydrogen and oxygen then rise through the cell as a gas which is slightly brown in colour. Hence, HHO gas is also called as a “Brown gas.”

Reactions taking place are as follows:

Cathode (reduction) reaction:  $2\text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-$

Anode (Oxidation) reaction:  $4\text{OH}^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^-$

Overall reaction:  $2\text{H}_2\text{O} \rightarrow 2\text{H}_2 (\text{g}) + \text{O}_2 (\text{g})$

Properties of Hydrogen [19]:

**Table 1.** Properties of Hydrogen gas

<b>Auto-ignition temperature</b>	<b>858K</b>
<b>Calorific Value (LCV)</b>	119.93 MJ/kg
<b>Burning velocity in NTP air</b>	265-325 m/s
<b>Minimum energy for ignition</b>	0.02 mJ
<b>Diffusion coefficient in NTP air</b>	0.61 cm <sup>2</sup> /s
<b>Limits of flammability in air</b>	4-75 vol.%

#### 4.3 Different Materials and Components:

Flashback Arrestor: The function of bubbler or flashback arrestor is to prevent flashback from the engine. The most important function of bubbler is to collect HHO gas and to prevent any case of backfire from the engine. Also, bubbler helps to remove the fumes of electrolyte from HHO gas to prevent its flow to the engine. The construction of bubbler is very simple as it is made of plastic. Plastic bubbler is used because, if problem of backfire occurs then that plastic may tear off quickly and generation of gas can be controlled quickly. It has provided one inlet for the flow of brown gas from electrolyser and one outlet for the HHO gas which is to be supplied to engine.

Battery: Battery of capacity 12V, 65Ah was used to provide supply voltage for the electrolyser. Rheostat: The function of rheostat is to increase or decrease the resistance in the circuit for the control of flow of current through the circuit. Since the generation of gas is dependent on the amount of current, by varying the current, different flow rates of gas were obtained.

#### 4.4 Engine Test Bed Specifications:

Figure 3 shows the actual experimental setup. Experiment was conducted on Honda GX-160CC SI engine. Engine was coupled with eddy current dynamometer for the application of load. Fuel consumption was measured by using burette and stopwatch. HHO electrolyser was integrated with engine as shown in figure below. HHO gas was generated by using 12V DC supply while the flow rate was adjusted by changing the values of current by using rheostat. Load was increased by increasing the current in steps while keeping the speed of the engine constant. HHO gas was then passed through the bubbler to avoid any flashback from the engine. No modifications were done in the engine but the inlet air pipe was modified to have inlet for HHO gas introduction in engine.



**Figure 3.** Engine Setup

Engine Specifications:

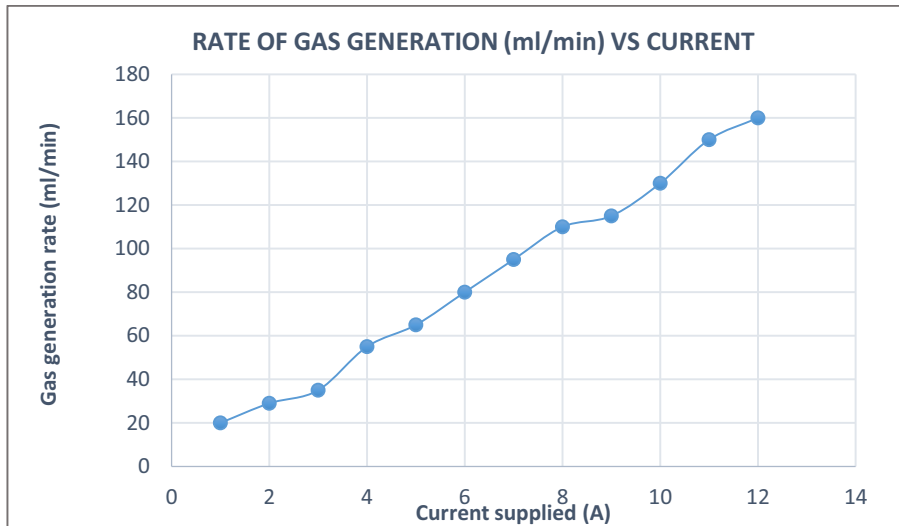
**Table 2.** Engine Specifications

<b>Make</b>	<b>Honda GX-160CC</b>
<b>Configuration</b>	4 Stroke, Single Cylinder Petrol Engine
<b>Stroke length</b>	0.045m
<b>Bore diameter</b>	0.068m
<b>Rated RPM</b>	3000
<b>Maximum B.P.</b>	4.68Hp @ 3000 rpm
<b>Cooling type</b>	Water cooled
<b>Orifice diameter</b>	0.0142m



**5. Results and discussions:**

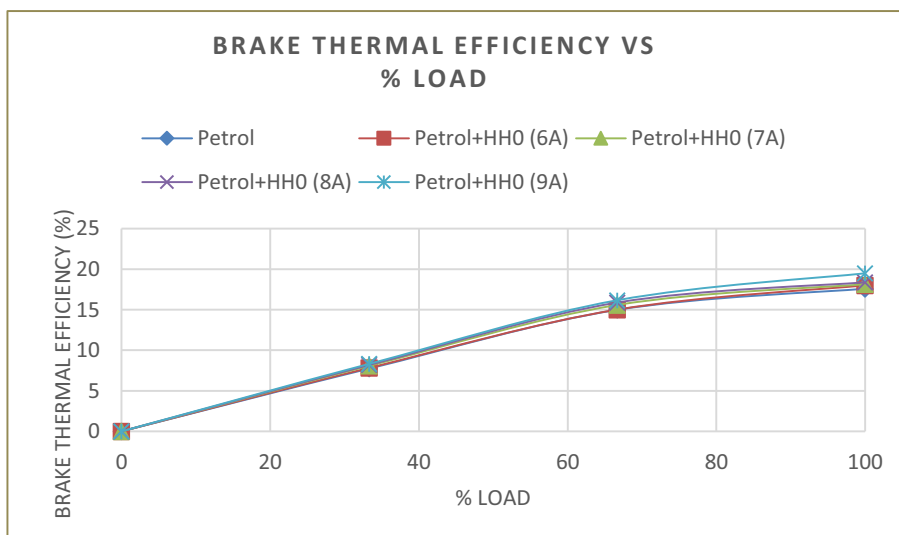
**5.1 Rate of generation of HHO gas:**



**Figure 4.** Gas generation rate with different current inputs

Figure no.4 shows the rate of generation of HHO gas with respect to change in current. It was observed that, as the current was increased, rate of generation of gas was increased. For the current of 1A, the gas generated was 20ml/min and maximum current supplied was 12A and rate of gas generation was 160 ml/min which is about 9.6LPH.

**5.2 Effect on brake thermal efficiency:**



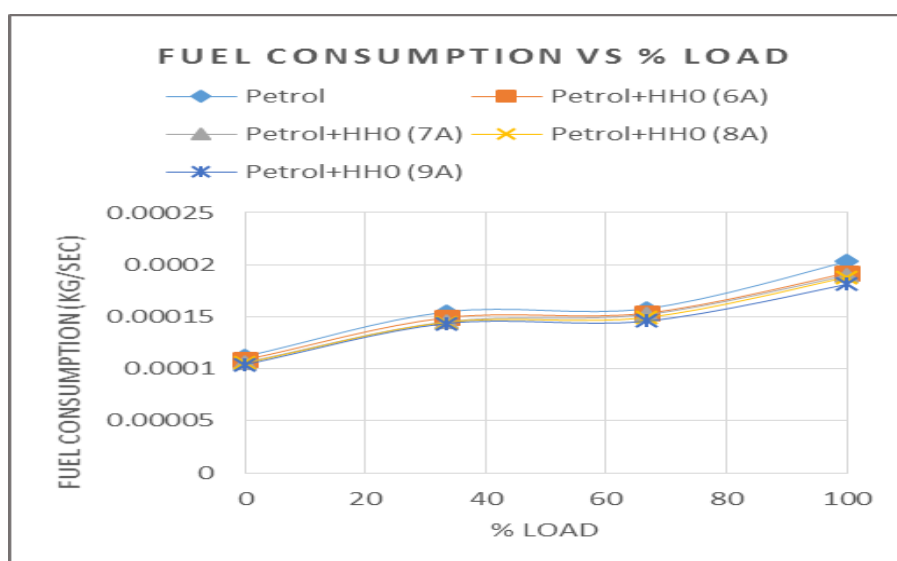
**Figure 5.** Variation of Brake thermal efficiency with load for different current inputs

The effect of adding HHO gas on Brake thermal efficiency of a spark ignited engine is shown in Fig.5. As the speed of flame-front in HHO assisted engine is much higher than a normal spark ignited engine also the flammability range of hydrogen is much wider than that of gasoline, the overall mixture will be having a higher burning velocity and extended flame than pure petrol, which results in a shorter burning period than and more complete burning. The high pressure and temperature wave collides with fuel droplets causing its defragmentation giving more exposure to oxygen present inside the combustion chamber. The faster flame speed of HHO gas and petrol results in a higher degree of combustion while having a constant volume. It states that, the tendency of an engine to operate at an ideal cycle increases and results into rise of brake thermal efficiency. Also it can be stated that, due to the large amount of energy is liberated at faster rate, Hydrogen gives out large amount of energy during combustion process increasing brake mean effective pressure inside the combustion chamber. From the graph it is clear that the brake thermal efficiency increases as the rate of HHO gas input was increased.

**Table 3.** Effect on Brake thermal efficiency by varying current

Current supplied	% increase in Brake thermal efficiency
6A	2.36%
7A	3.146%
8A	4.464%
9A	10.801%

### 5.3 Effect on fuel consumption:



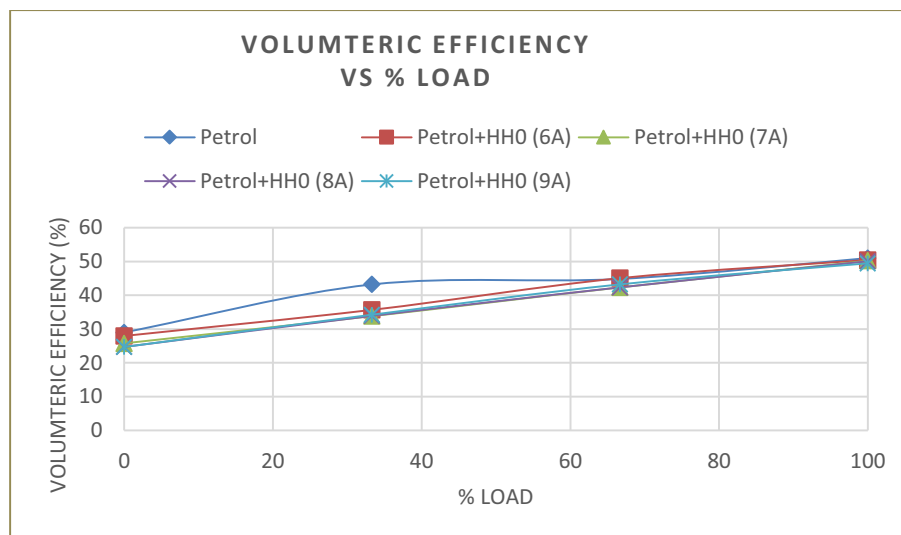
**Figure 6.** Variation of Fuel consumption rate with load for different current inputs

The nature of curve for the graph of fuel consumption shown in Fig.6 is of increasing type. As the load increases, engine requires more amount of fuel to meet the increasing load demands. It is clear that after increasing the supply of HHO gas steadily, the rate of fuel consumption is lowered to a certain amount. Due to induction of HHO gas it results into formation of leaner mixture which ends up with complete combustion. HHO is extremely efficient as it has very minute array of oxygen and hydrogen bundled together as a single combustible unit. When these diatomic bundle interacts with thousands of carbon molecules it results in efficient combustion.

**Table 4.** Effect on rate of fuel consumption by varying current

Current supplied	% decrease in fuel consumption
6A	5.418%
7A	6.40%
8A	7.39%
9A	10.83%

#### 5.4 Effect on volumetric efficiency:

**Figure 7.** Variation of Volumetric Efficiency with load for different current inputs

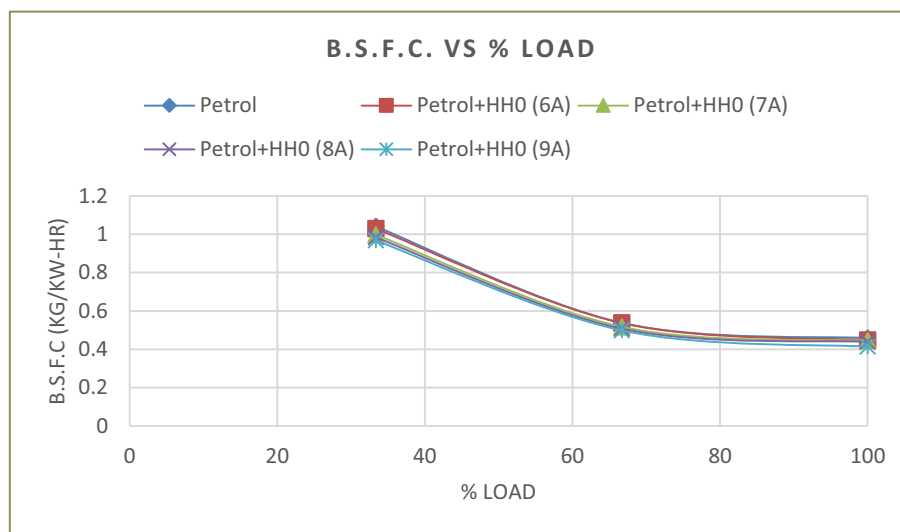
From the graph of volumetric efficiency shown in Fig.7, it is clear that as HHO supply increases drop in volumetric efficiency is observed. This is mainly due to the difference in the density of

hydrogen and air. As hydrogen is lighter, it occupies area at faster rate than air, on the other hand fuel droplets takes very less area inside the combustion chamber. Hydrogen occupies more space causing less quantity of air to be sucked inside the cylinder. Due to this the mixture formed is of lesser density, resulting in decreased volumetric efficiency.

**Table 5.** Effect of varying current on Volumetric efficiency

Current supplied	% decrease in Volumetric efficiency
6A	1.12%
7A	1.57%
8A	1.85%
9A	3.05%

#### 5.5 Effect on brake specific fuel consumption:



**Figure 8.** Variation of Brake Specific Fuel Consumption with load for different current inputs

The outcome of adding HHO gas to spark ignited engine is shown in Fig.8. It is clear that, addition of HHO gas has reduced the B.S.F.C. of the engine by a differentiable amount. The diffusivity of hydrogen gas is very high, due to this nature it results into formation of a homogenous mixture with oxygen and air. Due to high flame speed as mentioned earlier better atomization of fuel droplets takes place. Further due to wider flammability, combustion take place more efficiently. The hydrogen and oxygen present in HHO are weakly bonded. When HHO gas goes inside the combustion chamber it results into formation of pulverized water droplets. Due to density difference when the fuel droplets comes in contact with pulverized water

droplets, water forms the core portion and fuel covers it from outside. During compression stroke the water droplets explode resulting in better atomization of fuel. Due to explosion, droplets breaks down into further minute droplets separating hydrogen and oxygen. Hydrogen increases the octane rating of fuel and oxygen assists combustion process. Hence the overall efficiency of engine increases and brake specific fuel consumption decreases.

**Table 6.** Effect of varying current on B.S.F.C

Current supplied	% decrease in B.S.F.C
6A	2.31%
7A	3.05%
8A	4.29%
9A	9.74%

## 6. Conclusion:

The experimental tests to study the performance of a single cylinder petrol engine under the influence of HHO gas has been carried out. HHO gas has been generated from the electrolysis of water with KOH solution as a catalyst. The rate of generation of gas has been studied by varying the supplied current. It was observed that, HHO electrolyzer can be easily integrated with petrol engine. The gas was first allowed to mix with fresh air stream just before the inlet of carburetor. Following results are drawn from the tests conducted.

Considering full load conditions-

1. The maximum increase in brake thermal efficiency observed was **10.82 %** for 9A of current supply.
2. Brake specific fuel consumption was decreasing as the supply of HHO gas was increased. For 9A the decrease in B.S.F.C observed was **9.74 %**.
3. As the brake thermal efficiency was increased, there was a dip in curve for fuel consumption rate. Maximum decrease observed was **10.83%**.
4. Volumetric efficiency was decreased by **3.05 %** for 9A of current supply.

From the results drawn we can conclude that HHO can be used as a supplementary fuel. The entire cost of HHO gas generator setup is less and it can be implemented easily. Induction of HHO gas will always have positive effect on performance of gasoline engine.

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