Reduction in fuel consumption & GHG emission by using Hydrogen gas in gasoline engine

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Abstract: Energy need per capita in the world has a tendency to increase continuously. The increase in the energy demands also increases the dependency on fossil fuels especially petroleum and natural gas. In addition to comfort and design aspects, subjects such as fuel consumption and efficiency have become one of the most important matters of automobile buyers and sellers. One of its reasons is the fuel efficiency standards which have become strict gradually. In this paper, we are analyzing the scope of hydrogen as a supplementary fuel, in 4-Stroke internal combustion engine. A hydrogen generation system is developed for producing hydrogen and injecting the hydrogen as a fuel supplement into the air intake of carburetor. Hydrogen and oxygen is produced with a fuel cell at low temperature and pressure from water in a tank. This engine is compared with conventional engine and through testing results found that such hydrogen engines are more fuel efficient due to the optimization of the engine operation. These all operations will help us to decrease the Green House Gas level & Increase the fuel efficiency.

***IndexTerms* – Hydrogen generation kit, reduction of GHG emission, plug-in hybrid electric engine.**

1. INTRODUCTION

Over the century hydrocarbon has served the thirst for power generation and automobile industry. In recent years, problems like increased fuel prices, declining oil reserves, higher awareness of environmental effects of HC use have started troubling the mammoth energy industry. Drastic Increase in the pollution in the environment due to emissions from greedy industries has forced the world to move towards the alternate fuel types. Fuel substitutes like LPG, CNG, Hydrogen, vegetable oil, biogas, biodiesel have been dedicated studied by various researchers. Hydrogen being the leading and promising candidate for the future of energy, has been studied by Saravanan [6] in the spark ignition engines. Combustion of hydrogen gives only water as byproduct, unlike bunch of pollutants emitted by conventional engines – CO, CO_2, NOx, and unburnt HC.

$$2H_2 + 0_2 \longrightarrow 2H_2O$$

The present work is focused on the use of hydrogen in Internal Combustion Engines (ICE), more specifically as hydrogen fuelled Spark Ignition (SI) [8]. Fuel - air mixture rich in hydrogen is found effective in reducing pollution, giving higher Brake Thermal Efficiency (BTE). Hydrogen here acts as a support substance which lifts up the overall energy content of system. Higher diffusivity of hydrogen, comparatively higher than petrol and diesel gives it advantage to disperse in the air mixture. Diffusion co-efficient of hydrogen is 0.61 cm^2/s [4].

According to N. Saravanan, G. Nagarajan (2007), NO_x concentration decreases with the use of hydrogen- air- fuel mixture in engine and Carbon monoxide emissions decreases by 50%, unburnt HC by 58% [6]. Findings of Changwei Ji et al. [9] also states that HC emissions were reduced by 44.8% when hydrogen volume fraction was increased from 0 to 5.2%. CO and CO_2 emissions were also reduced after blending H_2. Researchers have focused their attention on hydrogen as an alternative fuel in ICEs and in the development of fuel cell powered vehicles and hybrid electric vehicles (HEVs). Hydrogen can be used as a independent fuel in spark ignition (SI) engine, either by direct injection or carburation.

Hydrogen however comes with storage and production difficulties in the purview of IC engines. Low density of hydrogen makes it difficult to store it onboard, but hydrogen generation on-site with considerable purity can serve the purpose. Here, hydrogen has been generated on site using electrolysis of alkaline water, only when engine is running, thus eliminating the storage problem.

Plug-in electric vehicle (PEV) is a motor vehicle that can be recharged from an external source of electricity, such as wall sockets and electricity stored in the rechargeable battery packs drives or contributes to drive the wheels. PEV is a subset of electric vehicles that includes all electric or battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs) and electric vehicles conversion of Hybrid electric vehicles and conventional internal combustion engine vehicles. Plug-in Hybrid electric vehicles can play a role in reducing Greenhouse gas emissions from the transport sector. It is found that GHG emissions can be reduced by 32% by using PHEV compared to the conventional vehicle. Batteries are important component of PHEVs. GHG associated with lithium ion battery materials and production account for 2 to 5% of life cycle emission of PHEVs.

This paper involves the enrichment of fuel – air mixture with various percentages of hydrogen in a petrol engine using petrol as ignition source to reduce the fuel consumption and GHG emissions.

1.1 HYDROGEN AS A FUEL

Hydrogen is the lightest element in the periodic table having atomic weight 1.008 amu. It occurs as hydrogen gas (H_2) in nature. Its monoatomic form (H) is the most abundant chemical substance in the universe. hydrogen is a colourless, odourless, tasteless, non- toxic, non-metallic, highly combustible diatomic gas with molecular formula H_2. Hydrogen literally means 'water-forming' as it was first discovered by metallic reaction and then burnt to form water in 16^{th} century [11].

The hydrogen is considered to be an alternative for internal combustion engines because it has many desirable properties [03], such as low ignition energy, high diffusivity, wide flammability, high flame velocity and short quenching distance. As per previous studies, hydrogen has been proved to be a green alternative energy and would be used on vehicles [8]. Automotive manufacturers have profited from different technologies such as fuel cell, hydrogen fuelled ICE and hybrid configurations to evolve different type of vehicles. Fuel cell system is nothing but the assembly of pure Hydrogen and Oxygen; purity of hydrogen makes this cell even more expensive to manufacture and accommodate in automobile. So, in this work, we go for enrichment of fuel- air mixture with Hydrogen. Hydrogen is the most promising additive with its unique combustion properties among many additives and it can reduce fuel consumption and harmful emissions emitted by ICEs [4]significantly. Karagoz et al. [4]used H_2/O_2 mixture as a supplementary fuel in an SI engine at idle condition, and it was found that brake thermal efficiency of engine increased, HC and CO_2emissions decreased via hydrogen addition.

1.1.1 Hydrogen - its properties:

Hydrogen, has several physical as well as chemical properties, among them, technical properties that contribute to its use as a combustible fuel are its:

Wide Range of Flammability:

Hydrogen can be combusted in an internal combustion engine over a wide range of fuel-air mixtures. The flammability range in air at 298K at 1 atm for hydrogen is 4% - 75% while for petrol it is 1%- 7.6%. [1] A significant advantage of this is that hydrogen can run on a lean mixture. A lean mixture is one in which the amount of fuel is less than the theoretical, stoichiometric or chemically ideal amount needed for combustion with a given amount of air. Additionally, the final combustion temperature is generally lower, reducing the amount of pollutants, such as nitrogen oxides, emitted in the exhaust.

Low Ignition Energy:

Hydrogen has very low ignition energy. The amount of energy needed to ignite hydrogen is an order of 0.02 MJ in magnitude and it is less than that required for petrol air mixture. [1] This enables hydrogen engines to ignite lean mixtures and ensures prompt Ignition.

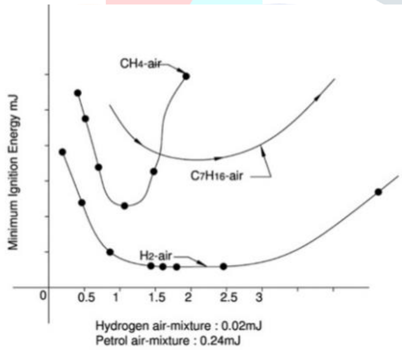

Fig. 1 Minimum Ignition Energy: A comparison

Small Quenching Distance:

Hydrogen has a small quenching distance, 0.6 mm which is smaller than gasoline, 2.0 mm. Consequently, hydrogen flames travel closer to the cylinder wall than other fuels before they extinguish.

High Auto Ignition Temperature:

Hydrogen has a relatively high auto ignition temperature, 536^0C. The temperature rise during compression is related to the compression ratio. The temperature rise is shown by the equation:

$$T1 = T2 * (\frac{V1}{V2})\gamma - 1$$

Where, V_1/V_2, T_1, T2, γ arethe compression ratio, absolute initial temperature, absolute final temperature and ratio of specific heats respectively.

High Flame Speed:

Hydrogen has high flame speed at stoichiometric ratios. This means that hydrogen engines can more closely approach the thermodynamically ideal engine cycle than gasoline. As per the findings [7], the comparative laminar speeds of gasoline, It is easily visible that hydrogen has very highspeeds and sufficient for giving instant combustion.

High Diffusivity:
This ability to disperse in air is considerably greater than gasoline and is advantageous for two main reasons. Firstly, facilitation the formation of a uniform mixture of fuel and air. Secondly, if a hydrogen leak develops, the hydrogen disperses rapidly. Thus, unsafe conditions can either be avoided or minimized.

Low Density:
This results in two problems when used in an internal combustion engine. Firstly, a very large volume is necessary to store enough hydrogen to give a vehicle an adequate driving range. Secondly, the energy density of a hydrogen-air mixture, and hence the power output, is reduced.

Physical and thermal properties of Hydrogen are compiled in a table as follows:

Table 1 Comparative study of properties between Hydrogen, Methane, Diesel, Gasoline

Property	Hydrogen	Methane	Diesel	Gasoline
Molecular Formula	H_2	CH_4	$C_nH_{1.8n}$	C_8H_{18}
Auto Ignition Temperature(K)	858	813	530	501-744
Minimum Ignition Energy	0.02	0.29	-	0.24
Flammability Limits (Volume %in Air)	4-75	5.3-15	0.7-5	1-7.6
Stoichiometric Air Fuel Ratio on mass basis	34.3	6.4	14.6	14.7
Laminar Burning Velocity in air(cm/s)	200-230	37-43	35-40	37-43
Diffusion coefficients in air(cm^2/s)	0.61	0.16	-	0.05
Density (kg/m^3)	0.0838	0.7174	833-881	700-750
Lower heating value (MJ/kg)	120	53	45.35	44
Octane Number Research	130	120	30	88
Flame temperature in air (K)	2318	2148	2516	2470

1.3 Generation of hydrogen:

There are several methods for production of hydrogen at industrial as well as laboratory level. It can be derived from natural resources such as coal, oil shale and uranium or from renewable resources based on solar energy. H_2 can be commercially produced from electrolysis of water and by coal gasification; it can also be produced by several other methods such as the thermo-chemical decomposition of water and solar photo-electrolysis, although these are currently still in the laboratory stage. In this work I have used electrolysis method for the production of hydrogen by using alkaline water.

2. METHODOLOGY

2.1 Experimental Objectives:

- To produce high purity hydrogen in a mobile device – electrolyser, with safety features, reliable and uniform generation rate.
- To control the hydrogen generation and supply rate.
- To study the effect of hydrogen enrichment with different ratios on BTE (Break Thermal Efficiency), bp (Break Power) and emission composition.
- To analyse the future scope of plug-in hybrid vehicle combined with hydrogen duel fuel cell.

2.2 Hydrogen Production process:

In this work, hydrogen is produced by using an electrolytic cell/ electrolyser, by breaking apart H_2 and O_2 from alkaline water

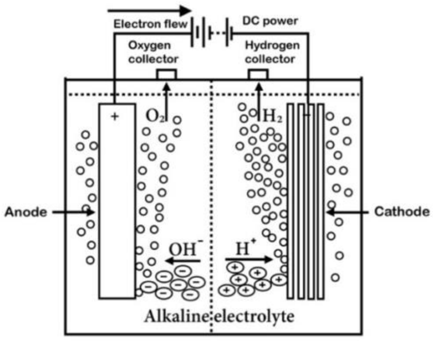

Fig. 3 Schematic of Electrolytic cell

solution. The main units of an electrolyser are an anode, a cathode, and an electrolyte which transmits the ions between anode and cathode (electrodes). With the help of literature review, as mentioned in Fig.5, when the power is turned on, water decomposes into positively charged hydrogen ions and negatively charged hydroxyl ions. The positive hydrogen ions move to the negatively charged electrode (cathode) and form as hydrogen gas (H_2) and the negative ions move to the positively charged electrode (anode) and form as oxygen gas (O_2).

At the anode: $2\,H_2O\,(l) \rightarrow O_2\,(g) + 4\,H^+\,(aq) + 4\,e^-$

At the cathode: $2\,H_2O\,(l) + 2\,e^- \rightarrow H_2\,(g) + 2\,OH^-\,(aq)$

Overall reaction: $2\,H_2O\,(l) \rightarrow 4H_2\,(g) + O_2\,(g)$

In this work, purity and amount of hydrogen generated is to be calculated.
For calculating theoretical hydrogen generation rate, stoichiometric calculations are done as follows:

Considering 1 litre of 30% aqueous KOH solution,
number of moles of water in 1 Litre solution = 1000g/(18 g/mole)= 55.56 moles
As per the electrolytic cell reaction, breaking of one molecule of water produces two molecules of hydrogen,
Thus, hydrogen generated = 55.56*2 = 111.12 moles
Amount of hydrogen generated in litres = [111.12*(2 g/mole)] / [0.083 g/litre]= 2677.59 litres
Where, density of hydrogen is 0.083 g/litre.

With the help of above calculations, we can say that electrolysis of 1 Litre of water can produce maximum 2677.59 litres of hydrogen when continued till infinite time.

For calculating experimental hydrogen generation rate following test procedure would be followed for Electrolyzer:

1. Hydrogen Generation rate:
   A. Hydrogen gas generated from Electrolyzer, measured by measuring volume through soap solution filled class A burette and time observed by with stopwatch.
   B. the volume of hydrogen, generated at current of 12-volt dc and 6.5 ampere, measured along with time.
2. Purity of hydrogen : gas analysis the sample of hydrogen gas evolved from the port of electrolyser would be sampled in a gas tight sampling form 250 ml capacity at ambient temperature 500µL of sample taken in syringe and injected in gas chromatograph having thermal conductivity detector and analysed for its purity.

2.3 Experimental setup

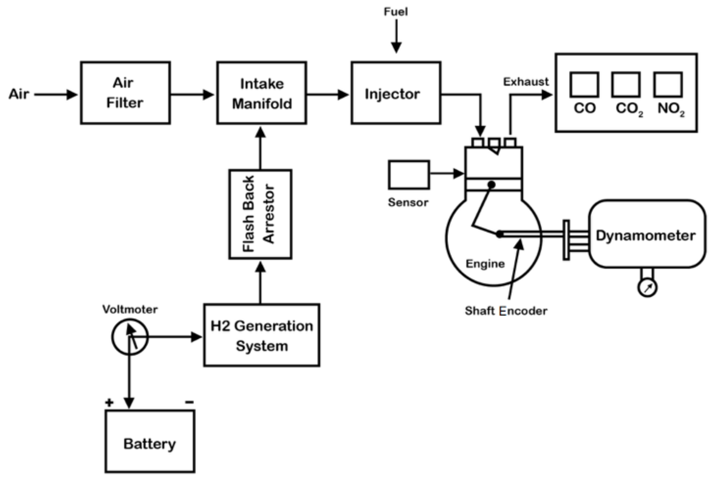

Fig. 4 Experimental setup

2.4 Parameters and Equations:

A. Break Thermal Efficiency:

$$\eta th = \frac{\text{brake power}}{\text{fuel power}} \qquad \eta th = \frac{3600*bp*100}{TFC*CV}$$

η_{th} = thermal efficiency
bp = brake power [kW]
TFC = fuel consumption [kg/h]
CV = calorific value of a kilogram fuel [kJ/kg]
ρ = relative density of fuel [kg/L]

B. Brake Power: bp is the output power measured at the crankshaft.

$$bp = \frac{(bmep)\ L\ A\ n\ K}{60 * 1000}$$

and can be also expressed as

$$bp = \frac{2\ \pi\ N\ T}{60 * 1000}$$

L: Length of the stroke [m]
A: Cross-section area of the piston [m^2]
n: number of power strokes
N: Crankshaft speed [RPM]
K: number of cylinders
T: Engine torque [N.m]

C. Torque:

$$T = F * R$$

Where, T, F, R are Torque [N.m], Force [N] and Radius [m] respectively.

D. Total fuel Consumption TFC (Kg/hr):

$$TFC = \frac{10 * 3600 * 0.83}{t * 1000}$$

t: time of operation in sec
Density of hydrogen : 0.83 kg/cm^3

2.5 Emission Analyzer:

Concentration of Exhaust gas (O_2, CO_2, CO, HC, NOx) will be analyzed by the One of the most popular methods is the non dispersive infrared detection where the radiation used is broad band radiation. The absorption by a gas depends on the concentration level and also the path length over which the electromagnetic radiation travels through the gas. The concentration will be given in ppm by the device.

3. Experimental Setup

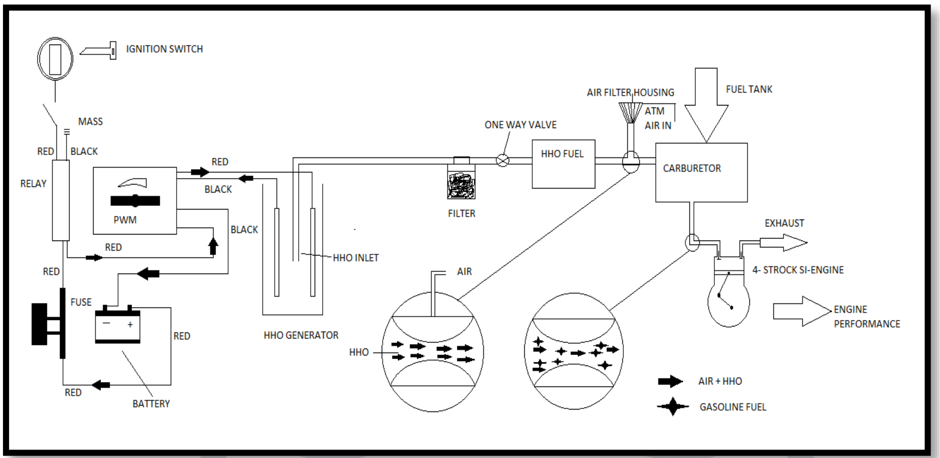

Fig. 6. Schematic of experimental setup

Fig. 5 Schematic of experimental setup

Setup can be divided into two main parts. First is the hydrogen generator unit along with electrical equipment and second is IC engine with attached parameter measuring equipment. Hydrogen gas generation is done by the electrolysis process. Electrolysis remains a standard method of producing high purity hydrogen, though it is much more cost feasible to produce large volumes of hydrogen from fossil fuel hydrocarbons. Gas flow is controlled by butterfly valve. Hydrogen gas is then passed into carburetor along with air through a common pipe, which eventually enters into 4 stroke test engine. Engine parameters were studied with addition of hydrogen fuel in different composition and without hydrogen gas too.
List of components is as follows:
HHO generator aka Hydrogen generator is a device which is used for the production of H_2 gas. Basically, H_2 generator involved in production of hydrogen and oxygen through the process of electrolysis. In this process a DC current passed through water, as a result of which it is divided into its primary constituent's viz. Hydrogen and oxygen. Then the produced H_2 gas with the help of electrolysis is added in to the air intake manifold and injects into the cylinder where H_2 mixes with the fuel ignites and results in complete combustion of the hydrocarbons fuel, lowering emission and increasing fuel efficiency.
Power supply: A 12V battery was used to pass electrical current into water. It was a standard dry battery used for regular mid-range motor cycles. It can be operated at maximum 5 Ampere DC.
Fuse: Fuse is immensely necessary for direct application of DC like this. Its main role is to save the battery from short circuits.
PWM: Pulse Width Modulation device is specifically used for controlling the intensity of pulse to the electrolysis unit. This device is used to control the rate of generation of hydrogen. If continuous current is supplied, it may generate enormous volume of hydrogen, which is dangerous to handle.
One Way Valve: 'no go' valve was used to allow the flow of hydrogen only in one direction, so as to supply only limited quantity of hydrogen to the system and not more than the required. And, in case of accidental fire, it will be isolated upto one point only, saving the rest of the unit from fire.
The Engine and Dynamometer:
The procedure for analytical testing of hydrogen enrichment using specifications of four stroke single cylinder engine of Hero Splendor motorcycle, which is available at our Institute.

The photographic image of the setup available at Institute's (Silver Oak College of Engineering and Technology) laboratory is depicted here.

Fig.7. Experimental setup for observations

3.1 Hydrogen Production process:

In this work, hydrogen is produced by using an electrolytic cell/ electrolyser, by breaking apart H_2 and O_2 from alkaline water solution. The main units of an electrolyser are an anode, a cathode, and an electrolyte which transmits the ions between anode and cathode (electrodes). With the help of literature review, as mentioned in Fig.5, when the power is turned on, water decomposes into positively charged hydrogen ions and negatively charged hydroxyl ions. The positive hydrogen ions move to the negatively charged electrode (cathode) and form as hydrogen gas (H_2) and the negative ions move to the positively charged electrode (anode) and form

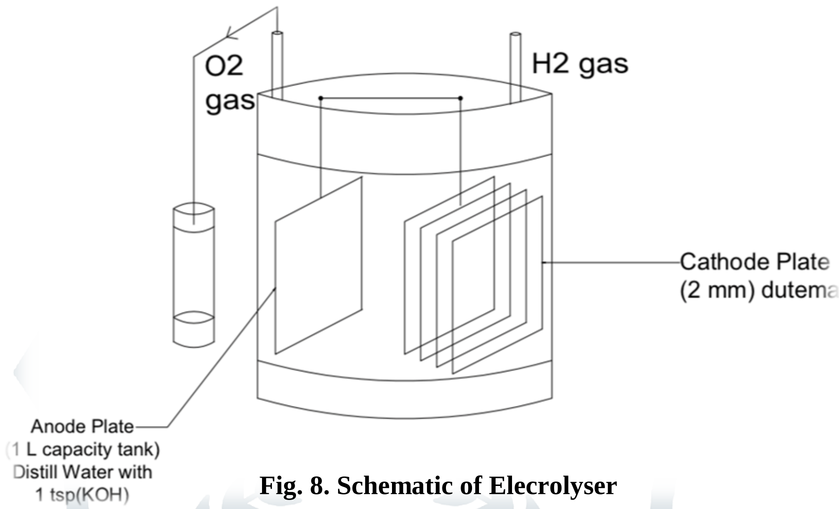

Fig. 8. Schematic of Elecrolyser

as oxygen gas (O_2).

At the anode: $2\,H_2O\,(l) \rightarrow O_2\,(g) + 4\,H^+\,(aq) + 4\,e^-$

At the cathode: $2\,H_2O\,(l) + 2\,e^- \rightarrow H_2\,(g) + 2\,OH^-\,(aq)$

Overall reaction: $2\,H_2O\,(l) \rightarrow 4H_2\,(g) + O_2\,(g)$

500µL of sample taken in syringe and injected in gas chromatograph having thermal conductivity detector and sent to lab for analysis of its purity.

Experimental setup of Electrolyser is as shown in the figure. As per the electrolytic reaction, it is clear that hydrogen is generated at anode, at the same time oxygen forms at cathode. As it's a single vessel, both mixes and forms an ignitable mixture of H_2 and O_2. Main task was to separate the oxygen and to maintain an uniform stream of hydrogen. Solution to this problem is to dissolve the oxygen into water and let go hydrogen. As oxygen is highly soluble in water, hydrogen insoluble, later one gets as pure as 99% H_2.

Details of Hydrogen generator unit are as follows:

3.1.1 Power supply: A standard dry battery capable of supplying continuous 12V DC and maximum 5 A DC current was used for the setup. The battery is rechargeable and connected in the circuit with fuse and potentiometer.

3.1.2 Potentiometer is a device which gives variable resistance. A knob in the device can be rotated to obtain different resistance values in the circuit. In our circuit, 2KΩ (Kilo Ohm) potentiometer is used. It can give resistance ranging from 0 Ω to 2 KΩ. This behavior of potentiometer allows us to adjust the current of potential difference across the electrolyser. Thus, with the help of a simple knob, hydrogen generation rate can be controlled by controlling current passing into electrolyser.

3.1.3 Electrode Plates: SS 304 was used to prepare electrode plates of size 2' * 2'. Five cathode plates and seven anode plates were mounted on the stainless steel rods, used as electrical connection between battery and electrode plates. SS 304 is considered best for transferring current into chemical solutions, without any rusting or by-reaction. Copper was used to pass electrons effectively into electrode plates.

3.1.4 Acrylic vessel: A customized vessel of acrylic material was used to prepare the outer vessel of electrolyser. Acrylic is transparent and clear view of how bouts of inside of electrolyser. As shown in the photograph, Acrylic cylinder was operated on lathe and packed from both sides with caps. Upper cap was drilled and valve openings were mounted on it. Also electrode rods were attached from the top of vessel. Acrylic vessel was well sealed off to prevent any gas/liquid leakages from it. A gas outlet was drawn out from the top itself. Total vessel capacity is 2.4 L. For experimental purpose it shall be filled up to ¾th of height, in order to keep electrode plates in touch with electrolyte solution.

Volume of electrolyser tank:

$$V = \frac{\pi}{4} * d^2 * H$$

Where, d & H are diameter[m] and Height[m] of the tank resp.

$$= \frac{\pi}{4} * (0.1)^2 * 0.3048$$

$$= 0.0024\ m^3\ (\text{i.e., } 2.4\ L)$$

3.1.5 Electrolyte solution: Electrolysis of pure distilled water will result into separation of water molecule into hydrogen and oxygen but the reaction is very slow. External catalyst is used to speed up the process. Here KOH (Potassium Hydroxide) was used. 4% KOH solution was prepared and kept in the acrylic vessel.

3.1.6. Pure Hydrogen: As a result of electrolysis mixture of hydrogen and oxygen is obtained and passed through a tube into another vessel filled with water, to dissolve oxygen and keep hydrogen free from impurities. Hydrogen samples was stored and sent to lab for testing the purity of hydrogen gas.

4. Results and Calculations:

Experiments over petrol engine were conducted in the laboratory. Fuel consumption of 10 ml was observed in terms of time taken by varying the load on engine by using Hydrogen and without using Hydrogen gas.. Thus, fuel consumption was analysed over different load conditions with and without H_2.

4.1 Experimental Results are tabulated as follows:

1. Without Introducing Hydrogen gas into Engine.

Table 2 Fuel consumption behavior without hydrogen

Load on Engine	**Fuel Consumption (mL)**	**Time for consumption(s)**
No Load Condition	10	19
Weight 2.5 Kg	10	12
Weight 7.5 Kg	10	11

2. After Introducing Hydrogen gas into Engine.

Table 3 Fuel consumption behavior with hydrogen

Load on Engine	**Fuel Consumption (mL)**	**Time for consumption(s)**
No Load Condition	10	24
Weight 2.5 Kg	10	20
Weight 7.5 Kg	10	14

It is now clearly evident that Hydrogen gas reduces the fuel consumption by considerable amount. This will make a difference over a long run. The results are plotted on the graph

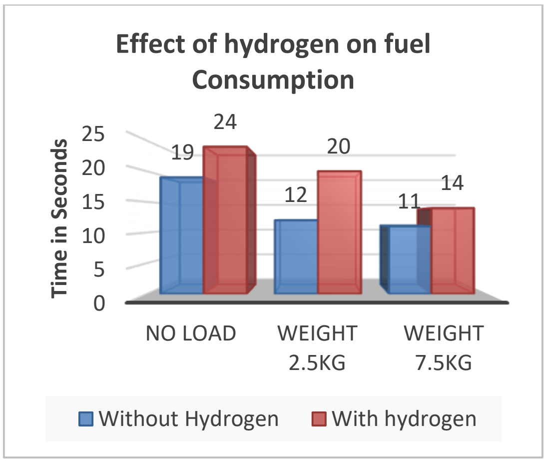

Fig. 9. Effect of hydrogen on fuel Consumption

4.2 Calculations of swept volume and clearance volume:

1) Swept volume (V_s):

$$V_s=(\Pi*d^2*L)/4=\{3.14 \text{ x } (0.05002)^2 \text{ x } 0.05\}/4= 9.83 \text{ X } 10^{-5} \text{ m}^3$$

Where d& L are diameter of piston &length of stroke respectively

2) Clearance volume (V_c):

$$V_c=(\Pi*d^2*L)/4=\{3.14 \text{ x } (0.05002)^2 \text{ x } 0.00976\}/4= 1.92 \text{ X } 10^{-5} \text{ m}^3$$

3) Compression Ratio (R_C)

$$R_c = (V_s + V_c) / V_c= 1+ V_s/V_c= 1+ 9.83 \text{ x } 10^{-5} / 1.92\text{x}10^{-5}= 6.12$$

4.3 Calculations of brake power and indicated power:

Compilation of results is represented in the following table:

Table 4 Results comparision

Without Hydrogen	Parameters	With Hydrogen
6.8646	Torque [N.m]	7.1428
3.1613	Break Power (bp) [kW]	3.4390
1.396	Total Fuel Consumption (TFC) [g/hr]	1.245
16.98 %	Break Thermal Efficiency [%]	20.72 %

4.4 Purity of hydrogen:

Hydrogen generation device was sent for testing the purity and flowrate. It was tested by M/s Bhagwati dyestuff industries Pvt. Ltd. Reports were obtained from laboratory.

Following tests were carried out on hydrogen generation device for automobile.

A. Hydrogen Generation rate:
   1) Hydrogen gas generation from device was measured by measuring through soap solution filled class – A burette (Range 50mL, least count 0.1mL) and time (stopwatch, range 99hrs, 59mins, 59secs, 1/100 secs, least count 0.01 sec).
   2) The volume of hydrogen gas generated at 12V DC and 5A measured along with time.
   3) Average of three reading at a particular current is reported.

B. Hydrogen generation purity(Gas Analysis): (As per IS 9434-1992)
   1) The sample of hydrogen gas evolved from one port of the device was sampled in a gas tight sampling bomb (25 mL capacity) at ambient temperature. The gas from another port was vented in atmosphere. 500 mL of the sample taken in a gas tight syringe and injected into a gas chromatograph having Thermal Conductivity Detector(TCD) and analyzed for its purity.(least count 0.01%)
   2) The results are reported in term of % purity, where Voltage (DC), Current (Amp) and Flow rate (mL/min) is 11.57 V, 4.8 A and 354 mL/min respectively.

Hydrogen Generation Purity:

Table 5 Purity of Hydrogen generated

Sr. No.	Name of Gas	Purity (%)
1.	Hydrogen (H_2)	99.6
2.	Oxygen (O_2)	0.4

5. CONCLUSION

Electrolysis of alkaline water yields better quality of hydrogen using proper hydrogen – oxygen separation process. Continuous stream of pure hydrogen gas can be obtained by the electrolyser device. Hydrogen with 99.6% purity was obtained and used for conducting experiments. The behavior of gasoline engine was studied under controlled conditions with and without hydrogen gas and graphs were plotted (Fig. 9). It was found that Break thermal efficiency improved by 3.74% with the hydrogen gas. However there was reduction in the Total fuel consumption due to the use of hydrogen gas. Torque and Break power were also found to be improved by enriching the fuel with hydrogen gas.

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