



HYDROGEN ENHANCED CO-COMBUSTION IN I C ENGINE AND ITS EXHAUST ANALYSIS

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ABSTRACT

By combusting hydrogen with oxygen, in Spark Ignition Engine Fuelled by hydrogen, the comparative analysis shows that some amount of water is produced along with fewer amounts of harmful gases, making hydrogen the ultimate in “green” fuels. However, in air and at high burning temperatures, it also produces some oxides of nitrogen. These features make hydrogen an excellent fuel, potentially, meeting the ever increasingly stringent environmental controls of exhaust emissions from combustion devices. This also includes the reduction of greenhouse gas emissions. In a 4 stroke SI Engine hydrogen (which is produced by electrolysis) is injected to the engine cylinder with gasoline. emissions are observed by reducing the gasoline supply with the help of exhaust gas analyser. Different emission readings of CO, CO₂, HC, NO_x are taken by reducing the gasoline supply. Considerable reductions in emissions like CO, CO₂ are observed. So with hydrogen as an alternative fuel can be a solution to global warming to certain extent.

Keywords: Fossil Fuel, Greenhouse Gases, Renewable Energy, Hydrogen, Detonation

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I. INTRODUCTION

Fossil fuels (i.e., petroleum, natural gas and coal), which meet most of the world's energy demand today, are being depleted rapidly. Also, their combustion products are causing global problems, such as the greenhouse effect, ozone layer depletion, acid rains and pollution, which are posing great danger for our environment, and eventually, for the total life on our planet.

Due to the increased pollution problems and the energy crises, many researchers have considered alternative fuels to decrease fuel consumption, and lower the toxic emissions in the combustion products. Many have studied the effect of using hydrogen as an alternative fuel (pure or mixed with other fuel) on the performance of engines and pollutants emissions.

Hydrogen is one fuel that can be produced entirely from plentiful renewable resource water through the expenditure of relatively much energy. Many engineers and scientists also agree that the solution to all the global problems would be to replace the existing fossil fuel system with the clean hydrogen energy system.

Hydrogen is a very efficient and clean fuel. Its combustion will produce no greenhouse gases, no ozone layer depleting chemicals, and little or no acid rain ingredients and pollution. Hydrogen, produced from renewable energy (solar, wind, etc.) sources, would result in a permanent energy system which would never have to be changed.

By combusting hydrogen with oxygen, in Spark Ignition Engine Fuelled by hydrogen, the comparative analysis shows that some amount of water is produced along with fewer amounts of harmful gases, making hydrogen the ultimate in “green” fuels. However, in air and at high burning temperatures, it also produces some oxides of nitrogen. These features make hydrogen an excellent fuel, potentially, meeting the ever increasingly stringent environmental controls of exhaust emissions from combustion devices. This also includes the reduction of green house gas emissions. This would be more appropriate to meet the emission restriction which will be imposed later.

Fossil fuels possess very useful properties not shared by non-conventional energy sources that have made them popular during the last century. Unfortunately, fossil fuels are not renewable. In addition, the pollutants emitted by fossil energy systems (e.g. CO, CO₂, C_nH_m, SO_x, NO_x, radioactivity, heavy metals, ashes, etc.) are greater and more damaging than those that might be produced by a renewable based hydrogen energy system. Since the oil crisis, considerable progress has been made in the search for alternative energy sources. A long term goal of energy research has been, the seek for a method to produce hydrogen fuel economically to prove it to be an ultimate primary energy source. Lowering of worldwide CO₂ emission to reduce the risk of climate change (greenhouse effect) requires a major restructuring of the energy system. The use of hydrogen as an energy carrier is a long term option to reduce CO₂ emissions. However, at the present time, hydrogen is not competitive with other energy carriers. Global utilization of fossil fuels for energy needs is rapidly resulting in critical environmental problems throughout the world. Energy, economic and political crises, as well as the health of humans, animals and plant life, are all critical concerns. There is an urgent need of implementing the hydrogen technology.

A worldwide conversion from fossil fuels to hydrogen would eliminate many of the problems and their consequences. The production of hydrogen from non-polluting sources is the ideal way. The amount of solar energy reaching the Earth is enough to supply mankind with many thousand times the energy it presently requires. This energy supply is, however, neither constantly available nor distributed equally over the surface of the globe.

II. GENERAL DESCRIPTION

There are a number of unique features associated with hydrogen that make it remarkably well suited in principle, to engine applications. Some of these most notable features are the following:

Hydrogen, over wide temperature and pressure ranges, has very high flame propagation rates within the engine cylinder in comparison to other fuels. These rates remain sufficiently high even for very lean mixtures that are well away from the stoichiometric mixture region.

The associated energy release is also so fast that the combustion duration, tends to be short and contributes towards producing high-power output efficiencies and high rates of pressure rise following spark ignition. The lean operational limit mixture in a spark ignition engine when fuelled with hydrogen is very much lower than those for other common fuels. This permits stable lean mixture operation and control in hydrogen fuelled engines.

The operation on lean mixtures, in combination with the fast combustion energy release rates around top dead center associated with the very rapid burning of hydrogen–air mixtures results in high-output efficiency values. Of course, such lean mixture operation leads simultaneously to a lower power output for any engine size. One of the most important features of hydrogen engine operation is that it is associated with less undesirable exhaust emissions than for operation on other fuels. As far as the contribution of the hydrogen fuel to emissions, there are no unburnt hydrocarbons, carbon monoxide, carbon dioxide, and oxides of sulphur, smoke or particulates. The contribution of the lubricating oil to such emissions in well-maintained engines tends to be rather negligible. Only oxides of nitrogen and water vapor are the main products of combustion emitted. Also, with lean operation the level of NO_x tends to be significantly smaller than those encountered with operation on other fuels.

The fast burning characteristics of hydrogen permit much more satisfactory high-speed engine operation. This would allow an increase in power output with a reduced penalty for lean mixture operation. Also, the extremely low boiling temperature of hydrogen leads to fewer problems encountered with cold weather operation. Varying the spark timing in hydrogen engine operation represents an unusually effective means for improving engine performance and avoidance of the incidence of knock. Also, the heat transfer characteristics of hydrogen combustion in engines are significantly different from those in engines operating on other fuels. The radiative component of heat transfer tends to be small yet the convective component can be higher especially for lean mixture operation. The sensitivity of the oxidation reactions of hydrogen to catalytic action with proper control can be made to serve positively towards enhancing engine performance.

III. FEATURES OF HYDROGEN FOR ENGINE APPLICATIONS

In addition to the previous unique features associated almost exclusively with hydrogen, a number of others can be cited in support of hydrogen applications in engines. To list some of the main of these features:

Less cyclic variations are encountered with hydrogen than with other fuels, even for very lean mixture operation. This leads to a reduction in emissions, improved efficiency, and quieter and smoother operation. Hydrogen can have a high effective octane number mainly because of its high burning rates and its slow pre-ignition reactivity. Hydrogen has been shown to be an excellent additive in relatively small concentrations, to some common fuels such as methane. Its gaseous state permits excellent cold starting and engine operation. Hydrogen remains in gaseous state until it reaches its condensation point around 20 K. Hydrogen engines are more appropriate for high-speed engine operation mainly due to the associated fast burning rates. Less spark advance is usually needed, which contributes to better efficiencies and improved power output as the bulk of the heat release by combustion can be completed just after the TDC region. Hydrogen engine operation can be associated with less heat loss than with other fuels.

Moderately high compression ratio operation is possible with lean mixtures of hydrogen in air, which permits higher efficiencies and increased power output.

Hydrogen engines are very suitable for cogeneration applications since the energy transfer due to condensing some water vapor can add up significantly to the thermal load output and the corresponding energy efficiency. Hydrogen unlike most other commercial fuels is a pure fuel of well-known properties and characteristics, which permits continued and better optimization of engine performance.

The reaction rates of hydrogen are sensitive to the presence of a wide range of catalysts. This feature helps to improve its combustion and the treatment of its exhaust emissions. The thermodynamic and heat transfer characteristics of hydrogen tend to produce high compression temperatures that contribute to improvements in engine efficiency and lean mixture operation.

Hydrogen high burning rates make the hydrogen fuelled engine performance less sensitive to changes to the shape of the combustion chamber, level of turbulence and the intake charge swirling effect. Internal combustion engines can burn hydrogen in a wider range of fuel-air mixtures than with gasoline. Hydrogen with wider flammability limits and higher flame speed makes it more efficient in stop and start driving. Hydrogen can tolerate better the presence of diluents. This would allow a better exploitation of low heating value fuel mixtures.

IV. PRODUCTION OF OXY-HYDROGEN GAS

Oxy-hydrogen is an enriched mixture of hydrogen and oxygen bonded together molecularly and magnetically (Brown, 1978). Oxy-hydrogen gas is produced in a common-ducted electrolyser and then sent to the intake manifold to introduce into combustion chamber of the engine. Oxy-hydrogen gases will combust in the combustion chamber when brought to its auto-ignition or self ignition temperature. For a stoichiometric mixture at normal atmospheric pressure, auto-ignition of oxy hydrogen gas occurs at about 570°C (1065°F). The minimum energy required to ignite such a mixture with a spark is about 20 micro joules. At normal temperature and pressure, 'oxy-hydrogen gas' can burn when it is between about 4 and 94% hydrogen by volume.

Electrolysis is the general method which is used for the generation of oxy-hydrogen gas. This method makes use of the basic principle of faradays law. An electrical power source is connected to two electrodes, or two plates typically made from some inert metal such as platinum or stainless steel which is placed in the water. In a properly designed cell, hydrogen will appear at the cathode (the negatively charged electrode, where electrons enter the water) and oxygen will appear at the anode (the positively charged electrode). Assuming ideal faradic efficiency, the amount of hydrogen generated is twice the number of moles of oxygen and both are directly proportional to the total electrical charge conducted by the solution. Following are the reactions that normally take place at cathode and anode:

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

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

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

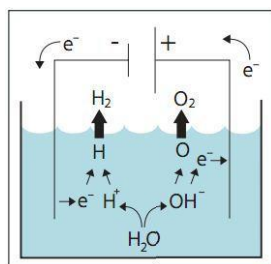


Fig 1 Electrolysis of Water

The electrolyser shown in Figure 1 is based on the common-duct series-cell electrolyser concept originally developed and patented by William Rhodes, Ernest Spirig, Yull Brown and later refined by Bob Boyce, George Wiseman, etc. It uses an alkaline (NaOH, KOH) electrolyte to split distilled water into hydrogen and oxygen components very efficiently.

The produced hydrogen and oxygen gasses are not separated to separate containers, but kept mixed. The produced oxy-hydrogen gas is a stoichiometric mixture of hydrogen (2 parts vol.) and oxygen (1 part vol.) and can be combusted in vacuum.

The combination of series-cell topology is very efficient, because it allows the cells to operate as close to their optimal cell voltage (1.47V) as possible. The electrolyser runs fairly cool, at about 3⁰-5⁰ C depending on the current and electrolyte.

V. EXPERIMENTAL SET-UP

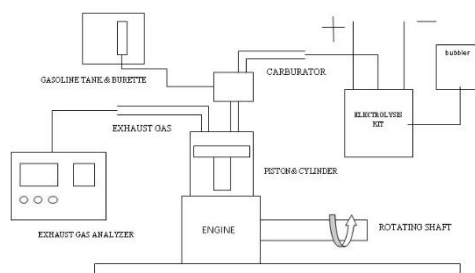


Fig-1 Block diagram of experimental set-up

Hydrogen is produced from the electrolysis circuit which is supplied to the 4-stroke SI engine before the carburettor simultaneously with the gasoline supply. The fuel metering device in the form of burette is used to calculate amount of gasoline (for certain period of time) supplied to the 4-stroke engine. The exhaust gas analyser is coupled with the silencer of the motor vehicle for exhaust gas analysis. The exhaust temperature measurement device is used to measure the exhaust temperature of the exhaust gases. Digital tachometer is used to measure the engine RPM at different fuel supply. Stop watch is used to measure the time-period for certain amount of fuel consumption.

VI. EXPERIMENTAL PROCEDURE

The experiment includes following steps:

- ✚ Fill the oil tank with gasoline. Then regulates the oil by means of a regulator so that the burette will fill up to certain level.
- ✚ Start the engine.
- ✚ Set the tuning to run the engine at constant RPM with out the use of throttle valve.
- ✚ Note the engine RPM by means of a digital tachometer.
- ✚ Calculate and note the time taken for consumption of 2cc of gasoline by means of a stopwatch.
- ✚ Emission analysis and exhaust temperature are measured with the help of an exhaust analyser and digital thermometer respectively.
- ✚ Connect the electrolytic cell with a 12 volt battery so that oxy-hydrogen gas will be generated in the electrolysis kit.
- ✚ Connect the oxy-hydrogen pipe to engine carburettor.
- ✚ Wait for 2 minutes so that the hydrogen gas will completely mix with the air-gasoline mixture and the engine will run at constant RPM.
- ✚ Note the RPM of the engine and this RPM is brought to the previous RPM recorded while running with gasoline only by adjusting the fuel knob.
- ✚ Again we measure the consumption of 2cc of gasoline and note the difference between the two (gasoline and gasoline with hydrogen).
- ✚ Again we measure the exhaust emission and exhaust temperature and note down the readings.

VII. DESCRIPTION OF TEST RIG

				
Fig.6.2 4-Stroke Engine	Fig.6.3.fuel metering system	Fig.6.4 Electrolysis kit for production of Hydrogen Gas	Fig.6.5A. Front view of the Electrolysis Circuit	Fig.6.5 B. Top view of the Electrolysis Circuit

			
Fig 6.6 Exhaust gas Analyzer		Figure 6.7 Digital Tachometer	Figure 6.8 Stopwatch
A. Front view	B. Back side view		

FUEL SUPPLY SYSTEM WITH METERING

The primary fuel of engine i.e. Gasoline is stored in the fuel tank of the bike. Here an extra arrangement of tank is done for the measuring process. The required pipe arrangements are done to supply the fuel to the engine [1]. One calibrated burette of capacity 30 ml is connected with the external tank. The fuel from tank first comes to the burette, then it is supplied to the engine through carburettor.

Hydrogen gas is used as the very important hybrid fuel for the engine. It is used as the secondary fuel of the engine. The hydrogen gas is produced by “Electrolysis Process”. This gas is also supplied to the engine through carburettor with some amount of gasoline.

ELECTROLYSIS CIRCUIT

The electrolysis circuit is a handmade device to produce the Oxy-Hydrogen gas from dissociation of water with KOH, when the external electricity is supplied. Some important features of this kit are:

- Electrolytic plate : 316 L Stainless Steel
- Electrolyte used : H₂O & KOH
- Spacer : Gasket
- End packing plate : Transparent Acrylic
- Packing material : Silica gel
- No. of plates : 7
- Dimension of plates : 160 x 200 mm
- No. of gaskets : 8
- Weight : 1.3 Kg
- Negative polarity supply : External two plates
- Positive polarity supply : Middle plate
- Battery : 12 V Excide
- Ammeter : 50 amp. Max.

EXHAUST GAS ANALYSER

To analyse the different composition of exhaust one Multi gas Analyzer is used. This electronic analysing device is made up of “NETEL COMPANY” having model NPM-MGA-1.

This model NPM-MGA-1 Multi Gas Analyzer is based on the international accepted principle of non-depressive infrared (NDIR) absorption. It is designed for measurement of CO, CO₂, HC and NO_x in the exhaust of 2-stroke and 4-stroke automotive petrol engines. A check of exhaust gases (CO, CO₂, HC and NO_x) from petrol engines essential if an engine is to be correctly set up or in order to diagnose possible operative malfunctions.

Unless exhaust values are correctly adjusted, it is absolutely impossible to obtain a good engine performance, particularly when the engine is equipped with electronic injection. Monitoring of Auto exhaust emission is currently essential in order to set up the engine correctly or to diagnose malfunctions.

The essential features of this analyser are:

RANGE OF MEASUREMENT

➤ CO	: 0 to 9.99% vol. Res. 0.01%
➤ HC	: 0 to 15000 ppm. (n-hexane) Res. ppm.
➤ CO ₂	: 0 to 20.00 % vol. Res. 0.10%
➤ Air/Fuel	: 0 to 30:1 Res.

Optional

➤ RPM Probe	: 0 to 9999 RPM Res. 10 RPM
➤ Oil Temp. Probe	: 0 to 150 deg. C Res. 1 deg. C
➤ NO _x	: 0 to 5000 ppm. Res. 1 ppm.
➤ Operating Temperature	: +5 deg. C to +45 deg. C Res. 2 deg. C
➤ Operating Pressure	: 800 to 1060 hpa
➤ Relative Humidity	: Up to 90% Max.
➤ Measuring Gas Intake	: 2 to 2.5 LPM approximately
➤ Flow Check	: Auto
➤ Leak Test	: Auto
➤ Condensate Discharge	: Auto
➤ Response Time	: < 6 second
➤ Warm Up Time	: Max. 60 seconds
➤ Power Supply	: 230 V+/- 10% 50 Hz.150 W
➤ Zero Setting	: Auto/ Manual
➤ Calibration	: Auto/ Manual
➤ Dimensions	: 400 x 320 x 200 mm
➤ Weight	: 10.5 Kg. Approximately

PRINCIPLE OF OPERATION

The instrument detects the CO/CO₂/HC/NO_x content according to the principle by which the selective absorption of infrared is measured for each gas.

The sample of gas is taken through the exhaust by means of the probe. The intake exhaust gas is further made free from the moisture with the help of moisture separator element. Dust is removed with help of dust element & inward filter. Then condensed moisture is routed to exhaust of the analyser through pump. Dust/moisture free sample gas is feed to the measuring cell.

Infrared light beam is directed to the measurement components (like optical filter& sensor), which is weakened at a certain wavelength by the sample gases in the cell.

Weakening occurs at specific wavelength according to the type of gas in question (absorption spectrum). Molecules of gas with the same type atoms (H₂/N₂/O₂) cause no

absorption in the infrared region of the spectrum. On the other hand, molecules with different types of atoms (CO, HC, CO₂, NO_x) show different absorption bands in the infrared region. The greater the gas concentration is, the greater the absorption will be. These variations can be detected with the aid of electronic sensors preceded by respective optical filters which allow infrared rays to pass only at the specific wavelength.

When the gas gets introduced in the cell the absorption take place due to gases, which reduce the infrared radiation reaching to the sensor. This measurement is converted to show as the concentration of that particular gas.

PORTABLE DIGITAL TACHOMETER (CONTACT TYPE)

Digital tachometer is sensing device which measures the RPM of the rotating engine shaft when it is contacted with it. The tachometer is developed with an advanced micro computer LIS circuit with Quartz Crystal to give a high accuracy and fast measurement. The use of durable, strong ABS plastic housing assumes maintenance free performance for long duration. Four number of pencil battery is used to supply the required amount of power. A high contrast Digital display is provided for the easy readings of the RPM. This digital tachometer can have a wide measurement range i.e. 15 to 75,000 RPM.

When the contact point of the tachometer is touched with the rotating shaft it just counts number of pulses for one minute then divide by 60, this gives the no. of pulses per min and its reciprocal time for these pulses will be $60/N$, where N are pulses for one minute. Then we apply these pulses (which in fact decide open gate time for counting the pulses of a clock signal). Now the no. of pulses of clock signal which are counted by a counter and divide by the open gate time ($60/N$) gives frequency of the of the rotating object. Since this frequency i.e. number of pulses, so this is the original speed (RPM) of the rotating shaft.

VIII. CALCULATION

CALCULATION FOR MASS FLOW RATE OF GASOLINE

- When only gasoline is supplied

Let t sec is required to burn v cc of gasoline when only gasoline is supplied to engine.

So mass flow rate of gasoline $= (V_{cc}/t) * \text{density of gasoline g/sec}$

Where of density of gasoline $= 0.770 \text{ g/cc}$ (assumption)

- When H_2 is supplied in addition to gasoline

Let t sec is required to burn V_{cc} of gasoline when both H_2 and gasoline is supplied to the engine.

Thus mass flow rate of gasoline $= (V_{cc}/t) \text{ g/sec} = m_1 \text{ g/sec}$

So save in mass flow rate of gasoline is when H_2 is supplied is $m_g = m_1 - m_2$

CALCULATION OF MASS FLOW RATE OF HYDROGEN

Energy supplied by H_2 = Energy saved by gasoline due to H_2 supply

Assuming C_v for gasoline $= C_{vg} = 50 \text{ KJ/gm}$

C_v for hydrogen $= C_{vh} = 140 \text{ KJ/gm}$

$140 \text{ KJ/gm} * m_{H_2} \text{ gm/sec} = 50 \text{ KJ/gm} * m_g \text{ gm/sec}$

Here m_{H_2} = mass of hydrogen supplied per sec

$m_{H_2} = 50 * m_g / 140 \text{ gm/sec}$

SAMPLE CALCULATION

From observation table, we get 34.56 sec is required to burn 2cc of gasoline when H₂ is not supplied to the engine.

So mass flow rate of gasoline without H₂ supplied= $m_1g=(2*0.770)/34.56 =0.044\text{gm/sec}$
 Again 40.38 sec is required to burn 2cc of gasoline when H₂ is supplied in addition to gasoline.
 So mass flow rate of gasoline without H₂ supplied = $m_2g=(2*0.77)/40.38 =0.038 \text{ gm/sec}$
 Therefore mass flow rate of gasoline due to H₂ supply = $mg =m_1g-m_2g$
 $=0.044-0.038$
 $=0.006 \text{ gm/sec}$

Mass flow rate of H₂

$M_{H_2} = (50*mg)/140 \text{ gm/sec}$
 $= (50*0.006)/140 \text{ gm/sec} = 0.00214 \text{ gm/sec}$
 Where M_{1g} = mass flow rate of gasoline when hydrogen is not supplied
 M_{2g} = mass flow rate of gasoline when hydrogen is supplied
 M_g = save of gasoline per second due to hydrogen supply
 M_{h_2} = mass flow rate of hydrogen

CALCULATION OF PERCENTAGE OF H₂

Combustion period for 1ml gasoline is T₁ sec. when H₂ is not supplied. For same power production when H₂ is supplied the combustion period become T₂ second. Hence additional amount of power is from H₂.

To calculate that percentage of H₂, first we have to find out the additional power production per gram = $(50*T_2)/T_1 = E \text{ KJ}$

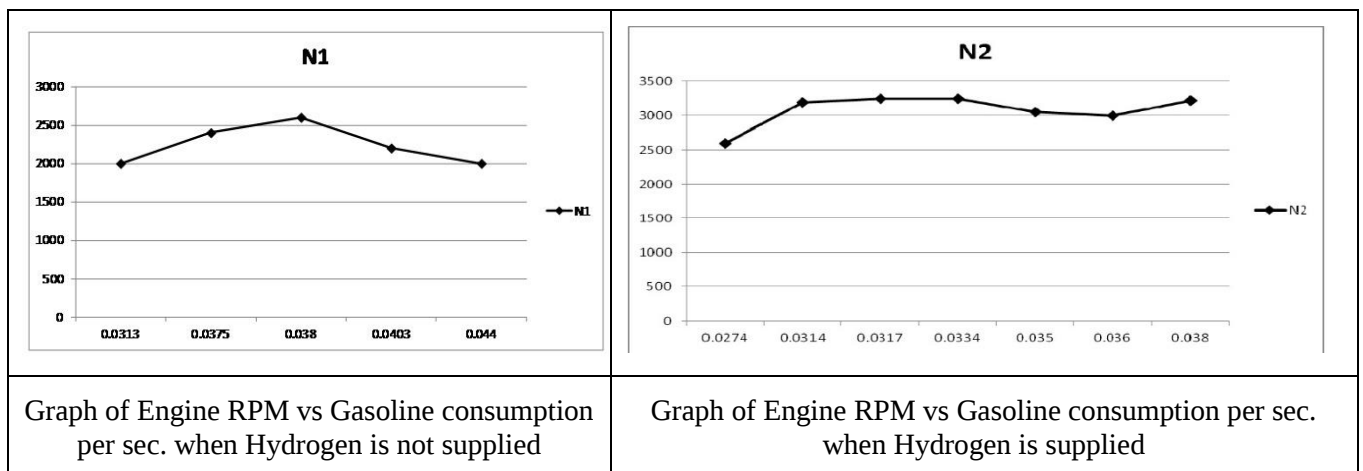
Additional power due to H₂ = $(E-50) \text{ KJ} = E_2(\text{say})$

Calorific value of 100 % H₂ = 140 KJ/gm.

Hence $(140*E_2)/100 = \text{percentage of H}_2$

IX. RESULTS

From above experiment we reached to some results like consumption of fuels, change in emission of different gases which is shown below in different graphical methods.



From the Fig-1 we can find that with increase in fuel consumption the engine RPM increases, after some richness or after stoichiometric fuel air ratio it again starts decreasing. This is due to with fuel enrichment incomplete combustion occurs, which leads to decrease in power production.

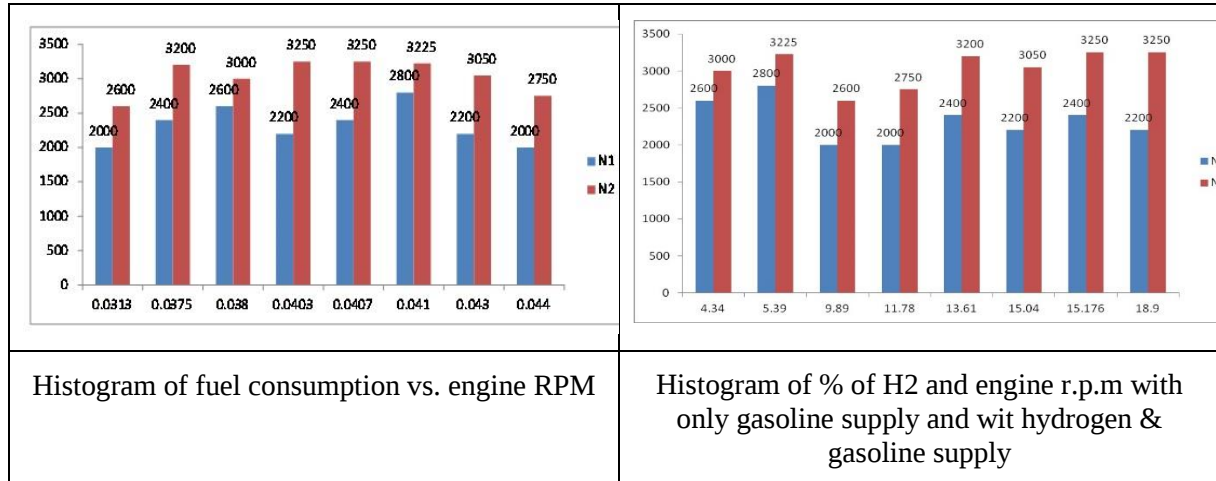
Power= $T * \omega$

Where T= torque in N-m

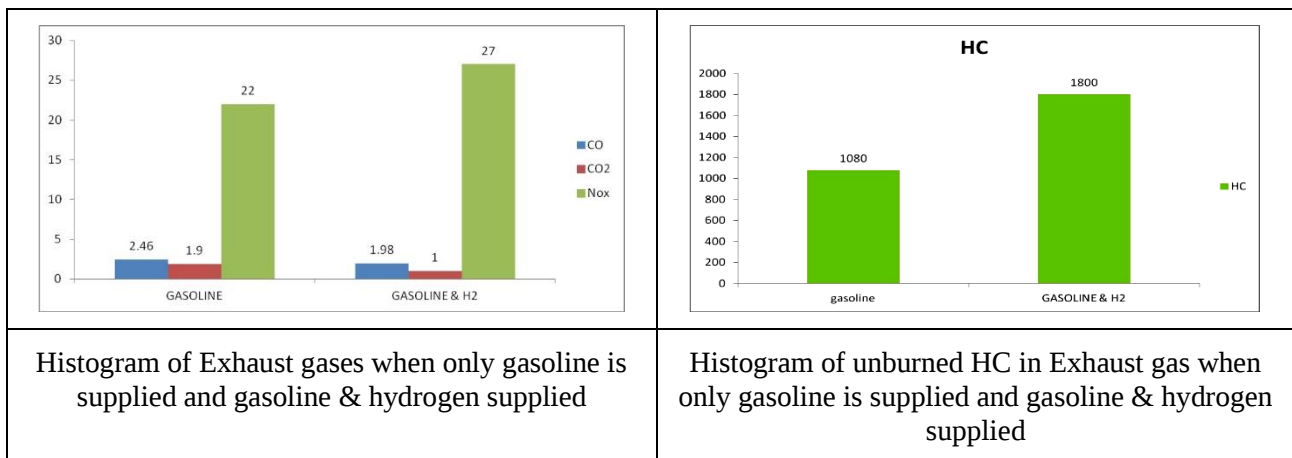
ω = speed of engine rad/sec

Hence ω will follow the trend of power production

- From Fig-2 we can find that the engine speed increases with increase in fuel supply.
- It can also seen that due to hydrogen supply, there is a significant increase in speed than that of supply of only gasoline, which can easily notice from the histogram.



- From above histogram it is clearly visualize that with increase in percentage of hydrogen the difference in RPM with hydrogen supply and without hydrogen supply increases. N1= engine speed when hydrogen is not supplied N2= engine speed when hydrogen is supplied along with gasoline



- From above two histogram it is resulted that there is a significant decrease in CO and CO2 composition due to supply of hydrogen gas.
- But we can also find that an increase in NOx and Hydro Carbon is also occurring. This can be explain as follows:
- With increase in hydrogen supply there is less fuel consumption, which directly reduces the composition of CO and CO2 in the exhaust gas.
- As the energy density of hydrogen gas is more than that of gasoline, hence maximum temperature increases, according to Zeldovic effect with increase in temperature NOx emission increases.
- With increase in hydrogen supply there is a significant increase in Hydrocarbon. Though hydrogen is more reactive than gasoline it will engulf oxygen more rapidly as compared to gasoline, which leads to increase of unburnt hydrocarbon.

X. FUTURE SCOPE

Till now we have developed our Electrolysis kit and the Hydrogen engine and we are able to calculate various parameters like fuel consumption, analysis of exhaust gases and calculation of engine speed. With application of advanced technology and knowledge we can convert it in a more advanced vehicle. Some of these ideas are:

- By varying the supply current, we can increase the production of Hydrogen gas up to 70%. So that we will achieve a better fuel consumption ratio.
- We will use better electrode to increase the production of Hydrogen.
- By adding additional equipments we will calculate the load factor, break power, maximum temperature and exhaust temperature.
- By providing a better and stable design we can make it run on road without any problem.
- To compensate the poor volumetric efficiency we can use a supercharge engine.

XI. CONCLUSION

From the above experiment we got the conclusion that by using “Hydrogen gas” as a hybrid fuel with gasoline there is a significant increase in power production and also a sharp decrease in exhaust emission like Carbon monoxide (CO), Carbon dioxide (CO₂). But there is a increase in emissions of Hydro carbon (HC) and NO_x.

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