An Experimental Investigation of Performance and Exhaust Emission Characteristics by Addition of HHO Gas in IC Engine

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Abstract— In this project, the main objective is to study alternative fuels which will benefit to enhance the engine's economic and performance characteristics. The advantage of using alternative fuels for internal combustion engine is among other a long-term renewable and less polluting fuel, non-toxic, odorless, and has wide range flammability. Alternative fuel is important and it should be fossil one. Actually, we spend one third of our income for our vehicle fueling and the vehicle gives harmful decomposed material like CO, NOx, HC, WCBSFC, etc. in the form of smoke. These materials are all affects the engine performance, and pollutes the environment. While crossing a gas or diesel operated car we can feel the small of the respective fuels, it should that the fuel is not completely burnt. It is explicit that we waste fuel and pollute the atmosphere. To avoid these drawbacks, the HHO has Polymorphism that it is acts differently – before burning, while burning, and after burning. Before burning of Hydrogen, which is a lightest gas with one proton and one electron and more efficient fuel three times of the explosive power then camper to fuel gas and five times than petrol. Actually, the hydrogen requires little bit of energy of ignition to produce wide level of tremendous flammable temperature in the speed of lightning and there is no chance to compare with other fuels in this world. As a result of fact, it increases the engine performance, torque, and millage and minimize the fuel consumption.

Keywords: Engine, Economic and Performance Characteristics, Alternative Fuel, Non-Toxic, Pollution, Polymorphism, Engine Efficiency

I. INTRODUCTION

A. Problem Statement:

As in new era we are facing the problem of increasing cost of conventional fossil fuels, researchers worldwide are working overtime to cost effectively improve internal combustion engine (ICE) fuel economy and performance characteristics. Alternate fuel is important and it should be fossil one. Actually, we spend one third of our income for our vehicle fueling and the vehicle gives harmful decomposed materials like CO, NOx, HC, WCBSFC, etc. in the form of smoke. These materials are all affects the engine performance, and pollutes the environment.

B. Objectives:

1) To reduce the pollution by using alternative fuels rather using conventional fuels.
2) To design engine which can operate on hydrogen fuel.
3) To improve fuel economy and performance characteristics of engine.
4) To save money by using alternative or renewable fuels.

C. Relevance:

Water is one of the free resources and by applying the technique, it can be converted into hydrogen with oxygen, its chemical term is HHO and in general "Free Energy". It is cheaper, safer, tremendous explosive and never pollutes the atmosphere. While crossing a gas or diesel operated car we can feel the smell of the respective fuels, it shows that the fuel is not completely burnt. It is explicit that we waste fuel and pollute the atmosphere. To avoid these drawbacks, The HHO has Polymorphism that is it acts differently - before burning, while burning, and after burning. Before burning of Hydrogen, which is a lightest gas with one proton and one electron and more efficient fuel three times of the explosive power when camper to fuel gas and five times than petrol. Actually, the Hydrogen requires little bit of energy of ignition to produce wide level of tremendous flammable temperature in the speed of lighting and there is no chance to compare with other fuel in this world. As a result of fact, it increases the engine performance, torque, and millage and minimizes fuel consumption. During burning the HHO into the engine with a tremendous explosion on that area and gives off high power of energy and automatically reverts to water vapor at once. Due to this action the engine not only getting higher torque but also gets easily cooled from 10 to 20 times faster than other fuels.

II. LITERATURE REVIEW

A. Bhavesh V. Chauhanet.al [1]

In this paper they stated that, petroleum-based fuels which are more in demand in the world. Fossil fuels are available in limited reserves. Nowadays, more researchers focus on protecting the environment and maintain the greenhouse effect. So, in this study they use the hydrogen gas with diesel fuel in CI engine. Many processes and methods of hydrogen production are found by researchers. Some processes are not economical so, in this paper use the cheaper method of hydrogen production which is electrolysis process. The HHO gas was produced by the process of water electrolysis. Hydroxy gas was produced by the electrolysis process of different electrolytes with various electrode designs in a hydrogen generator. In this experiment hydrogen used at a constant flow rate in CI engine. This paper presents the concern with the HHO gas addition on performance and combustion characteristics of a constant speed CI engine with variable compression ratio like that 16, 17 and 18 and variable load like that 1, 3, 5, 7and 9. The effect will be shown on the graphs of CI engine for the brake thermal efficiency, indicated thermal efficiency, mechanical efficiency and fuel consumption with the use of HHO and a variable compression ratio at 16, 17 and 18 and variable load like that 1, 3, 5, 7and 9.

B. Ali Can Yilmazet.al. [2]

In this paper al They have said that, hydroxy gas (HHO) was produced by the electrolysis process of different electrolytes KOH (aq), NaOH(aq), NaCl(aq)) with various electrode designs in a leak proof plexiglass reactor (hydrogen generator). Hydroxy gas was used as a supplementary fuel in a four-cylinder, four stroke, compression ignition (CI) engine without any modification and without need for storage tanks. Its effects on exhaust emissions and engine performance characteristics were investigated. Experiments showed that constant HHO flow rate at low engine speeds (under the critical speed of 1750 rpm for this experimental study), turned advantages of HHO system into disadvantages for engine torque, carbon monoxide (CO), hydrocarbon (HC) emissions and specific fuel consumption (SFC). Investigations demonstrated that HHO flow rate had to be diminished in relation to engine speed below 1750 rpm due to the long opening time of intake manifolds at low speeds. This caused excessive volume occupation of hydroxy in cylinders which prevented correct air to be taken into the combustion chambers and consequently, decreased volumetric efficiency was inevitable. Decreased volumetric efficiency influenced combustion efficiency which had negative effects on engine torque and exhaust emissions. Therefore, a hydroxy electronic control unit (HECU) was designed and manufactured to decrease HHO flow rate by decreasing voltage and current automatically by programming the data logger to compensate disadvantages of HHO gas on SFC, engine torque and exhaust emissions under engine speed of 1750 rpm. The flow rate of HHO gas was measured by using various amounts of KOH, NaOH, NaCl (catalysts). These catalysts were added into the water to diminish hydrogen and oxygen bonds and NaOH was specified as the most appropriate catalyst. It was observed that if the molarity of NaOH in solution exceeded 1% by mass, electrical current supplied from the battery increased dramatically due to the too much reduction of electrical resistance. HHO system addition to the engine without any modification resulted in increasing engine torque output by an average of 19.1%, reducing CO emissions by an average of 13.5%, HC emissions by an average of 5% and SFC by an average of 14%.

C. Mohamed Samathet.al [3]

This paper gives an idea about past history of IC engine design and development, hydrogen has been considered as a better replacement to hydrocarbon-based fuels. Hydrogen gas combustion produces uncontaminated exhaust from spark ignition engine due to its desirable characteristics. Hydrogen for the experiment is produced by using fuel cells, and they examine the performance characteristics and emissions of a hydrogen fueled conventional spark ignition engine. Slight modifications are made for hydrogen feeding, which do not change the basic characteristics of the original engine. Comparison is made between the gasoline and hydrogen operation was discussed. The important pollutants from spark ignition engine like HC, CO, smoke and NOx are reduced due to hydrogen combustion. Certain remedies to overcome the backfire phenomena are attempted.

D. Karagoz Yet.al [4]

In this paper they have stated that, use of hydrogen in SI engines as additional fuel to gasoline rises as a preferable fuel through both enhanced combustion characteristics, relative lower costs and good applicability hence, storage and production handicaps limit use of hydrogen in road vehicles. In the framework of the study hydrogen was introduced into the inlet manifold, used in ICE as supplementary fuel to gasoline. Asset of tests using various amount of hydrogen-oxygen addition has been carried out in order to observe the effects of hydrogen addition on performance and emissions. Three different supplementary fuel which contains 0% H_2, 3% H_2 + 1.5% $O_2$and 6% H_2 + 3% O_2volume fractions of intake air, were used during the tests where 0% represents pure gasoline. H_2/O_2mixture fed into the intake manifold. Results show that higher brake thermal efficiencies, maximum brake torque and power, lower HC and CO emissions are achieved using H_2/O_2mixture as additional fuel to gasoline. Also, regarding higher in-cylinder temperature field and higher combustion efficiency, increased NOx and CO_2 emissions were observed.

E. M. R. Dahakeet.al. [5]

In this paper they have stated that emission from engine exhaust is serious problem from environment point of view. For that search, alternative fuels are encouraged. Hydroxy gas (HHO) is expected to be one of the most important alternate fuel in the near future to meet the stringent emission norms. The hydroxy (HHO) gas enrichment is resulted in better combustion and reduced emission outputs in compression ignition engines. To assist the poor ignition characteristics of diesel, the HHO gas can be used to improve combustion. When the hydroxy gas is enriched with air in diesel engine, the thermal efficiency for compression ratio 18 increases by 9.25% comparing to baseline diesel combustion and the specific fuel consumption is reduced by 15% at full load condition. The HC emission is reduced at an average of 33% due to better combustion at higher compression ratio with hydroxy gas. The CO emission is reduced marginally, an average of 23% reduction of CO emission is observed. NO is increased with hydroxy gas enrichment at full load condition. The exhaust gas temperature is also increased. Smoke opacity is 8% as compared 10% for baseline diesel operation is observed.

F. Yasin Karagoz, et.al [6]

This paper gives they have studied use of hydrogen in spark ignition engines as a supplementary fuel can enhance combustion and reduce toxic emissions. Difficulties in hydrogen storage and production limit its use in internal combustion engines. This paper investigates the performance of a spark ignition engine with the addition of a mixture of hydrogen (H_2) and oxygen (O_2) into the intake manifold. Hydrogen is produced by an alkaline electrolyser and consumed simultaneously to eliminate the need for a storage device. Flow rates of 0 and 10 L/min H_2-O_2mixture were introduced into the manifold. No flow, or 0 L/min, refers to the case without hydrogen, and 10 L/min represents the case with hydrogen. Brake torque, fuel consumption, nitrogen oxides, carbon monoxide, and total unburned hydrocarbons were measured. The results show that brake power, brake torque, and nitrogen oxide emissions increased with the addition of H2-O2, while total unburned hydrocarbons, carbon monoxide emissions, and brake-specific energy consumption decreased.

G. Shrikant Bhardwaj et.al [7]

In this paper they have stated that, there is something great importance to the world that is being suppressed and hidden, that abundant, clean energy can be derived from water. Water can be cheaply disassociated into Brown Gas (HHO) using efficient electrolyzing techniques which require very little power to operate, or sophistication to build. Brown Gas is a mixture of di-atomic and mono-atomic hydrogen and oxygen. It does not have a set burning temperature It reacts to the substance; it is contact with when being burned. It when mixed with Diesel or gasoline fuels will increase the burning efficiency of the mixture greatly. When HHO is added to the fuels and ignited, much more of the hydrocarbons are burned completely, creating much cleaner exhaust and more power to the engine. The result is increased gas mileage and smoother running, longer lasting motors that waste much less energy. This gas may take as a mileage Booster. HHO boosters help to reduce pollution and save energy and money all over the world. One aspect of HHO that it shows it's more superior heating phenomenon than any other energy because it has a high-temperature concentration phenomenon

H. Fenilet.al [8]

In this paper they have stated that, the menace posed by climate change and the striving for security of energy supply is issues high on the political agenda these days. Governments are making strategic plans in motion to reduce primary energy use, take carbon out of fuels and alleviate modal shifts. Electrolysis of water can give us hydrogen in form of oxy-hydrogen gas which can be used as an alternative fuel for any internal combustion engine. The work contains method design for the production of oxy-hydrogen gas. Later, blend of oxy-hydrogen gas and petrol or diesel is used instead of only petrol/diesel to study the influence of the oxy-hydro gas on the performance of the internal combustion engine. This article offers a comprehensive overview of HHO. Issues that are discussed include fundamental of internal combustion engine parameters, details of power calculations and their emissions characteristics and a state of the art on increasing power output and efficiency with lesser fuel consumption while controlling emissions.

I. A.Vamshi Krishna Reddyet.al [9]

They have stated that, the rapid depletion of fossil fuels and rising of oil prices has led to the search for Secondary fuels. The Secondary fuels that we are using should have the same efficiency or greater efficiency of the engine that uses ordinary fuel. In this project the secondary fu el used is HHO gas. HHO otherwise known as hydroxyl or Browns Gas is the gas produced from splitting water into hydrogen and oxygen from electrolysis and allowing the gas to stay in a premixed state for use on-demand without the need for storage. This reduces the exhaust gas emitted during the working of engine, and the temperature of the engine is also reduced which is produced by the burning of ordinary fuels. The HHO gas is injected into the inlet manifold of the combustion chamber through the air filter of the engine. From this design the fuel utility is reduced from 10% to 30% which minimizes the carbon deposition in the cylinder thereby increasing the changing period of engine oil, it also improves the efficiency of the engine and the life span. Engine torque also increased and pollution gets reduced to maintaining the greenhouse effect.

J. Prasad Kumar Puthaet.al [10]

They have stated that, in recent years, many researchers have focused on the study of alternative fuels which benefit enhancing the engine economic and emissions characteristics. In the present work, hydroxy gas (HHO), which was produced by the electrolysis process of an electrolyte (KOH (aq)) with stainless steel electrodes in a leak proof plexiglass reactor (hydrogen generator) is used as working substance. Hydroxy gas was used as a supplementary fuel in a single cylinder, spark ignition (SI) engine without any modification and without need for storage tanks. It effects on exhaust emissions. Engine performance characteristics and specific fuel consumption are investigated.

III. METHODOLOGY

This study/project would be consisting of following chronological step of working:

1) Phase I: Review of literature regarding the work to be done Broad review of the literature on this proposed topic. Review of the HHO generation methods, use of HHO in IC Engine and its effect on the performance of engine and engine emission will be studied.
2) Phase II: Development of HHO generator-Development of HHO generator by considering various approaches available for HHO generation, Also selection of HHO generation method according to the application. We design the various part of the pneumatic bumper like, chaises, cylinder, wheels, bumpers and braking system.
3) Phase III: Emission characteristics of engine- As we will be using HHO gas in the internal combustion engine, the emissions exhausted by the engine will be analysed in this phase.
4) Phase IV: Performance characteristics of CI engine-: By using HHO gas in the internal combustion engine. The various performance characteristics will be studied in this phase such as torque, power, and brake specific fuel consumption.

A. Working Principal:

1) Battery is connected to HHO generator.
2) When current is passed through the HHO generator the electrolysis process occurs giving HHO gas as a output.
3) Mainly HHO gas contains 2 hydrogen atoms and 1 oxygen atom. This gas is then passed before carburettor which is located after air cleaner.

4) Here air and oxy hydrogen gas gets mixed and passes to carburettor.
5) In the carburettor by using some controlling device mixture of air and oxy- hydrogen gas is supplied to the engine

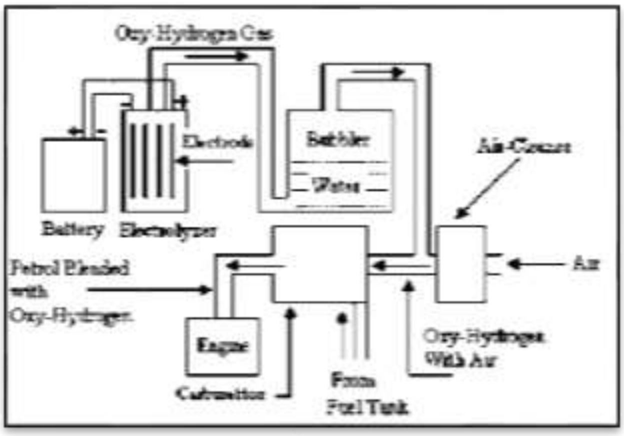

Fig. 3.1: Proposed Layout of Test Rig

B. Effect on performance of IC Engine

Improve internal combustion engine (ICE) fuel economy and performance characteristics. A long-term renewable and less polluting fuel, non-toxic, odorless, and has wide range flammability. Hydrogen is more efficient fuel three times of the explosive power when camper to fuel gas and five times than petrol. The Hydrogen requires little bit of energy of ignition to produce wide level of tremendous flammable temperature in the speed of lighting and there is no chance to compare with other fuel in this world. It increases the engine performance, torque, and millage and minimizes fuel consumption. During burning the HHO into the engine with a tremendous explosion on that area and gives off high power of energy and automatically reverts to water vapor at once. Due to this action the engine not only getting higher torque but also gets easily cooled from 10 to 20 times faster than other fuels. Thus, the engine life period gets wider, and reduces lubricating oil degradation beyond the limit of Km. Oil changing period also gets lengthened. It leads in decrease of the maintenance cost and increase of interval of maintenance. Thus, the exhausts emission (CO, NOx, HC, WCBSFC, etc.) also controls from 10% to 50%. The pollution also reduces and remaining Oxygen comes out from the exhausts.

C. Expected Outcomes

1) Improved performance characteristics such as less fuel consumption, Power, Torque characteristics.
2) Reduction in the emissions from the engine (CO, NOx, HC, WCBSFC, etc.).

D. Important Elements

1) HHO Generator

Hydrogen is one of the new and renewable energy which has a calorific value of 120 MJ/kg. The energy value is much greater than with gasoline, diesel or CNG gas fuel respectively. One way to get hydrogen is by electrolysis of water, a method for separating hydrogen and oxygen in water using an electric current. The equipment used is called HHO gas generator, which consists of dry and wet type.

Process	Advantages	Disadvantages
Solar gasification	Good hydrogen yield	Effective solar collector plates are required
Thermo-chemical gasification	Higher conversion can be achieved	Gas conditioning and tar removal is to be done
Pyrolysis	Gives carbonaceous material with oil, chemicals and minerals	Catalyst deactivation will occur
Supercritical conversion	Sewage sludge can be used easily, difficult by gasification	Selection of supercritical medium
Direct bio-photolysis	H_2 can be produced directly from water and sunlight	Requires high intensity of light, low photochemical efficiency and O_2 is inhibitory.
Indirect bio-photolysis	Blue green algae can produce hydrogen from water. It has the ability to fix N_2 from atmosphere	Uptake hydrogenases are to be removed.
Photo-fermentation	A wide spectral energy can be used by photosynthetic bacteria.	O_2 is inhibitory on nitrogenase enzyme and light conversion efficiency is low.
Dark fermentation	It can produce H_2 without light. No oxygen limitations and can produce several metabolites as by-products. Various substrates can be used in this anaerobic process.	Relatively lower H_2 yield. At higher H_2 yield, process becomes thermodynamically unfavorable.
Two-stage fermentation	Can produce relatively higher H_2 yield. By-products (metabolites) can be efficiently converted to H_2.	Requires continuous light source which is difficult for large scale processes.

Fig. 3.2: Advantages and limitations of various hydrogen production processes

2) Electrolysis Process

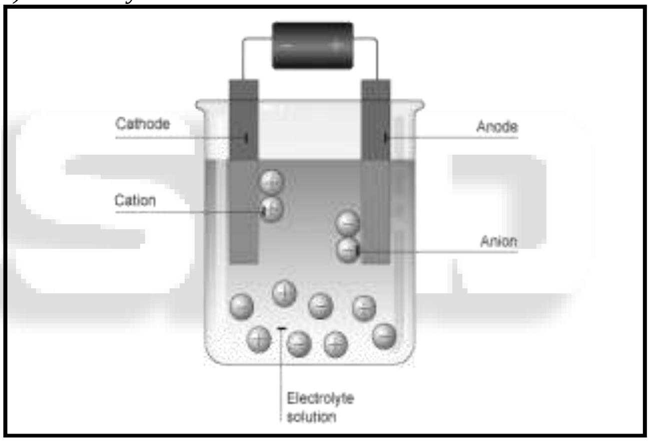

Fig. 3.3: Electrolysis component

Electrolysis process at the HHO gas generator will separate the atoms bond 2H2O into 2H2 and O2, which this gas is known as HHO gas or Brown's gas. Electrolysis is an electrochemical process in which electrical energy is the driving force of chemical reactions. Substances are decomposed, by passing a current through them.

As mentioned before, water is decomposed to hydrogen and oxygen, by passing a current through it in the presence of suitable substances, called electrolytes. Electric current causes positively charged hydrogen ions to migrate to then negatively charged cathode, where a reduction takes place in order to form hydrogen atoms. The atoms formed then combine to form gaseous hydrogen molecules (H2). On the other hand, oxygen is formed at the other electrode (the positively charged anode). The most important part of construction of electrolysis units is to use adequate electrodes to avoid unwanted reactions, which produce impurities in hydrogen gas. Among all salts available potassium hydroxide is best suitable to be mixed in the water.

3) Electrolytic Solution

Use an electrolyte that suits the best to you HHO Gas generator design. The distance between the electrode plates does really matter. For electrodes with little distance between the plates you could use: tap water or distilled-rain- or de mi water with a very little of any of the catalysts mentioned below. For electrodes with more space between the plates tap water won't work. So, use distilled- rain- or de mi water with a little of the catalysts mentioned below. For electrodes with a lot of space between the plates tap water won't work. Use distilled or rain water with a one of the catalysts mentioned below.

1) Tap Water (H_2O)
2) White Vinegar – Acetic Acid (H_3C-COOH)
3) Baking Soda- Natrium bicarbonate ($NaHCO_3$)
4) Sodium Hydroxide (NAOH)
5) Potassium Hydroxide (KOH)
6) Potassium Carbonate (K_2CO_3)

4) Conductors

Conduction of electricity is the movement of electrically charged particles through a transmission medium i.e. electrical conductor. The movement of charge constitutes an electric current. Electric charge flows from higher potential to lower potential level. This flow of charge may arise as a response to an electric field or as a result of a concentration gradient in carrier density called potential difference. The flow of charge also depends upon the material called conductor. Conductors are materials through which an electrical current can flow easily i.e. with low resistance. This can be a metal or an ionic solution or an ionized gas. Usually the term conductor means current – carrier component of an electrical system through which current can be easily carried. Generally, three types of conductors are described.

1) Metallic Conductors
2) Ionic or Electrolytic Conductors
3) Plasma Conductors

5) Electrolytes and Non-Electrolytes

Let us see the difference between an electrolyte and a non-electrolyte.

1) Electrolyte - The substance which conducts electricity in its molten state or in the form of its aqueous solution is known as electrolyte.
2) Non-electrolyte – The substance which does not conduct electricity in its molten state or in the form of its aqueous solution is known as non-electrolyte.
3) Strong electrolyte - The electrolyte which dissociates or ionizes almost completely to form free mobile ions in the solution or in molten form is called a strong electrolyte.
4) Weak electrolyte - The electrolyte which ionizes or dissociates only partially to form a few free mobile ions in molten state or in solution is called a weak electrolyte.

IV. PROPOSED WORK

A. Dry Cell HHO Generator

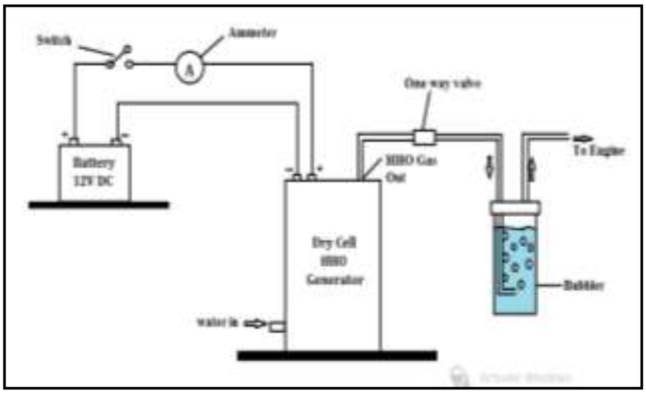

Fig. 4.1: Experimental Setup

Figure shows complete setup consisting of Dry Cell HHO generator containing electrolyte and electrodes that are connected to the 12V battery in order to provide the cell with required current for electrolysis process. The cathodes and anodes are manufactured from stainless steel 316L. The plate electrodes dimension is (length31.8 cm, width17.3 cm and 2mm thickness) The spacing between the anodes, cathodes and neutral plates is 2-3mm.The electrical current was measured by an Ammeter connected in series with the circuit. The bubbler was connected right after the electrolysis and used as a safety piece. When the HHO gas comes out of the electrolysis, it goes through the bubbler which is filled with a liquid (usually water or vinegar) and out of the other end to be used from there. Therefore, the bubbler cools the warm gas and cleans it from any electrolyte particles going out with gas. It is important to use a non-return valve between the electrolyzes and the bubbler top event bubbler water being pushed back into the electrolysis in case of backfire Before using the electrodes for the first time, they were pretreated or activated because smooth surfaces would not produce significant quantity of HHO without activation. Therefore, the electrodes left unused in the KOH solution for 24 hours in order to receive a white coating. Once the power was first applied, very little electrolysis took place as the active surfaces get covered with bubbles which stick to them and a scum was formed on the water surface. After cleaning the scum and repeating the process few times, the scum no longer forms and the active electrodes surfaces had the white coating

B. Detailed Drawing of HHO generator

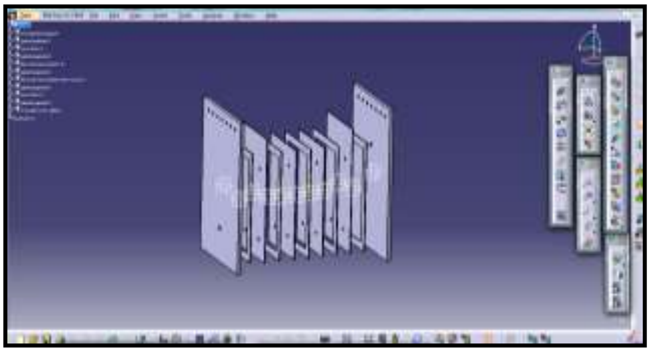

Fig. 4.2: CAD model different of plates (electrodes) of HHO generator

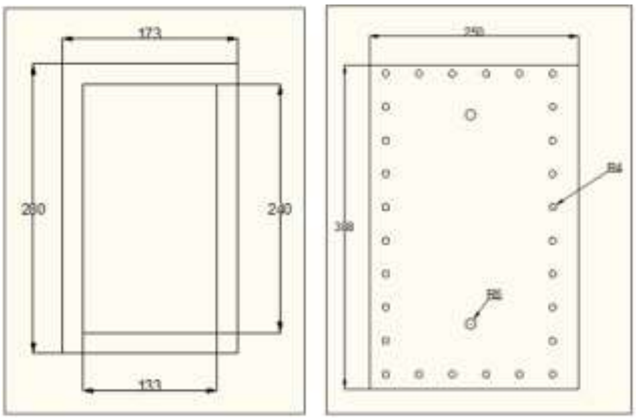

Fig. 4.3: Drawing of Gasket and End Plates

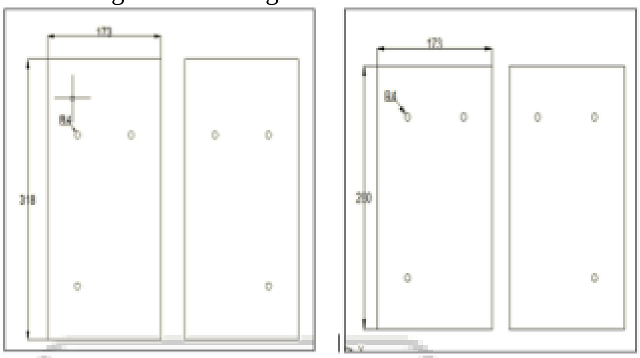

Fig. 4.3: Drawing of Cathode, Anode and Neutral Plates

V. CALCULATION

A. *Electrolysis of Water*

1-gram atom = atomic mass
1-gram mol= molecular mass
Water = H_2O, so$_2$ atoms H and 1 atom O

B. *Distribution of mass*

Atomic mass H = 1
Atomic mass O = 16
So, the Molecular mass H2O = 1+1+16 = 18
Total mass of H in water = 2/ ((18*1%)) = 11.11%
Total mass of O in water =16/ ((18*1%)) = 88.89%
F = Force required to pull brake
A = Area of piston in cylinder
Given :1 liter of water has a mass of 1000gr and equals 1000 cm
1 liter of molecular H has a mass of 0.09gr,
1 liter of molecular O has a mass of 1.47gr

C. *Quantity of H_2 and O_2*

For H2: Total mass of H in H2O 11.11%
so, 11.11% x 1000gr =111.1gr of H
111.1/ (0,09x1 liter) = 1234.44-liter H
The above pressure is within pneumatic operation range which is in between 1 to 10 bar. So, our design is validated.

D. *Flow Rate*

Approximate flow rate required for engine is 2.5 lit/min.
We have to produce the HHO at rate of 2.5 lit/min.
We can convert 1 lit of water + KOH solution into 1.8 lit of HHO gas theoretically.
Flow rate of water we required 0.6337 lpm theoretically.

E. *Results*

Voltage (V)	Electric Current (amp)	Number of Neutral Plates	Concentration of KOH (Gram Per Liter)	Flow rate (LPM)
12	6	4	15.6	1.33

Table 1: Results

The efficient method for generation of HHO is an electrolysis process. The generation HHO gas is accomplished by HHO dry cell generator. It is possible to make such types of generators by applying effective design procedure and manufacturing technique. An HHO generator developed with of 21 plates made of steel, rubber seals enclosed in box. The HHO is produced with distilled water and potassium hydroxide as electrolyte. From developed 21 plate HHO generator the flow rate obtained of HHO gas approximately equal to 1.33 LPM.

F. *Sample Testing*

1) *Engine Details*

IC Engine set up under test is Research Petrol having power 4.50 kW @ 1800 rpm which is 1 Cylinder, Four stroke, Variable Speed, Water Cooled, Petrol Engine, with Cylinder Bore 87.50(mm), Stroke Length 110.00(mm), Connecting Rod length 234.00(mm), Compression Ratio 10.00, Swept volume 661.45 (cc)

2) *Combustion Parameters*

Specific Gas Const (kJ/KgK): 1.00, Air Density (kg/m^3): 1.17, Adiabatic Index: 1.41, Polytrophic Index: 1.28, Number Of Cycles: 10, Cylinder Pressure Reference: 0, Smoothing 2, TDC Reference: 0

3) *Performance Parameters*

Orifice Diameter (mm): 20.00, Orifice Coeff. Of Discharge: 0.60, Dynamometer Arm Length (mm): 185, Fuel Pipe dia. (mm): 12.40, Ambient Temp. (Deg C): 27, Pulses Per revolution: 360, Fuel Type: Petrol, Fuel Density (Kg/m^3): 740, Calorific Value of Fuel (kj/kg): 44000

4) *Testing Parameters*

1) Air and fuel flow

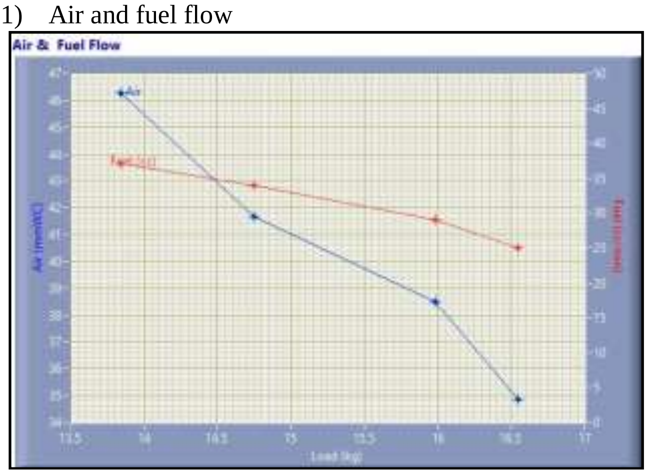

Fig. 5.1 Air and Fuel Flow

Speed (rpm)	Load(kg)	Air	Fuel (cc/min)
1807.00	13.84	46.27	37.00
1609.00	14.75	41.67	34.00
1408.00	15.98	38.47	29.00
1204.00	16.55	34.85	25.00

Table 2: Air & Fuel Flow

2) Indicated & Brake Thermal Efficiency

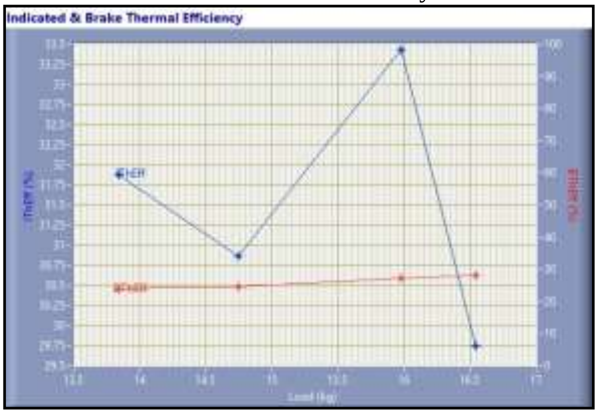

Fig. 5.2: Indicated & Brake Thermal Efficiency

Speed(rpm)	Load(kg)	ITE (%)	BTE (%)
1807.00	13.84	31.87	23.67
1609.00	14.75	30.86	24.44
1408.00	15.98	33.43	27.17
1204.00	16.55	29.74	27.91

Table 3: Indicated & Brake Thermal Efficiency

3) SFC & Fuel Consumption

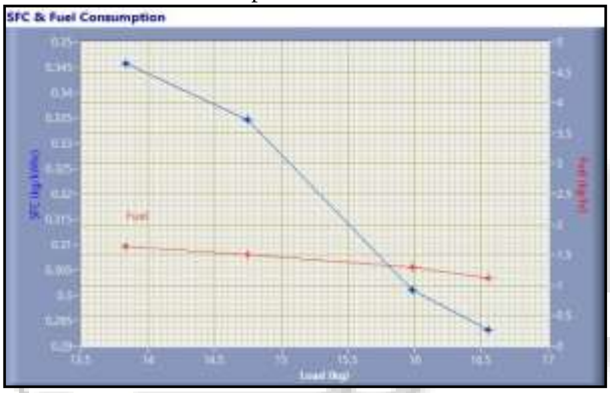

Fig. 5.3: SFC & Fuel Consumption

Speed(rpm)	Load(kg)	SFC (kg/kWh)	Fuel(kg/h)
1807.00	13.84	0.35	1.64
1609.00	14.75	0.33	1.51
1408.00	15.98	0.30	1.29
1204.00	16.55	0.29	1.11

Table 4: SFC & Fuel Consumption

4) Torque, Mechanical & Volumetric Efficiency

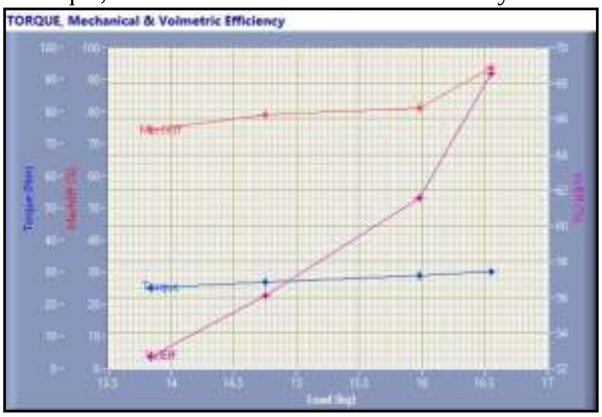

Fig. 5.4: Torque, Mechanical & Volumetric Efficiency

Speed (rpm)	Load (Kg)	Torque (Nm)	Mech Eff (%)	Vol Eff. (%)
1807.00	13.84	25.12	74.26	52.63
1609.00	14.75	26.77	79.21	56.09
1408.00	15.98	29.00	81.29	61.59
1204.00	16.55	30.03	93.83	68.55

Table 5: Torque, Mechanical & Volumetric Efficiency

5) HBP, HJW & H Gas

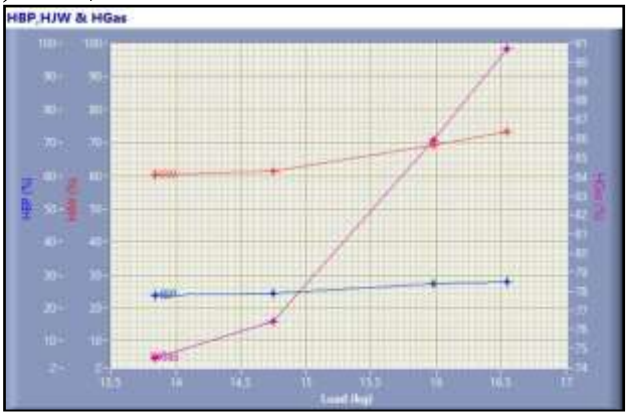

Fig. 5.5: HBP, HJW & H Gas

Speed (rpm)	Load (kg)	HBP (%)	HJW (%)	H Gas (%)	H Rad (%)
1807.00	13.84	23.67	36.36	14.47	25.50
1609.00	14.75	24.44	36.79	15.17	23.60
1408.00	15.98	27.17	42.01	16.70	14.11
1204.00	16.55	27.91	45.35	17.42	9.33

Table 6: HBP, HJW & H Gas

5) *Emission Characteristics*

1) CO Emission

CO emissions reduces with the increase in percentage of hydrogen.

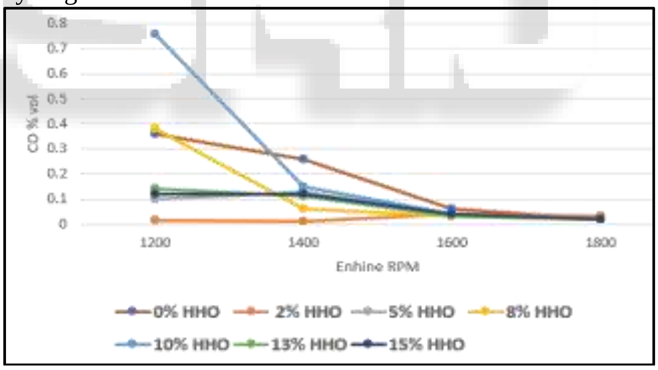

Fig. 5.6: Variation of CO emission with speed for various hydrogen volume fraction

2) CO_2 Emission

Co2 emission first increases up to certain extent after it decreases mainly due to increase in the cylinder temperature & pressure.

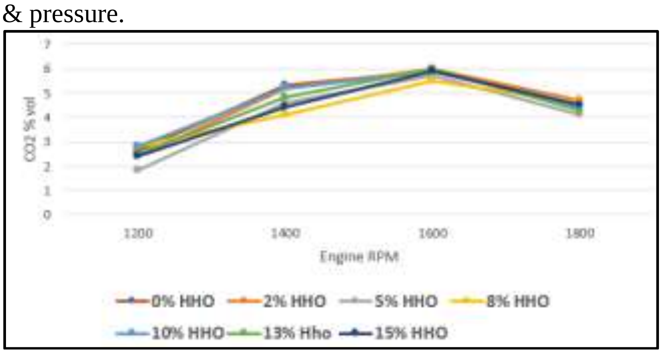

Fig. 5.7: Variation of CO_2 emission with speed for various hydrogen volume fraction

3) HC Emission

HC emissions reduces with the increase in percentage of hydrogen.

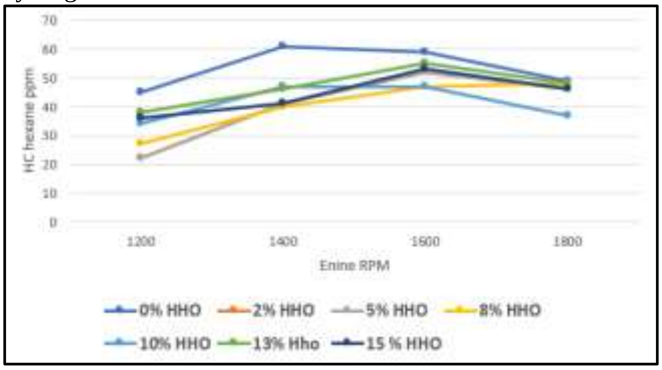

Fig. 5.8: Variation of HC emission with speed for various hydrogen volume fraction

4) Variation of O2

O2 emissions first decrease with the increase in hydrogen addition. Increase O2 values are observed for engine operating at higher speed for all the fuel blends.

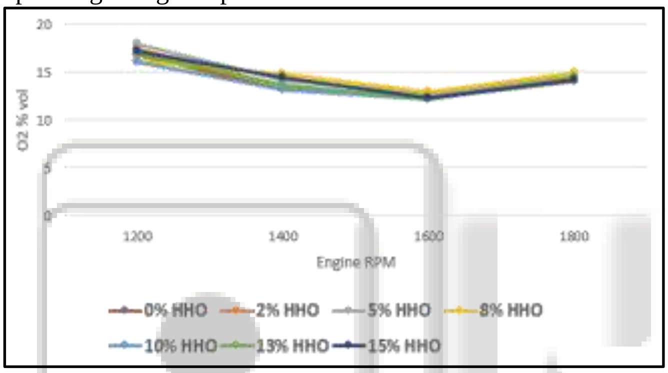

Fig. 5.9: Variation of O_2 emission with speed for various hydrogen volume fraction

6) *Air Fuel Ratio*

The theoretical or stoichiometric combustion of hydrogen and oxygen is given as:

$2H_2 + O_2 = 2H_2O$

Moles of H2 for complete combustion = 2 moles

Moles of O2 for complete combustion = 1 mole

Because air is used as the oxidizer instead oxygen, the nitro-gen in the air needs to be included in the calculation:

Moles of N2 in air = Moles of O2 x (79% N2 in air / 21% O2 in air)

= 1 mole of O2 x (79% N2 in air / 21% O2 in air)

= 3.762 moles N2

Number of moles of air = Moles of O2 + moles of N2

= 1 + 3.762

= 4.762 moles of air

Weight of O2 = 1 mole of O2 x 32 g/mole

= 32 g

Weight of N2 = 3.762 moles of N2 x 28 g/mole

= 105.33 g

Weight of air = weight of O2 + weight of N (1)

= 32g + 105.33 g

= 137.33 g

Weight of H2 = 2 moles of H2 x 2 g/mole

= 4 g

Stoichiometric air/fuel (A/F) ratio for hydrogen and air is:

A/F based on mass: = mass of air/mass of fuel

= 137.33 g / 4 g

= 34.33:1

A/F based on volume: = volume (moles) of air/volume (moles) of fuel

= 4.762 / 2

= 2.4:1

The percent of the combustion chamber occupied by hydro-gen for a stoichiometric mixture % H2 = volume (moles) of H2/total volume (2)

= volume H2/ (volume air + volume of H2)

= 2 / (4.762 + 2)

= 29.6%

As these calculations show, the stoichiometric or chemically correct A/F ratio for the complete combustion of hydrogen in air is about 34:1 by mass. This means that for complete combustion, 34 pounds of air are required for every pound of hydrogen. This is much higher than the 14.7:1 A/F ratio required for gasoline. Since hydrogen is a gaseous fuel at ambient conditions it displaces more of the combustion chamber than a liquid fuel. Consequently, less of the combustion chamber can be occupied by air. At stoichiometric conditions, hydrogen dis-places about 30% of the combustion chamber, compared to about 1 to 2% for gasoline.

VI. Constructional Details

A. *Fabricated Model*

Fig. 5.1: Actual Model

VII. Conclusion

Internal combustion engine powered vehicles can possibly operate with both petroleum products and dual-fuels with hydrogen. Because of hydrogen has a wide range of ignition, hydrogen engine can be used without a throttle valve. By this way engine pumping losses can be reduced. Direct injection solves the problem of pre-ignition in the intake manifold; it does not necessarily prevent pre-ignition within the combustion chamber. An appropriate DI system design specifically on the basis of hydrogen's combustion characteristics for a particular engine configuration ensures smooth engine operational characteristics without any undesirable combustion phenomena. Backfiring is limited to external mixture formation operation and can be successfully avoided with DI operation. Proper engine design can largely reduce the occurrence of surface ignition.

Optimizing the injection timings can also control the onset of knock during high hydrogen flow. Hydrogen engine may achieve lean-combustion in its actual cycles.

1) The addition of hydrogen helps in improving Bmep. The maximum Bmep obtained at 15% blend of hydrogen for an engine operating in between 1600 to 1800 rpm speed.
2) The addition of hydrogen is effective on improving engine brake thermal efficiency. An increase of brake thermal efficiency was observed till a hydrogen fraction of 15%. Beyond this, the brake thermal efficiency is declined due to reduction in air quantity.
3) The volumetric efficiency decreases as the percentage of hydrogen increases as hydrogen tends to replace air from the mixture.
4) HC and CO emissions reduces with the increase in percentage of hydrogen mainly due to increase in the cylinder

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