

# Effect of Hydroxy (HHO) Gas Addition on Performance and Exhaust Emissions in Spark Ignition (Si) Engine – A Review

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**ABSTRACT:** Over the last hundred years, there have been a number of advancements in mechanical engineering on a wider horizon of engine size, engine power, engine speed, engine efficiency. The oil crisis in past effected the beginning of a push for more fuel efficient vehicles or even fossil-fuel-free vehicles. Of course, the current price of gasoline isn't the only reason we should be interested in alternative fuels. Reducing the emission pollution associated with oil combustion is gaining an increasing interest worldwide. The ideal solution would be implemented to completely eliminate fossil fuel utilization altogether. In this study the alternative has been suggested in order to overcome twin problems. Hydroxy is a mixture of hydrogen (H<sub>2</sub>) and oxygen (O<sub>2</sub>) gases. Mixture of these gases can be obtained by electrolysis, which uses an electric current to dissociate the water molecules. This gas can use as secondary fuel for IC engine. Past research has indicated results a 20-30% reduction in fuel consumption, lower exhaust temperature and consequently a reduction in pollution. The emission tests have been performed with varying the engine speed. The results have shown that nitrogen monoxide (NO) and nitrogen oxides (NO<sub>x</sub>) have been minimized to about 50% when a mixture of HHO, air and fuel was used, the carbon monoxide concentration has been minimized to about 20%. Also a reduction in fuel consumption has been observed and it ranges between 20% and 30%.

**KEYWORDS:** Hydroxy (HHO), Fuel cell, Renewable energy, Combustion, Performance and Emissions.

## I. INTRODUCTION

Global increasing consumption of fossil fuel is primary reason for search for alternative fuel. Reserve of fossil fuel is limited. Price of the petroleum has been increasing over span of time. Hence in past efforts have been taken to improve fuel efficiency were limited by the increased use of heavy vehicles such as sport utility vehicles and light trucks for personal use. On the other hand, fossil fuel combustion releases large amounts of greenhouse gases, the most significant being carbon dioxide. Greenhouse gases trap heat in the earth's atmosphere. Increased concentrations of carbon dioxide in the atmosphere contribute to global warming, which has been receiving world-wide attention as a significant environmental problem. This problem allows researchers and scientist community to seek interest in search of alternate fuel. HHO can be additive to the SI engine. Problem can be raised on production, storage and utilization.

## II. HHO OR HYDROXY AS AN ALTERNATE FUEL

Basically HHO is a mixture of 2/3 of hydrogen and 1/3 of oxygen bonded together molecularly and some water vapour. It is generally produced by dissociation of water [1]. When electric current passed through water, it divides into hydrogen and oxygen. The hydrogen and oxygen rise from the liquid water as gas. This gas is called HHO Gas or Brown gas. At the instant that the water splits, the hydrogen and oxygen are in their mono-atomic state, this is H for hydrogen and O for oxygen. Normal electrolyzers encourage the hydrogen and oxygen to drop to their di-atomic state. The di-atomic state is a lower energy state, the energy difference shows up as heat in the electrolyzer. This energy is now available to the flame. HHO gas is odorless, colorless and lighter than air. The HHO gas is highly flammable due to presence of hydrogen much more than gasoline. The Oxy-hydrogen explosion

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is so quick that it fills the combustion chamber at 3 times faster than gasoline explosion. At one atmosphere Pressure auto ignition of Hydroxy occurs at about  $570^{\circ}$ . Hydroxy gas has very high diffusivity. This ability allows to disperse in the air is considerably greater than gasoline. At normal temperature and pressure Hydroxy gas can burn when it is between about 4% to 94% hydrogen by volume. Oxy-hydrogen is  $0.535 \text{ kg/m}^3$  this results in a storage problem. When ignited, the gas converts to water vapors and release energy of about 241.38 KJ of energy (LHV) for every mole of  $\text{H}_2$  burned. Most of the research on IC engine fuel has been done on hydrogen as in pure form. It is perfect, super clean and cheap energy source. However it's volatile in gas form, it is Highly Flammable and while that makes it able to accomplish huge tasks, as well as it makes it hazardous to work around and use. This hazardous effects have taken into account and viable solution has been suggested that utilizing hydrogen by producing on demand in other words on-board production of hydrogen diminished hazard effects of storing and transportation.

### III. EFFECTS OF HHO ON COMPRESSION IGNITION ENGINE

S.Bari and M.Esmaeil [13] were performed experimentation on four cylinder direct injection diesel engine the experiment were carried out under constant speed of 1500 rpm with three different power level of 19 kW, 22 kW and 28 kW applied. Under each load condition flow rate of diesel and other parameter were recorded without HHO then small amount of HHO mixture was introduced to the engine and measured the performance parameter at each load condition then flow rate of HHO gas was increases and required data were collected. The result showed that with introduction of HHO gas at different percentage into diesel engine, the brake thermal efficiency increased by 2.6% at 19kW, 2.9% at 22 kW and 1.6% at 28 kW. The brake specific fuel consumption of engine reduced by 7.3% at 19 kW, 8.1% at 22kW and 4.8% at 28kW. It was also noticed that adding HHO beyond 5% does not have significant effect on engine performance. The emissions HC, CO and  $\text{CO}_2$  were found to be reduced while NOx increases due to higher temperature achieved during combustion process. Ali Can Yilmaz, et al. [12] produced HHO gas with different electrolytes KOH (aq.), NaOH (aq), NaCl (aq) with various electrode design in a leak proof Plexiglas reactor. Engine used was four cylinders, four stroke compression ignition engine. Dynamometer used has a torque range of 0-1700 Nm and speed range of 0-7500 rpm. performance parameter were measured by computer via a data logger software result showed that there was 19.1% increment in engine torque when HHO system was used compared to diesel operation where as 14% gain was achieved on specific fuel consumption using Hydroxy gas. Also about 13.5% reduction in CO emission and 5% reduction in HC but experiment showed that at low engine speed with constant HHO flow rate turned into disadvantage for torque, CO, HC, and SFC this is because of long opening time of intake manifold at low speed which cause excessive volume occupation of HHO in cylinder which prevents correct air to be taken into combustion chamber due which volumetric efficiency decreases and decrease in volumetric efficiency influenced combustion efficiency which had adverse effect on performance parameter therefore Hydroxy electronic control unit (HECU) it sense engine speed as soon as it lower and decrease HHO flow rate by decreasing voltage and current automatically and compensate disadvantage under lower engine speed. Hsin-Kai Wang et al [14] investigated emission reductions of polycyclic aromatic hydrocarbons (PAHs), hydrocarbons (HCs), carbon monoxide (CO), carbon dioxide ( $\text{CO}_2$ ), particulate matters (PM), and nitrogen oxides (NOx) from a heavy-duty diesel engine (HDDE) at one low load steady-state condition, 24.5% of the maximum load (40 km/h), using premium diesel fuel (PDF) mixed with various amounts of  $\text{H}_2/\text{O}_2$ . Measurements showed that the mixed fuel of HO60 reduced the brake specific fuel consumption (BSFC) most, by an amount of 12.6%, as compared with PDF. Meanwhile, with HO60, the emission of air pollutant was decreased by 32.3% for PAHs, 9.5% for HCs, 7.2% for CO, 4.4% for  $\text{CO}_2$ , and 19.3% for PM, but the emission of NOx was increased by 9.9%. K.S. Varde et al [16] investigated effect of hydrogen on smoke particulate they have found reduction in smoke levels was limited; this effect due to the lower amounts of excess air available in the cylinder. It was found that the engine thermal efficiency was dependent on the portion of hydrogen energy, out of the total input energy, supplied to the engine. There was no significant change in the hydrocarbon emissions but oxides of nitrogen in the exhaust increased with an increase in hydrogen energy. Sawant S. M. et al [10] they have investigated effect of oxyhydrogen and diesel on CI engine. They concluded brake thermal efficiency increases for the blend of oxy hydrogen and diesel. The efficiency increases by almost 10% for the blend compared to only diesel as a fuel. The

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volumetric efficiency of the engine increases by almost 10% when the blended fuel is sent inside the combustion chamber. Wall J. [23] implemented on board hydrogen production method to utilize hydrogen and investigations of performance parameters have been taken. He concluded that introduction of hydrogen in combustion chamber indicates the effects such as Increase thermal efficiency and decrease fuel consumption. Decrease carbon monoxide and unburned hydrocarbon emissions. Increase NOx emissions unless proper timing and mixture adjustments are used.

### IV. EFFECTS OF HHO ON SPARK IGNITION ENGINE

Ammar A. Al-Rousan et al. [11] conducted performance test on the single cylinder spark ignition air cooled 197cc engine and HHO production system was designed, constructed, integrated with a gasoline engine. i.e. the output of fuel cell connected to the intake manifold of the gasoline engine and performance test was performed before and after attaching fuel cell with constant load and variable speed (from 1000 to 2500 rpm) and result shows that brake thermal efficiency increase about 3% for cell B and 8% for cell C and 20 to 30% reduction in fuel consumption and exhaust temperature. And research showed that use of HHO in petrol engine enhances combustion and optimum surface area needed to generate enough amount of HHO is about twenty times that of piston surface area also, the volume of water needed is about one and half times engine capacity. Musmar and Al-Rousan et al. [9] conducted research on single cylinder 197cc gasoline engine to see effect of HHO gas on combustion emission. The emission test has been taken with constant load and varying engine speed (1000-2300 rpm). Graph between CO Vs engine speed depicts that with addition of HHO gas there is 20% reduction in CO emission because of better combustion efficiency and better efficiency was due to the hydrogen and oxygen atoms intract directly without any ignition propagation delays and also due to HHOs flame speed was much higher than ordinary fuel. Also the reduction in HC concentration was observed. This reduction in HC emission increases with engine speed and at 2300 rpm, reduction in HC emission to about 40% this tells that HC emission is highly affected by the engine speed. It was also noticed that exhaust gas temperature reduces when HHO gas utilized with gasoline and exhaust gas temperature was directly related to NOx concentration this leads to lower NOx emission. This was a result based on no control on electric current feed to HHO generator. A.M.Falhat, et al. [2] carried out experimentation on 197 cc SI engine with gasoline and HHO gas as secondary fuel and compared with pure gasoline fueled engine. In this HHO flow meter was employed with HHO production system to add HHO gas at 1,1.5 and 2 lpm and engine speed was varied from 1350 to 2250 rpm and it was noticed that gasoline produced less torque and power compared with gasoline and HHO mixture and it was increased with increase in flow rate of HHO gas, maximum increase of torque and brake power about 12.6% further it was noticed that specific fuel consumption decreases about 16.9% at 1350 rpm whereas minimum reduction was about 2.9% at 1750 rpm when HHO flow rate was 2 lpm. The graph between thermal efficiency Vs speed depicts that for all speed range studied gasoline produced less thermal efficiency compared with gasoline and HHO mixture and also noticed that the maximum gain is about 23% at 1350 rpm and minimum was about 14% at 2250 rpm. And it was seen that the concentration of CO and NOx is decreases with increase of flow rate of HHO gas. In more recent work, Tuan Le Anh, et al. [4] carried out experimentation study on 97cc SI engine equipped with two injection system (HHO gas and additional air) on the intake manifold. Also, test rig was integrated with electronic HHO control (EHC) unit which control the flow of HHO into intake manifold. The experimental studies were carried out at three position of throttle 30%, 50% and 70% with different range of speed for test lamda matrix. The speed controlled by level of water in brake and HHO were controlled by EHC in order to obtained the ratio of HHO gas in the mixture about 1.95% by mass over all of considered throttled position the formula for calculating lamda of petrol and HHO mixture is as follows.

$$\lambda = \frac{(dm/dt)_{Air}}{(dm/dt)_{Gasoline} \cdot (A/F)_{Gasoline} + (dm/dt)_{HHO} \cdot (A/F)_{HHO}}$$

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For each throttle position and engine speed, the engine was fueled with three mixture, gasoline with intake air (case1), gasoline + intake air + HHO (case2) and gasoline + intake air + HHO + additional air (case 3). The result shows that engine power increased by 2.35% and 2.78% when adding only HHO gas and mixture of HHO gas + additional air respectively whereas the changes in exhaust gas emission in case-2 and case-3 shows same trend in NO<sub>x</sub> and HC emission however CO and CO<sub>2</sub> showed opposite trends in case 2 and case 3. From this it has been concluded that effect of HHO gas addition at light load and lean condition is more acceptable whereas the addition of only HHO gas makes mixture rich and which brings adverse effect to CO however HHO + additional air can makes mixture leaner and lower the CO emission. Author also developed one-dimensional model of engine in AVL boost software

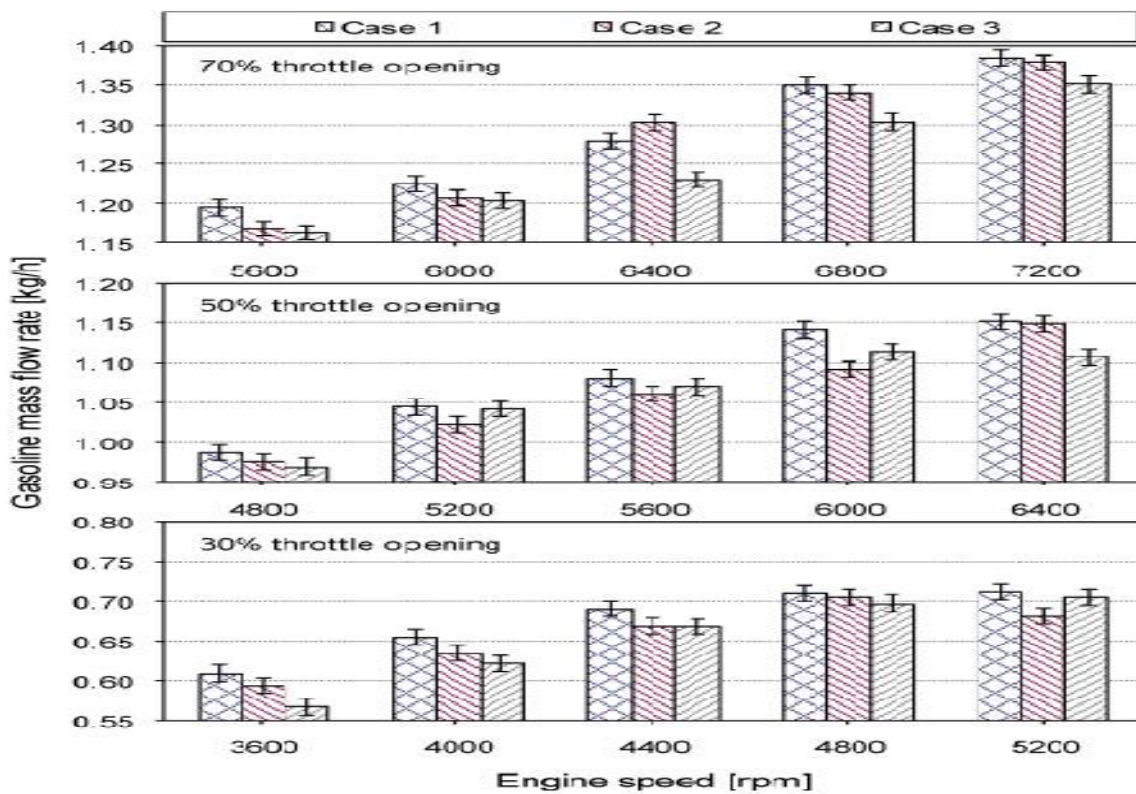


Figure 1. The measured gasoline mass flow rates in three cases at different engine speeds and throttle positions [source 4]



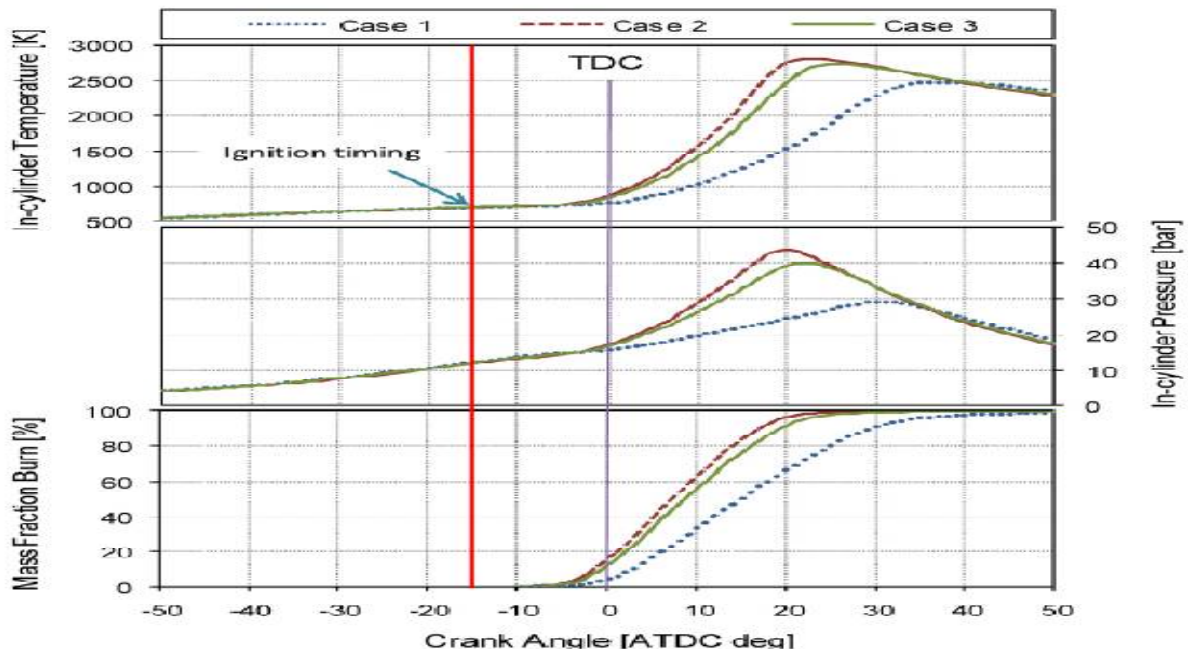


Figure 2 Simulation combustion characteristics in three cases at engine speed of 4000 rpm and 30% throttle opening [source 4].

to estimate the combustion characteristics of the engine fuelled with HHO gas. The mass fraction of two gases were considered as 0.889 for oxygen and 0.111 for hydrogen and fractal combustion model was chosen for analysis and the difference between simulated and experimental data of 2.88% which ensures accuracy and result were validated. M. B. King [6] presented a hypothesis on water electrolyser and zero point energy. Which stated that energy comes from Hydroxy is not from hydrogen rather than charged water clusters. This hypothesis offered is that the single-duct electrolyzers are producing charged water gas clusters, which is the dominant energetic component instead of hydrogen. The electrolyzers that yield the largest energy anomalies appear to make more charged water clusters and less hydrogen. He further Analyzed the gas and he found there is no hydrogen content, and then reconfirm that it still exhibits the welding torch anomalies. At that point he mentioned the scientific community would have a pure energetic anomaly to study: a form of water that appears to “burn” with extraordinary coherent energy content. Further to investigate the energy content of the pure water gas. He concluded that If it runs a generator, then the generator’s output power and the electrolyzer’s input power can be measured. If excess energy is measured, then a closed loop system can be attempted. If a closed loop system involving a (internal combustion engine) generator can idle for a significant time, then a new energy source would be demonstrated. At this point it would be valid for the academic community to consider the zero-point energy hypothesis as a possible explanation. Daniel M. Madyira et al. [7] an electrolytic cell was constructed and installed into the engine compartment of a 1989 Ford Laser vehicle. The cell produced HHO gas that was introduced into the intake manifold of the engine. The vehicle was put on a dynamometer and tested under varying load conditions and speeds. These tests have been conducted in order to determine the load performance of the car provided curves that conformed to the expected behavior Introduction of HHO led to increased power and torque was a significant reduction of unburned hydrocarbons as a result of the increase in HHO inclusion. Ruggero Maria Santilli [5] he has performed experiment which indicated that the creation of the gaseous and combustible HHO from distilled water at atmospheric temperature and pressure occurs via a process structurally different than evaporation or separation, Thus suggesting the existence of a new form of water, apparently introduced in this paper for the first time, with the structure  $(H \times H)-O$  where “ $\times$ ” represents the new magnecular bond and “ $-$ ” the conventional molecular bond. The transition from the conventional  $H-O-H$  species to the new  $(H \times H)-O$  species is predicted by a change of the electric polarization of water caused by the electrolyzer. They have stated that when  $H-O-$

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H<sub>2</sub> is liquid, the new species (H<sub>2</sub>H)-O can only be gaseous, thus explaining the transition of state without evaporation or separation energy. Finally, the new species (H × H)-O is predicted to be unstable and decay into H × H and O. Senthil, K. et al. [21] they have studied the influence of different fuel blends including gasoline, ethanol, stabilized hydrogen peroxide, water and Brown's gas (oxy-hydrogen or HHO gas) on the operation of a two-stroke engine. Fuel consumption and temperature at the exhaust port were measured while the rpm of the engine was kept constant at 3600 rpm. Their tests showed significant effects of the addition of HHO gas on engine operation and fuel consumption. Increasing concentrations of ethanol in gasoline resulted with significant increasing trends of fuel consumption with ethanol concentrations above 20 % in gasoline and increased combustion temperatures. Results indicated that fuel comprising 20 % ethanol in gasoline achieves the highest efficiency as compared to other blends, pure gasoline and pure ethanol. The components of the blends did not show any signs of separation/stratification from the mixture. They have concluded that a two-stroke engine can operate on ethanol-water-stabilized hydrogen peroxide blend, however with not more than 10 % water and 10 % hydrogen peroxide in ethanol. Kumar M. et al [26] they have observed effect of hydrogen on SI engine and concluded thermal efficiency is improved with hydrogen addition to gasoline as fuel. For the mixed fuel, HC and CO<sub>2</sub> emission are found to decrease. CO emission is noted to be more particularly near stoichiometric air fuel ratio conditions.

Wang J et al [17] studied the effects of hydrogen on gasoline engine and concluded that the brake thermal efficiency is greatly improved with the addition of hydrogen, especially at lean conditions. further he stated that [18] Hydrogen addition is helpful on decreasing engine flame development. [19] The engine cycle-by-cycle variation and misfire is reduced with hydrogen enrichment; HC emissions are reduced while NO<sub>x</sub> emissions are increased with the increase of hydrogen addition for a specified excess air ratio. CO emission decreases with hydrogen enrichment level at lean conditions. However, when the engine runs nearly to the stoichiometric conditions, the 8% hydrogen-rich engine tends to expel more CO than 3 and 6% hydrogen-rich engine, but still lower than the original one and propagation durations; P. Van Blarigan et al [27] they have conducted experiments utilize a flat cylinder combustion chamber shape with two ignition points at high (14: 1) compression ratio. Emissions and indicated thermal efficiency measurements with fuels of hydrogen, natural gas and a blend confirm low emissions and high thermal efficiency. They have concluded from this experiment that the single cylinder research engine demonstrate that it is possible to build a high efficiency, equivalent zero emissions auxiliary power unit for hybrid vehicles fuelled by hydrogen or 30% hydrogen/70% natural gas blends. C.M. White et al [15] they have given review of contemporary research on the hydrogen-fueled internal combustion engine due to low volumetric efficiencies and frequent preignition combustion events, the power densities of premixed or port-fuel-injected hydrogen engines are diminished relative to gasoline-fueled engines. Significant progress has been made in the development of advanced hydrogen engines with improved power densities. D.R. Gabhane et al [28] presented a research by finding appropriate ratio of HHO to gasoline required to get optimum mileage as well as desired emission level. G. Venkateswara Rao et al [8] conducted research in which Oxy hydrogen gas has been generated by electrolysis process and producer gas by pyrolysis. They have compared these two. Both the alternative fuels mixed with fresh air before entering the combustion chamber. BSFC, Brake thermal efficiency, speed and load are the performance parameters kept under observation. Oxy hydrogen is superior in every aspects of performance. Y.V.S. Saisantosh et al [3] they have suggested number of options for secondary fuel for IC engine. They have performed investigation and concluded uniform and improved mixing of Hydroxy-air and oxygen content of HHO stimulate combustion which has a major effect on SFC by using an adequate capacity system. Wide flammability range, high flame speed and short quenching distance of Hydroxy yield diesel fuel to be combusted completely under high speed conditions and low speed conditions.

## V. DESIGN OF ELECTROLYSER

Romdhane Ben Slama [22] he performed electrolysis by solar and concluded to increase the hydrogen produced flow by electrolysis, the electrolyzers parallel assembly choice was essential. According to the hour of the day, the evolution of the parameters such as consumed current, efficiency, and specific energy differs from a material with another, which could be explained by the variation of solar energy during the day. Allan D et al [24] they have performed experiment which able to self-run a 1000-watt generator from the HHO gas generated from their electrolysis process. So the electrolysis unit produces HHO gas which runs a genset (an engine connected to an alternator that

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produces electricity), and the electricity produced then runs the electrolysis unit. K.W. Harrison et al [22] they have given the standard method for calculating the efficiency of a fuel cell power plant or other electrical generation device is to divide the electricity produced by the HHV of the fuel used. That was reasonable method for calculating power

plant efficiency, 
$$\eta^{Electrical} = \frac{Electricity_{produced}}{HHV_{of\ fuel}}$$

Therefore, there is a maximum theoretical limit to the electrical efficiency attainable by a fuel cell system represented by the Gibbs free energy divided by the heat of combustion of the fuel. In the case of the hydrogen fuel cell this value is the Gibbs free energy/HHV (237.2 kJ/mole / 285.8 kJ/mole = 83%). The use of HHV here is in keeping with to calculate efficiency for internal combustion (IC) engine/generators and gas turbine/generator systems.

## VI. CONCLUSION

From the literature review we can conclude that work on Hydroxy hasn't done with precise measurement of each constituents. We can make following conclusions

- Rate of production of Hydroxy during test is directly proportional to current and voltage.
- For achieving complete Hydroxy system relative quality of Hydroxy and gasoline needed.
- Hydroxy cannot have calorific value equivalent to hydrogen due to the fact that Hydroxy is blended with oxygen and water vapour.
- Scientist claimed that it is not even hydrogen, it is charged water clusters which produces energy after burning in other words zero-point energy of water is responsible for producing energy such claims have been failed due to lack of evidence.
- When H-O-H is liquid and it electrolyzed the new species (H×H)-O can only be gaseous so Hydroxy gas cannot be compressed.
- Hydroxy can be blended with ethanol to get better performance.
- Hydroxy is very versatile when it comes to adapt SI and CI engine.
- It helps to reduce amount of unburnt hydrocarbon, Nox, CO and Fuel consumption
- It increases power and torque of the engine thermal efficiency to a substantial amount.

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