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Experimental Investigations on the Effects of HHO Gas Fuel Additive on Performance of a Gasoline Engine

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Abstract- **The hydrogen hydroxyl (HHO) gas as a fuel additive in gasoline for SI engines has a positive impact on improving the performance and reducing the consequences of the burning of fossil fuels alone, which are continuously depleting and causing severe problems to the environment. In this paper, the effect of injecting HHO gas additive in the gasoline fuel of a gasoline engine was experimentally explored in detail to improve the overall efficiency in terms of performance indicators such as engine fuel consumption, brake horsepower, and engine torque developed. The engine was coupled with an electric generator to be used for the production of electricity at a relatively low cost. An experimental setup was established to measure the performance indicators and it consists of an HHO gas generator integrated with solar panels, a gasoline engine coupled with an electricity generator, a storage battery, and relevant measuring instruments. The HHO gas was produced and injected into the intake manifold of the engine whilst it was running at different load conditions. The main parameters such as engine RPM, output voltage/amperes of the electric generator were measured and performance indicators were calculated to determine the overall efficiency of the system. From the results, it was found that the HHO additive had increased performance of the gasoline engine performance more evidently when the gasoline concentration was lower in the air-fuel mixture.**

***Index Terms*—Fuel Additive, Fuel-saving, Gasoline Engine, Performance analysis.**

I. INTRODUCTION

There is a continuous increase in the energy demand of the world, which is presently being met mostly by the burning of fossil fuels (hydrocarbons) which have also a negative impact on the environment by the production of greenhouse gases (GHG) [1]. The price of fossil fuels, fear of depletion of fossil fuels reserves and increase of GHG in the environment has caused globally serious threats towards the environmental safety and pollution problems for survival. In underdeveloped countries, there are consistent energy crises imposing a burden on the economy and hurdle towards the development of the country. Moreover, less practice of advanced technologies and high usage of HC result in higher contamination of the environment. Due to these concerns, the researchers are attempting to explore renewable and sustainable energy resources to eliminate or reduce the utilization of hydrocarbons (HC). For overcoming these concerns, there are many technologies are being incorporated in addition to the conventional fossil fuels burnings, such as hydrogen fuel cell technology [2].This technology has many advantages over the other alternative solution, the most appealing advantage of this technology is that it can be added to any conventional fuel technology without any considerable modifications. The HHO gas can be blended in many Hydrocarbons as a performance enhancer, such as gasoline, diesel, and natural gas [3-12]. The application of hydrogen cell technology enables, cleaner fuel for power generation, environment friendly, without GHG gases and zero pollution being utilized in developed countries for many years in the power and transport industry. The production of hydrogen involves mostly the breakdown of water (electrolysis) and hydrocarbons into hydrogen and oxygen. Similarly, the production of HHO gas is the product of water electrolysis proposed in the present study, which will be used as a fuel additive in gasoline having the potential to lessen the utilization of hydrocarbon fuels and environmental pollution. Recently in some studies [13- 17], it has been shown that HHO gas not only reduces the HC consumption in the engine but also assists in the maximum combustion of HC fuels resulting in the reduction of unburnt HC emission in the environment [18-23].

- The adaptation of an HHO generator in the IC engine coupled with an electric generator is proposed as one of the possible solutions for the above-mentioned problems because the initial cost is not much higher and the HHO generator can be introduced in any IC engine without involving any major modification.
- In the present experimental work, an HHO generator was developed and integrated with a gasoline engine for evaluating the contribution of HHO gas addition into the engine along with common gasoline fuel.

- This hybrid electricity generator was developed to ensure the maximum burning of HC fuel in the engine's combustion chamber. As the gasoline engine also has the capability to run on natural gas, the HHO addition was also tested in the addition with natural gas and it also provided positive results.
- As in subcontinent Asia there is plenty of solar energy available, the addition of solar panels was also made in this hybrid system. Rather than adding the solar panel output into the electricity production of the generator, it was utilized for the electrolysis of the water for producing HHO.
- The utilization of solar power to generate HHO enabled the uninterrupted output power analysis of the electricity generator in different experimental conditions.
- The positive evidence of the system output provided the confidence of introducing this hybrid electricity generator as a sustainable domestic and commercial solution to the problem of load shedding in underdeveloped countries, especially for the remote areas.
- Not only on the hybrid conditions but also on the individual levels this electricity generator has an advantage that for the lesser requirement of electricity only solar panel shall be utilized, and on higher requirements, it can be run on a hybrid fuel.
- There is a storage battery for storing the solar power in the availability of sunlight for the time when it is not available. Moreover, this generator can also run solely on gasoline as well as natural gas when solar energy is not available for much time.
- The focus of this research was to provide a sustainable option for reducing HC consumption, HC emissions and to strive for a renewable or partial renewable source of energy.

From the literature review, the relevant studies were reviewed and are summarized as follows;

Mohamed et al [8] presented the performance of the HHO gas addition into the gasoline engine under different load conditions. Two different types of electrolytes were utilized for the production of HHO gas and it was shown that KOH in a concentration of 6g/L was most suitable for the electrolysis of water. It was concluded that HHO gas addition improved the engine thermal efficiency up to 10% along with the reduction of fuel consumption by 34% whilst the emission of NOx 15%, CO 18%, and HC was reduced up to 14%.

Sharma et. al. [9] studied the effect of HHO gas addition under different load conditions of a multi-cylinder four-stroke gasoline engine. From the results it was found that the addition of HHO in fuel improved the brake power of the engine up to 11.5%, the specific fuel consumption reduced up to 6.35%, and thermal efficiency improved 10.26%. Moreover, the temperature of exhaust also decreased by about 4%, and the concentration of NOx was reduced due to better combustion of fuel.

Bhardwaj et al [10] emphasized the utilization of HHO gas into engines as a fuel additive. From this work, it was found that HHO gas could be mixed with gasoline and air mixture safely. There was an increment in the thermal efficiency of the engine, there was an ignition delay and combustion was prolonged. From the exhaust reduction in the CO2, CO and HC were noted.

Musmar et al [11] experimentally analyzed the effect of HHO gas as an additive in the fuel of the Honda G-200 engine. The HHO was generated and mixed simultaneously in the intake air of the engine through the carburetor section. Afterward, the exhaust was analyzed and it was found that NOx was reduced by ~ 50%, the concentration of CO was decreased by about 20% and fuel consumption reduced ~ 20% to 30%.

Prasad et al [12] analyzed the effect of HHO gas addition in a common gasoline engine. HHO was added in a four-stroke SI engine without any modification and tank storage. The results showed that the HC emission was reduced by ~ 6.7% as compared to when the engine was running on only gasoline. As the HHO gas supply was increased the thermal efficiency was enhanced. On average there was a gain of 16.3% in S.F.C by the addition of HHO.

Chetan et al [13] evaluated the effects of HHO addition as a fuel additive in a common gasoline engine. From the results, it was found that the addition of HHO in the gasoline results in the reduction of unburnt HC in the combustion chamber of the engine. From the published works it has been proved that the HHO gas addition has the potential to increase the performance of the gasoline engines. In the present work, a special system was designed in which a solar-assisted HHO generator was developed and integrated with a gasoline engine coupled with an electric generator to evaluate the contribution of HHO gas addition in the overall output of the engine and reduction in the consumption of common gasoline fuel under different load conditions.

II. DESCRIPTION OF THE SYSTEM AND EXPERIMENTAL PROCEDURES

The schematic of the system under study for production of HHO gas production of HHO gas from water using solar energy and adding it along with the gasoline into the engine's intake manifold is illustrated in Fig. 1.

As explained in Fig.1, the HHO gas was produced through the electrolysis process HHO generator, using the distilled water with the addition of electrolyte from a reservoir and DC power from a PV module. The electrolysis of the distilled water is not a very rapid process and the required amount of HHO cannot be produced from the distilled water only, so there is a requirement of a suitable electrolyte to accelerate the process to get the desired amount of HHO production. From the literature, it was found that KOH is the most suitable electrolyte for the electrolysis of water in a Hydrogen generator [8]. KOH in ascending order of 5 g/L was added in distilled water to observe the production of HHO gas and a solar panel of 100 watts/12 volts was utilized for providing the electric power to the HHO generator. It was found that 10 g/L of KOH was most suitable for the suitable HHO gas production. A storage battery was also utilized for storing the solar power, to be utilized when sunlight was not available.

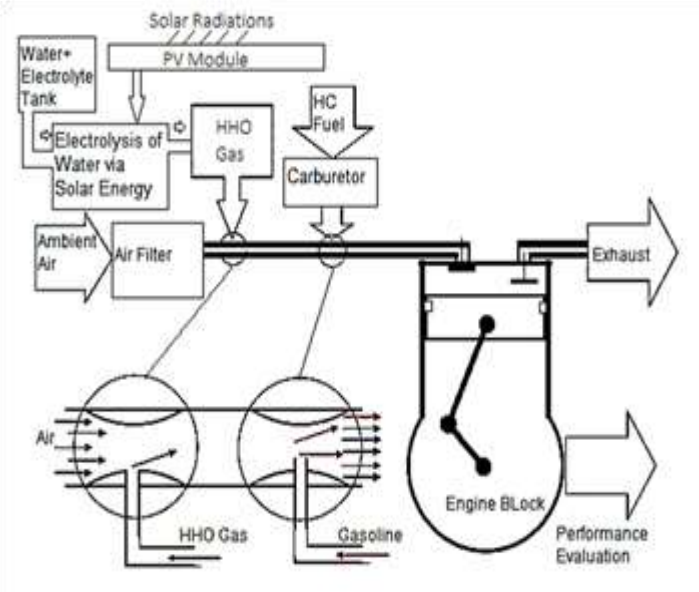

FIGURE 1: Schematic of the system for production of HHO gas from water using solar energy and adding with gasoline into the intake manifold of the engine.

The engine selected was a 4-stroke air-cooled, single-cylinder (41 CC), coupled with an electric generator having a maximum capacity of the power output of 1000 watts.
The purpose of this coupled electric generator was to analyze the performance of engine under the different load conditions. A framework of the system was designed to support different components, which consists of a mild steel frame. For design considerations first the CAD model of the system was designed in AutoCAD and afterwards practically it was assembled. The CAD model of the framework along is shown in Fig. 2.

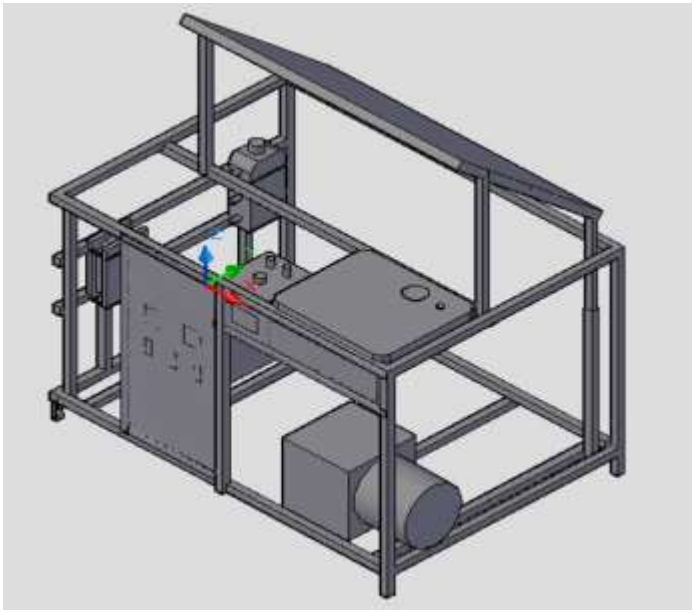

FIGURE 2: Design of the Hybrid Electricity Generator on CAD (ISO-metric View).

In the development of the system with the components such as engine, electricity generator, HHO cell, reservoir, and Battery, were selected very carefully, on the basis of their properties, and applications at different load conditions, through proper study.
The measuring and the testing instruments, RPM meter, Volt meter, Ampere meter, and measuring cylinders, required for the validation of the results were also precisely selected. The final output model of the system was named as the "hybrid electricity generator" which comprises different mechanical as well as electric/electronic components shown in Fig.3.

FIGURE 3: Hybrid electricity generator system (1: Solar Panel, 2: Electricity Generator, 3: HHO generator, 4: Reservoir, 5: Storage Battery, 6: RPM Meter, 7: AC Volt meter, 8: DC Volt Meter, 9: Ignition Switch, 10: 12v DC output, 11: 220AC output, 12: AC Ampere Meter, 13: One way natural gas valve, 14: Gasoline Tank, 15:Main Frame, 16: HHO generator switch, 17: Volt meter Switch, 18: Output Socket, 19: Control Panel, 20: Circuit Breaker, 21: Electric Connections, 22: Gas pipes, 23: Solar Panel adjuster, 24: Hand starter.

The solar panel was positioned on the top of the model, supported by a rotatable frame that can be adjusted in any position so that the solar panel can achieve maximum solar radiation depending upon the position of the sun in different time. A digital RPM meter was utilized to measure the variations in the engine's RPM under different load conditions and fuel variations. To measure the output voltage and current amperes, voltmeter and ammeter were used. Switches were used to connect or disconnect the power supply to the HHO generator. Flexible pipes were utilized to connect the HHO generator to the engine intake manifold with a valve utilized to avoid any backflow of HHO gas. Moreover for the measurement of the fuel consumptions in the absence and on the addition of HHO gas there were measuring cylinders utilized.

The HHO addition in the gasoline engine included the following steps,

- The engine was started and allowed to warm up to maintain its rpm.
- The gasoline fuel consumption of the engine was measured at different load conditions when the engine was running at 0, 200,400, 600, 800, and 1000 watts loads.
- The HHO gas production was started and measured for the addition of a required amount of HHO in the measured quantity of gasoline, figureure 4.
- Afterwards engine was run on a reduced fuel supply and applied with different loading conditions, similar to the previous conditions, to add HHO gas for performance analysis.
- In the next step the HHO gas was added to the fuel supply line (carburetor) and the engine's RPM was maintained to the similar values which were maintained in the utilization of the gasoline only.
- Once the engine was running at the same RPM its fuel consumption was also measured along with the output voltage and ampere. Moreover, the %age variation of RPM by the addition of HHO was also measured.
- There were two main input variables that were utilized for the design of experiments, the load conditions, and the engine's RPM. Table I.
- The gasoline and the combination of gasoline and HHO were utilized to run the engine on the applied load condition properly.

Table I: Input Variables

Sr. No.	Load (Watts)	RPM
1	200	1700
2	400	2000
3	600	2500
4	800	2700
5	1000	3000

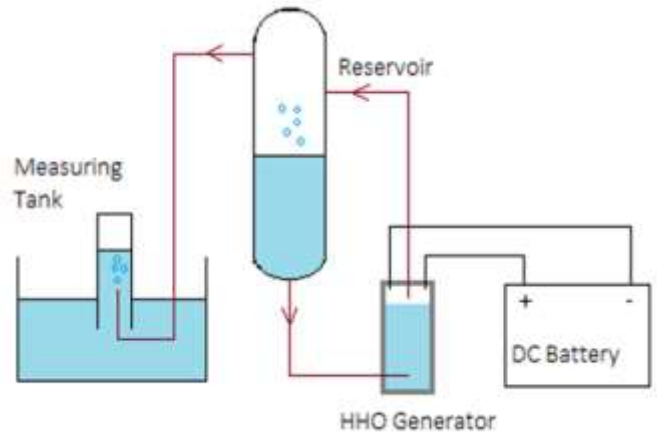

FIGURE 4: Schematic for the measurement of HHO gas production.

The HHO gas was measured by utilizing a measuring cylinder shown in Fig.4 and HHO gas was quantified by supplying continuous DC power to the HHO generator under the constant concentration of KOH in the distilled water. The HHO gas production was kept constant and injected into the carburetor of the engine, 1.5 liters per minute under different load conditions whilst fuel consumption varied at different load conditions.

III. RESULTS AND DISCUSSION

Experimental results of with and without HHO addition in gasoline Engine at different load conditions were obtained, at the environmental conditions, (Temperature = 28°C, Humidity = 67%), gasoline intake rate = 0.0025 l/min, HHO gas intake rate =1.5 l/min, and are displayed in Table I.

The results obtained are also expressed graphically to see the difference of results more clearly. The variation of engine R.P.M versus different loads in the range of 0 to 1000 watts with and without the addition of HHO gas in the fuel is shown graphically in Fig. 5.

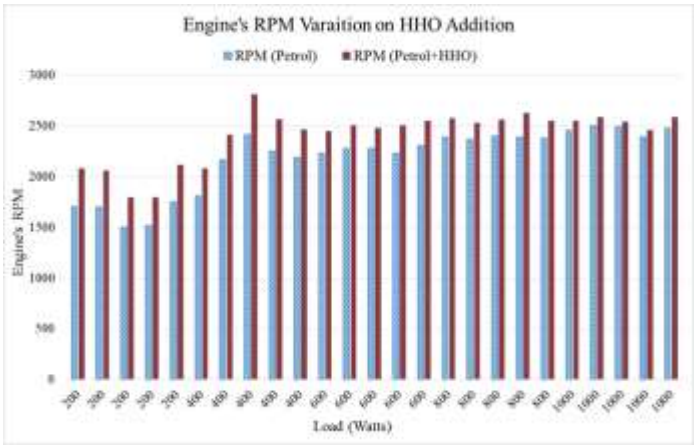

FIGURE 5: Variation of engine R.P.M versus different loads (watts) with and without the addition of HHO gas in the gasoline.

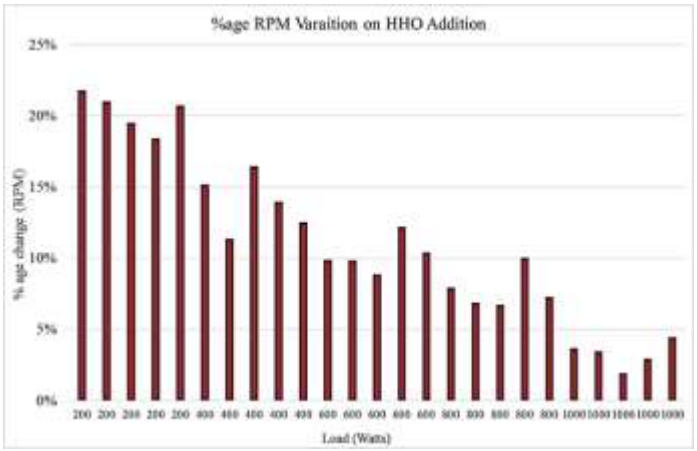

FIGURE 6: the percentage rise in the engine's RPM at different load conditions

Figure 5 shows the comparison of the engine's R.P.M while it is running with gasoline only and with gasoline + HHO to observe the effect of HHO addition in gasoline. It can be seen evidence that the R.P.M of the engine increased with the addition of HHO in the fuel. Moreover, from Fig. 6, it can also be seen that the addition of HHO has a higher effect when it is added in lean conditions i.e. when the engine is running at minimum load conditions. When the load on the engine is increased, more fuel is supplied to the engine whilst the HHO supply is constant so its effect is decreased at higher load conditions. On lower load conditions the rise in the RPM was more evident and it was gradually reduced on higher load conditions.

The variation in the overall output of the system in terms of Voltage (V) and Current (I) versus different loads in the range of 0 to 1000 watts was also represented graphically. Both output variables were also compared when the engine was running only on gasoline as well as on gasoline + HHO. From Figs. 7 and 8, it is very much clear that the addition of HHO has provided positive evidence on the outputs of the gasoline engine and the electricity generator coupled with it.

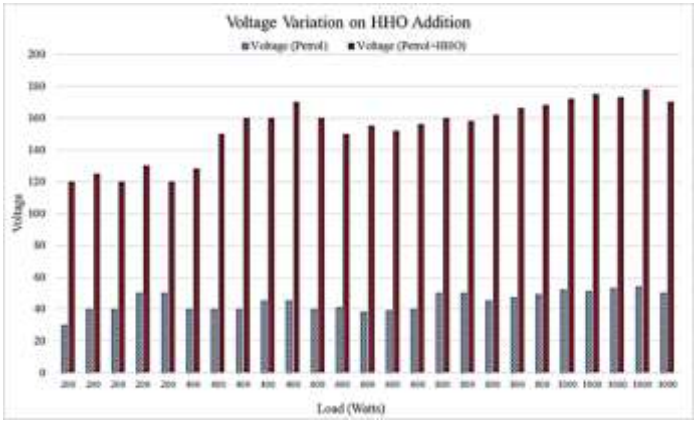

FIGURE 7: Effect of HHO addition on the output voltage of the Generator

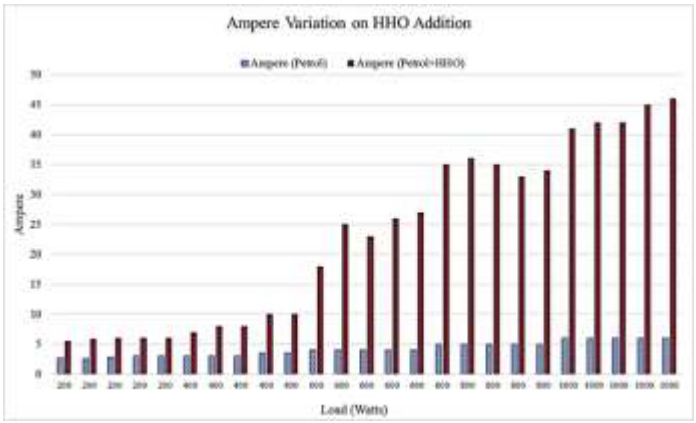

FIGURE 8: Effect of HHO addition on the output current of the Generator

Figure 7 and 8 show the comparison of electrical output from the electricity generator (coupled with a gasoline engine for electricity production) when it is running on gasoline only and when HHO is added to the gasoline. It was found that the values of output voltage were increased when HHO gas is introduced into the engine's inlet, initially, voltage values have a higher difference and after a certain load condition, the difference became smaller.

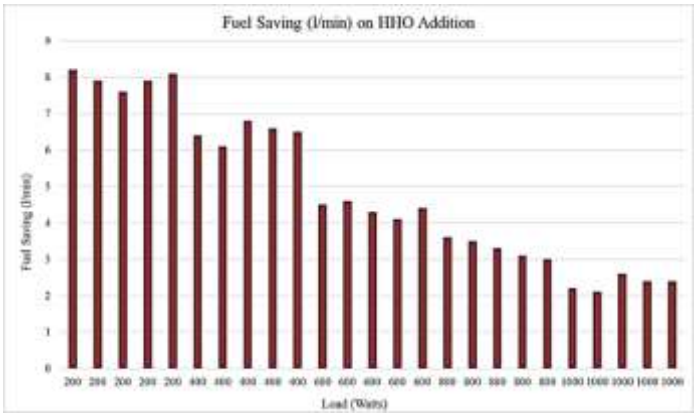

FIGURE 9: Fuel saving of engine by the addition of HHO gas.

Furthermore, the same increasing effect was observed for output current values as shown in Fig. 9, when HHO was added in gasoline. The constant quantity of 1.5 liters of HHO gas produced by the generator has provided clear evidence of increment in R.P.M of the engine.

The HHO gas is not only a fuel additive that adds up the fuel quantity resulting in the reduction of gasoline supply from the fuel tank, but it also enhances the combustion of the gasoline in the combustion chamber. This effect also results in a reduction of fuel consumption and it was also verified from the experimental results. The reduction of gasoline consumption was measured by utilizing a measuring cylinder and it was also verified that on lower load conditions when less gasoline supply was provided to the engine the more fuel-saving was observed and it was gradually reduced on higher load conditions.

A control panel was placed at front of the system having full controls to start/stop the system completely or any of its components.

This research revealed many useful aspects of utilizing the HHO cell technology on a smaller level however for utilizing this technology on an industrial level and power sector there is a lot of work required. As for bigger systems, the production of HHO is required on a higher scale which is highly risky and the storing of this gas is also a point of concern due to its higher risk of catching fire and explosion.

IV. CONCLUSION

Experimental analysis on the HHO addition was conducted in a gasoline engine (coupled with an electricity generator) to investigate the effect of HHO addition in gasoline, on the engine's R.P.M, fuel-saving, and on the output in terms of electric voltage (V) and amperes (I). After experimentally investigating these aspects, the following conclusions were drawn,

- HHO fuel additive has a positive impact on the engine's performance in terms of its crankshaft revolution per minute (RPM).
- HHO fuel additive helps to reduce the fuel (gasoline) consumption as it not only adds up the conventional fuel but also ensures the maximum fuel combustion and higher energy production.
- The increased RPM of engines by HHO addition by keeping the gasoline at constant supply on different load conditions provides positive evidence of improved fuel efficiency, brake horsepower, engine torque.
- The output voltage and amperes of current from hybrid electricity generators also provide evidence of positive impacts of HHO addition in gasoline, under different load conditions.
- As this HHO is the product of water electrolysis and its combustion results in the water this technology can be a very useful and important green source of energy. Moreover, as HHO burns quite vigorously it helps to maximize the burning of conventional hydrocarbon fuel in the combustion chamber, resulting in lesser HC emissions from exhausts, reducing environmental pollution.
- The conversion of solar energy into HHO output and utilization of that HHO as fuel additive has an overall positive impact on the system performance.
- This hybrid system has the advantage of being utilized, in different ways under different power requirements. Depending upon loads it can utilize as a hybrid system at higher energy requirements or for lower requirements its solar panels can solely be utilized.
- This system also has an option of being run on natural gas as well and also its performance was experimentally verified on the addition of HHO gas in natural gas, which was also found to be quite advantageous.

From all the above-mentioned findings, it can be concluded that the HHO addition has overall positive influences conventional hydrocarbon fuel systems. Furthermore, this modified hybrid electricity generator can be an effective solution for the shortage of electricity in underdeveloped countries and for remote areas where the provision of electricity is not feasible.

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