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Air Mixtures in Automotive Engines: Adding Hydrogen and Oxygen with Petrol in SI engine

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Abstract

In this study, a mixture of gas, composed of hydrogen and oxygen (HHO), was added to an engine as an addition to the fuel in a real-life test. HHO was produced through an electrolyser and the vehicle used had a 4-stroke spark-ignition engine with no modifications added. The procedure was carried out on the vehicle rather than having a lab test done on an engine model. The HHO electrolyser produced a constant amount of a mixed gas of hydrogen and oxygen on demand. Tests on the vehicle, both with the use of HHO mixed gas from the electrolyser and without the use of HHO, were taken and compared. The results showed that there was no damage to the engine and that fuel consumption was reduced by 10%.

Keywords: Hydrogen, SI engine, HHO, air mixture, Brown’s gas, fuel consumption, Spark Ignition,

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Introduction

The depletion of fossil fuel and the continually escalating prices of conventional fuel has created a global conscience in regards to finding alternative sources of energy. There is a constant demand, on both the local and global scale, for alternative sources of fuel that are inexpensive and that can be used in internal combustion engines. Moreover, increased awareness is growing in regards to developing more efficient fuel consumption systems. A mixture of hydrogen and oxygen (HHO), which is more popularly known as Brown gas or Rhode's gas, is proposed to improve fuel combustion efficiency when used within internal combustion engines. Apart from improving the fuel combustion efficiency, HHO has simultaneous benefits like improving emissions reduction.

The beneficial effects of HHO usage have been proclaimed for more than three decades. As reported by D.J.Cerini, the inclusion of an onboard hydrogen generator and the mixing of hydrogen will substantially improve the lean burn combustion able A/F ratios when mixed with gasoline in the internal combustion engines and substantially result in increasing the efficiency of the engine [1]. The hydrogen generation system used onboard is popularly referred to as the hydrogen on demand-supply system.

The usage of HHO with gasoline in multi-cylinder piston engines is reported in NASA publications, and the inclusion of hydrogen into gasoline for lean-burn A/F ratios and experimental results were reported to improve the thermal efficiency of the engine. In addition, the performance of the fuel mixture combustion was analyzed for its flame speed, and the combustion patterns were analyzed to report their favorable combustion conditions [2].

Minimum energy consumption equivalence ratios are reported to decrease from gasoline-burning to hydrogen mixed gasoline burning in the engines. Also, due to hydrogen peak temperature levels, NOx emissions are higher for hydrogen-gasoline mixture than in a gasoline combustion system; however, the NOx emissions levels are less in lower energy consumption equivalence ratios for gasoline-hydrogen mixture levels than in gasoline combustion systems.

Through experimental investigation, it is reported that the steam reformation of methanol is potentially an energy-conserving way to produce onboard hydrogen. A closed-loop control system is proposed to maintain engine performance and efficiency of the combined reformer-engine system. The inclusion of hydrogen in fuel combustion improvement is not only limited to liquid fuels. Even for gaseous fuels like natural gas, the flame combustion characteristics were reported to improve in the literature with experimental evidence [3].

The lean-burn limit of the natural gas engine was extended by adding hydrogen to the primary fuel. When combustion characteristics were studied in a slow and another fast-burning combustion chamber with varying amounts of hydrogen, and for different A/F ratios, more stable combustion close to the lean limit was observed. The effect was more evident for the lean operation with the slow combustion chamber. The emissions of the engine NOx were greatly reduced by the partial replacement of the hydrocarbon fuel by hydrogen combined with EGR. This is reported to simultaneously reduce the smoke and nitrogen oxide emissions without significant changes to engine efficiency [4].

The economy and emissions of the engines were reported to improve through adding hydrogen in the hydrocarbon fuel in partial replacement, as reported by Chinese scientists at Zhejiang University [5]. Also, literature results are available to support the allegation that the H2 rich reformat gas can be used as an excellent NOx reductant and can outperform raw diesel fuel as a reductant in a wide range of operating conditions. H2 rich reformat gas with gasoline in SI engines is reported to reduce up to 3.5% Co2 during the FTP test cycle. Research results also claim that the exhaust after the treatment system can be simplified, reducing the total cost of the catalysts.

There were also results, as claimed in the reports of HALO tests, that the sparkplug life and the NOx emissions in hydrogen-assisted lean operations were improved. Stable engine operations were reported at ultra-lean (relative air/fuel ratios of 2) conditions, which virtually eliminated Knox production. NOx values of 10ppm (0.07g/bhp-hr) were demonstrated, which is a 98% NOx emissions reduction, compared to the leanest un-supplemented. Spark Energy was reported to have been reduced by 22%. It was reported that it was further reduced to 27% by 17% hydrogen supplementation [6].

It was observed that the ignition energy has no impact on the Combustion duration but that only the hydrogen supplementation has an effect on the combustion duration. Using hydrogen as an additive enhances the conventional diesel engine performance and has been investigated and reported by several researchers in the past. The usage of 4% to 6.12% of the total diesel equivalent H_2/O_2 usage in the diesel engines improved the thermal brake efficiencies from 32% to 36% at a power ranging from 19kW to 28kW. This is reported to result in a fuel savings of around 15%. Also, emissions of HC, CO_2, and CO are reported to decrease substantially. There is slight increase in the NOx emissions as reported in the experimentations. In addition, H_2/O_2 beyond 5% is reported to have no effect on the engine performance [7].

As per other results available in the literature, the addition of HHO gas in the compression ignition engines has improved the performance and exhaust emissions. The investigation was performed on a four-stroke four-cylinder compression ignition engine. The HHO gas was produced by electrolysis of different electrolytes like KOH, NaOH, NaCl etc. Direct supply of H_2 on demand has resulted in better effects at both normal and high speeds and created disadvantages at the slower speeds. At lower speeds, the decreased volumetric efficiency has a considerable effect on the combustion efficiency of the engine. The engine torque output increased 19.1%, HC and CO emissions decreased by 13.1% and 5%, and SFC was improved by 14%.

Hydroxy (HHO) produced by the electrolysis of different electrolytes (KOH), NaOH, and NaCl, all aqueous solutions with different types of electrode designs, and plexiglass reactor was used in the internal combustion engines. Its effects on exhaust emissions and engine performance characteristics were investigated. Experiments showed that usage of HHO increased the performance by about 20% and emissions reductions from 5% to 15%, and SFC decreased by about 15%. However, at lower speeds below 1750rpm, HECU (Hydroxy electronic control unit) was designed so as to control the flow rate of HHO to compensate for the slower rotations and consequent A/F ration adjustments to prevent the over occupancy of a cylinder with HHO [8].

The HHO gas generator seems to be a beneficial solution as a device producing gas for doping gaseous biofuels for CI engines. The exhaust gas temperatures were found to reduce the usage of HHO in engines. Not combusted particles of fuel, which are highly carcinogenic for living organisms, produce gasification's by the effect of steam generated in the cylinder due to the addition of HHO, which will further enhance the productivity of the combustion process in the cylinder [9].

When used in the dual fuel mode in diesel engines, hydrogen improved the combustion characteristics and emissions of the diesel engine. The engine tested from light to medium loads and at several speed conditions. There was an improvement in the reduction of the emissions of the engines, with a slight compromise on the engine's efficiency [10].

Brown's gas was generated and mixed with the intake of SI engine, Honda G-200 single-cylinder engine for 197cc model. There was a calculated 20-30% of fuel consumption reduction. It was also found that the exhaust temperature was reduced and that there was a reduction in the pollution contents [11].

Emissions from the SI engines were greatly reduced by the usage of HHO in the engines; emission testing was done in the above engine and found that the nitrogen monoxide (NO) and Nitrogen oxides (NOx) were reduced to about 50% when a mixture of HHO, air, and fuel was used. Carbon monoxide concentration was reduced to about 20% [12].

Similar trends of increased fuel economy, which alternatively decrease the fuel consumption, are noticed in the SI engines by the usage of HHO in the internal combustion engines. In addition, there is a steep fall in the emissions by using HHO in the engines. Fuel consumption was reduced by about 6% in the gasoline engine, and the emissions of CO, NOx, and HC were reduced by about 30% [13].

When HHO from an HHO generator was used in a 100cc gasoline engine, air-cooled at 1500rpm for various loads and thereby replacing the conventional gasoline of the engine, it was found that there was a lot of improvement in the fuel economy, reduction in the emissions of the unborn HC and other gaseous and particulate emissions, as reported. Improvement of thermal brake efficiency of 5% - 7%, emissions reduced from 20% to as high as 94% as observed in the reporting's [14].

HHO gas, along with bio Diesel as a dual fuel with air preheating technology, was successfully used and found to reduce the contents of unburned hydrocarbons, carbon monoxides, and particulate emissions. Also, the air used in the combustion chamber was preheated, and the process improved the thermal efficiency of the engine operation [15].

Usage of direct injection hydrogen gas along with diesel for replacing jatropha oil in a single cylinder, a 4-stroke type agricultural engine was tested for its performance and found that there was an improvement in the thermal efficiency and peak power. In addition, there was a great reduction in the emissions of HC, CO2, CO, and smoke [16].

To summarize, there are several claims in the literature and reports to support the positive effects of HHO on engine performance, efficiency, emission reduction, and improvement of the engine life component. Most of these claims are valid for a range of operational loads and speed conditions.

Moreover, there is evidence that claims the positive effect of HHO mix in a range of engine types, different fuel types, engine models, and running conditions. HHO generator is a simple design with several generation technologies, with the electrolysis technique as the more popular. All HHO generators were mountable on the engine and supplied the fuel on demand.

However, to address some claims that question the HHO benefits in the engine usage, the current research work aimed to perform the experimental investigation of HHO performance in the internal combustion engine. The actual test set-up, methodology, and results are discussed further along in this study.

Materials and Methods

Current Work

The current investigation of the HHO genuineness in economizing fuel consumption was done through a systematic and critical analysis of the operational parameters of the internal combustion engine at constant loads and speeds. This investigation was done to check whether the HHO claims are genuine, as found in research reports. In addition, the investigation was done to confirm whether there are limitations in the versatility of the application of HHO in internal combustion engines. In the current testing work – A gasoline-based SI engine was selected for the test.

Technical Details of the Selected Engine

The engine of the vehicle tested is BMW x5 4-stroke engine v shape cylinders 4.4-liter displacement with port injection and specification in the table (1).

Table (1)

Production Year/Model	2003
Brand	BMW
Model	X5 (E53)
Engine	4.4i (286 HP)
Body Type	SUV
Doors	5
Seats	5
Engine Transmission	
Engine	4398 cm^3
Engine Power kW	210 kW
Engine Power HP	286 HP
Torque	440/3600 N*m/rot.
Fuel Supply System	Injection
Number of Cylinders	8
Diameter of Cylinders	92 mm
Fuel	Petrol
Fuel Tank Capacity	92 Liter 24 Gallons
Running Features	
Maximum Speed	230 km/h 144 MPH
Acceleration to 100km/h	7.5 s
Average Fuel Consumption	13.9 L/100km

The Constriction of Gas Generator (electrolyser)

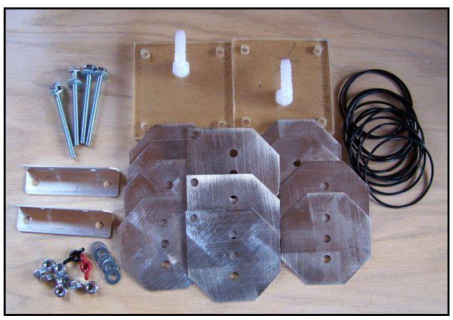
The dry cell electrolyser was chosen for this test for various reasons, such as possessing a suitable size to fit within the engine compartment. Other causes include its superlative production of HHO gas on demand. Finally, the dry cell electrolyser may easily be built in workshops, and its maintenance is inexpensive.

The HHO gas generator (electrolyser) consists of 11 plates (0.8mm thick) of stainless steel type 316, O rings to separate the plates, four screws with nuts, and two walls of transparent acrylic plates to hold the components, as shown in figures 1 and 2.

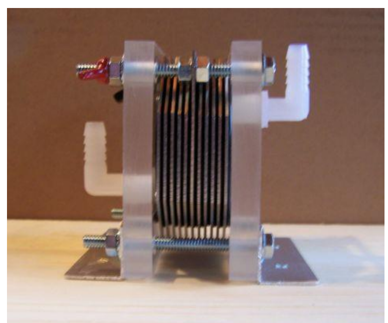
The KOH (Potassium Hydroxide) is mixed with the water and placed in the lower tube, which goes into the electrolyser, passes through the plates, and fills in the gaps between each plate. The upper tube is the outlet of gas that has been produced by the electrolyser and connected to the intake manifold. The generator produces 1 liter of HHO per minute on a power source battery of 12V and 14 – 12 Amp.

Figure 1: The electrolyser, shown assembled in (a) and unassembled in (b).

(a)

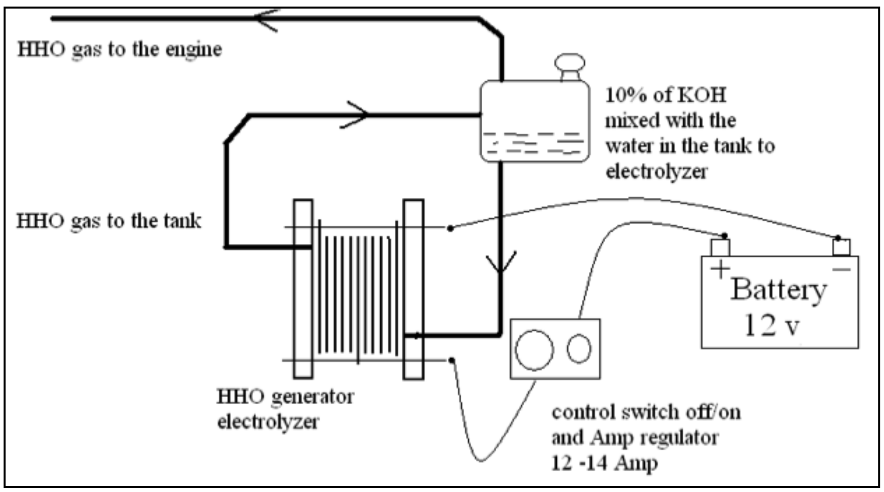


(b)



Install the electrolyser in the engine compartment and connect the power source from the battery and connecting water and gas hoses as shown in figure (2).

Figure 2: The figure illustrates how the electrolyser is installed in the engine compartment, including the electrical, liquid, and gas wiring.



Diagnostic device

The automotive diagnostic device, Autoboss V-30, was used to recorded mistakes/errors on the engine control unit, as shown in figure 3.

Figure 3: A picture of the Autoboss V-30 diagnostic device.

Test Procedure

The vehicle test, and the measurement of the amount of gas needed to cross 100 Kilometers within 100km/h, was repeated 20 times with a generator and 20 other times without a generator. The number of consumed liters was measured each time using a method in which the gas tank was completely filled before starting the experiment. Then, the vehicle crossed the required distance, and the engine was then turned off. Afterward, the amount of gas needed to refill the tank was measured, which was the amount of gas consumed to cross the distance. To ensure the accuracy of the result, the same road was used with the use of HHO and without HHO. The cooling liquid temperature was recorded by using the Autoboss V-30.

Certain measures were employed prior to each trial to ensure the accuracy of the results. Some of these measures were checking the tire air pressure, cleaning the air filter, and ensuring that the calumet air temperature ranged between 15 – 20 degrees Celsius. Other measures included ensuring that the temperature of the water coolant was 80 degrees Celsius before each trial and that the wind speed did not exceed 5 km/h. In addition, the same route had to be taken to cross the desired distance, both with and without using HHO. For that specific reason, a number of trials were dismissed due to traffic congestions, forced stops, and sudden wind change.

Moreover, the same kind of gas was used for every trial, and changing lanes was avoided as much as possible to ensure result accuracy. Also, the air conditioner and electrical equipment were not used during the trial so as to avoid alternator overload. Moreover, before starting any trial, the spark plugs were changed, along with the air and fuel filter, to guarantee the best engine efficiency. Finally, the engine oil was changed approximately three times, prior to each trial and after every 500 km, using the oil recommended by the manufacturer.

Results

The total distance traveled with the BMW during the test process was 2000Km, (1000km with the use of HHO, and the other 1000km without the use of HHO). The total fuel consumed was 201.7 liters of fuel with an HHO mix. The average fuel consumption was 10.085 liters, while the total fuel consumed was 224.9 liters of the fuel without HHO mix. The average fuel consumption was 11.245 liters, while the fuel consumption rate with HHO was 1.1 liters less for every 100 kilometers. The check engine light reported a fault for the lean mixture A/F ratio, and the cooling temperature rises 1 degree.

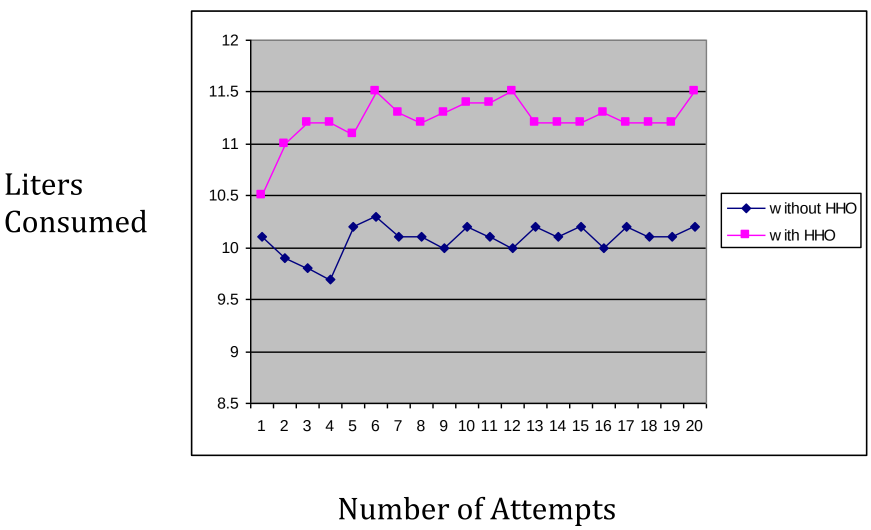
Table 1:
The following table illustrates fuel consumption in liters used in a trial of 20 times with HHO and 20 times without HHO.

No. of Attempt	Using HHO	Without Using HHO
1	10.1	10.5
2	9.9	11.0
3	9.8	11.2
4	9.7	11.2
5	10.2	11.1
6	10.3	11.5
7	10.1	11.3
8	10.1	11.2
9	10.0	11.3
10	10.2	11.4
11	10.1	11.4
12	10.0	11.5
13	10.2	11.2
14	10.1	11.2
15	10.2	11.2
16	10.0	11.3
17	10.2	11.2
18	10.1	11.2
19	10.2	11.5
20	10.2	11.5

Table 2:
The following table illustrates the rate of cooling liquid temperature with HHO and without the HHO.

No. of Attempt	Temperature Rate w/ HHO	Temperature Rate w/o HHO
1	92	91
2	92	91
3	93	91
4	92	92
5	92	91
6	93	91
7	92	91
8	93	91
9	93	91
10	93	91
11	92	92
12	92	91
13	93	92
14	92	92
15	92	92
16	92	92
17	92	92
18	93	91
19	93	91
20	93	92

Figure (1): The illustration of the number of attempts, with and without HHO, and of numbers of liters consumed in each attempt.



Analysis of the observations

The fuel consumption studies, when observed for the total distance of 100km duration with HHO mix and without HHO mix, show that there is a clear and visible decline in the amount of fuel consumption in every trial made with the HHO for a distance of 100km. Furthermore, the quantity of fuel consumption reduction was not less, but around 1.1 liters average, which is around 10% of the total fuel consumption. Hence, this is a considerable amount of fuel-saving.

However, the actual cost savings need to be worked out, and the actual fuel savings to be checked for the price savings against the cost of Rhode's gas generation and power consumption. Also, the payback period needs to be checked, including the total cost of the installation of the generator and other supporting components, along with their actual costs.

The current observations are based on the gasoline engine; however, a similar test plan is required to analyze the performance of the engine on other fuels like diesel, biodiesel, and other gaseous fuels. There are fair chances that the functionality of the engine will be better with the HHO and that there will be an improvement in fuel consumption in the engine with the HHO mix.

Exhaust gas analysis needs to be carried out for analyzing the emissions at different load conditions and speeds to check the fall in CO, NOx, and other emissions, with and without HHO.

Discussion and Future Prospects

Based on the current experimental investigation carried out on the eight-cylinder BMW Gasoline engine for the fuel consumption pattern analysis with and without HHO mix from HHO generator using the HHO generator – It is very clearly found that the fuel consumption is reduced in each trial with HHO and without HHO mix in the fuel. The result is true as the verification is done for a sufficiently higher number of trials, and the reduction in fuel consumption is observed.

However, to substantially support the HHO generator product and to recommend the usage of HHO in the engines, the limitations in the span of current research have to be extended. There should also be a complete analysis of the exhaust emissions and other operational impact effects on the pressure, component lives of the engine.

Furthermore, a test should be done for various speeds and fuel and air mixture ratios in order to get the complete details of the fuel consumption reduction trends and other positive features of the usage of HHO in the engines. Also, the engine tested was only for gasoline; similar tests and measurements are needed for diesel, biodiesel, gaseous fuels, and hence meaningful conclusion can be given for the claim confirmation of the HHO usage in engines.

The fuel consumption rate with HHO is 1.1 liters less for every 100 kilometers. It appears that the engine control unit added unwanted extra fuel to compensate for the high concentration of oxygen in the exhaust gases, which was indicated in the oxygen sensors. Further studies should be done to avoid this unwanted modification done by the engine control unit.

Finally, In the future experiment, we need to add more parameters in the engine to apply pressure sensors in the combustion chamber and adding exhaust gases temperature sensors for further studies.

List of Acronyms and Abbreviation

A/F	Air-Fuel ration
cc	cubic centimeter
CO	Carbon Monoxide
CO2	Carbon Dioxide
FTP	Federal Test Procedure(for emission)
EGR	Exhaust Gas Recirculation
g/bhp-hr	grams per brake horsepower-hour
HHO	Mix gas of hydrogen and oxygen
H2	Hydrogen
H2/O2	**Hydrogen Peroxide**
HC	**Hydrocarbon**
HECU	Hydrogen Eclectic Control Unite
Km	Kilometer
Km/h	Kilometer per hour
KOH	Potassium Hydroxide
KW	kilowatt
L	Liters
NacL	Sodium Chloride
NaoH	Sodium hydroxide/ Caustic Soda
NO	**Nitric Oxide**
NOx	Nitrogen Oxides
rpm	revolution per minute
SFC	Brake Specific Fuel Consumption
SI	Spark Ignition

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