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Study on Exhaust Gas Characteristics of SI Engine Using Fuel (Gasoline) & HHO Gas

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Abstract. Experiments have been carried out to investigate the effect of HHO gas on the emission and performance of SI engines. Water was converted into hydrogen and oxygen consisting of a 2:1 volume ratio by electrolysis process, which is called HHO (oxyhydrogen gas). An HHO fuel cell had been fabricated to generate the HHO gas required to feed the engine. This HHO is then mixed with filtered air, which is after the air filter system and before the inlet manifold system of the vehicle. In this investigation, a 125-cc single-cylinder 4-stroke air-cooled engine was used. The exhaust gas characteristics were sampled and measured using a gas analyzer. It was observed that when HHO gas had been introduced into the air/fuel mixture, it consequently reduced the concentration of NO, NO_x, CO, engine temperature, and HC by about 50%, 50%, 38%, 5% & and 45% respectively. Also, a reduction in fuel consumption is noticed for the same engine RPM and load conditions when HHO gas was imported into the A/F mixture. Also, when HHO is introduced into the system, the concentration of O_2 CO_2 increases by about 50% and 23% respectively.

Keywords. Exhaust gas, SI Engine, HHO (oxyhydrogen gas)

1. Introduction

For quite some time the main objective of scientists and researchers has been to lower the consumption of fuel as well as the emissions of internal combustion engines to minimize the detrimental effects of exhaust gas out of engines that are responsible for environmental pollution and global warming. These factors are motivating researchers to seek alternative solutions that would not require a dramatic modification in engine design but to reduce the negative impacts of the exhaust. The automotive sector is considered the largest consumer of fossil fuels. If these fuels are not utilized properly then they may last hardly for the next 100 years [1]. Also decreasing the sources of fossil fuels and constantly increasing the concentrations of atmospheric pollutants are some of the major challenges to society. In general, fuel economy is better and the combustion reaction is more complete only when an IC engine runs on a lean mixture. Hydrogen has a wide range of flammability when compared with all other fuels. Hence, hydrogen can be burned in an IC engine over a wide range of air-fuel mixtures. So advantage of this is that hydrogen can run on a leaner air-fuel mixture which ensures prompt ignition [2]. Also, from well-to-wheel analysis, it has been observed that hydrogen-powered vehicles have low consumption of fuel and emit few greenhouse gases throughout the cycle [3]. Also, it has been observed that HHO gas can be used as an additive along with petrol to reduce emissions [4]. Among the different probable alternative fuels, hydrogen is said to be the most promising due to its clean burning along with better combustion properties [5, 6]. Common duct water electrolyzers that can generate a hydrogen oxygen

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mixture which is used for injection into IC engines mostly promoted as a technique for improving thermal efficiency as well as fuel consumption and reducing emissions [7]. It also reduces HC, CO_2, and CO emissions but a considerable increase in NOx emissions [8, 9]. The overall engine performance increases as well [10].
The performance characteristics of the engine vary from speed to speed as the compression ratio changes over the combustion ratio. So, if the percentage of fuel burning increases then engine performance will also get better [11]. Finally, the addition of HHO gas as supplementary fuel reduced brake-specific fuel consumption and increased brake thermal efficiency. Also, a decrease in the values of HC and CO was observed [12, 13]
In this HHO gas was produced from water which is also known as oxyhydrogen or brown gas. This gas was obtained by the process of electrolysis. Hydrogen is a highly flammable diatomic gas having a gross calorific value of 141790 kJ/kg. After that experiments were conducted to investigate the effect of HHO gas on the emission and performance of SI engines.

2. Experimental Setup

2.1. Fuel Cell
Fuel Cell (Electrolyser) will supply Oxy-Hydrogen gas to the Engine. This device has different parts and each has a specific function. It also illustrates the possibility that in the future hydrogen can be used as a fuel. Yull Brown patented a technique to generate HHO gas based on the electrolysis process [15]. Nowadays, research on Fuel Cells (Electrolyser) is mainly adopted for HHO gas generation. In this work Fuel Cell (Electrolyser) was used as an electrolytic cell which will decompose distilled water into HHO gas. In this electrolysis process, Potassium hydro-oxide (KOH) was used with distilled water to accelerate the decomposition process [14]. HHO gas is generated by the separation of water molecules H-OH, this process is known as the electrolysis process. HHO gas has high potential energy, the caloric value of HHO gas is three times that of gasoline [14]. In Fuel Cell (Electrolyser), the cell plates were made from stainless steel. As shown in Fig: 1, the top hole was used to feed water to the generator while the bottom hole was fed out the HHO gas. Two end plates were used as

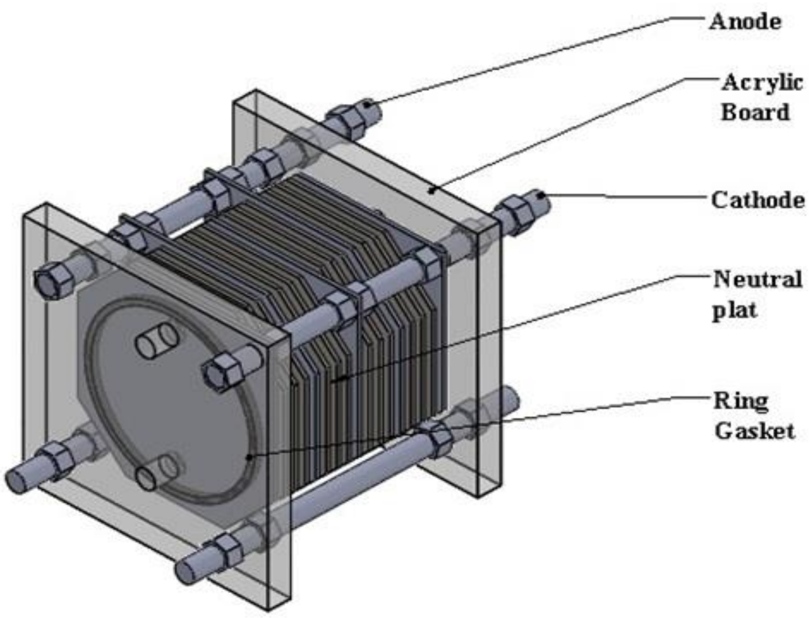

Figure 1. CAD Drawing of HHO Electrolyser

insulators, also it helps to assemble the system using nuts and bolts. The electrodes (Anode and Cathode) were used for the electrolysis process. The gaskets were used as insulators in between the electrodes. The electric current (12 volts, 30 Amps DC) enters the anode and then passes to the cathode through the electrolyte. Whenever the system is powered up, water molecules dissociate into hydrogen (H_2) and oxygen (O_2) and these H_2 and O_2 are emitted as gases from the cathode and the anode respectively. The stoichiometric equation of this process can be expressed as in

$$2\,H_2O(l) + 2e^- = H_2(g) + 2OH^-(aq) \tag{1}$$

$$4\,OH^-(aq) = O_2(g) + 2\,H_2O(l) + 4\,e^- \tag{2}$$

$$2\,H_2O(l) = 2\,H_2(g) + O_2(g) \tag{3}$$

The complete system of the HHO generator was equipped with an Electrolytic Tank. The reservoir is filled with the electrolysis solution (distilled water and the catalyst KOH) and connected to the generator. The produced gas, HHO was directed to the electrolytic tank. This electrolytic tank makes the HHO generation a circular process. HHO gas can be collected from the Electrolytic Tank as shown in Fig 2. Fuel Cell (Electrolyser) is of two types, one is a wet cell and another one is a dry cell. In this research dry cell was used because, compared to wet cell, the dry cell system requires less maintenance, there is no excessive heat generation i.e. less amount of wasted energy, less oxidation i.e. corrosion of electrodes gets reduced, requires less space for an improved design than the wet cell design and it is more robust and durable. [16].

Figure 2. HHO Dry Cell

The instrumental setup, as depicted in Figure 3, is constructed with all components interconnected.

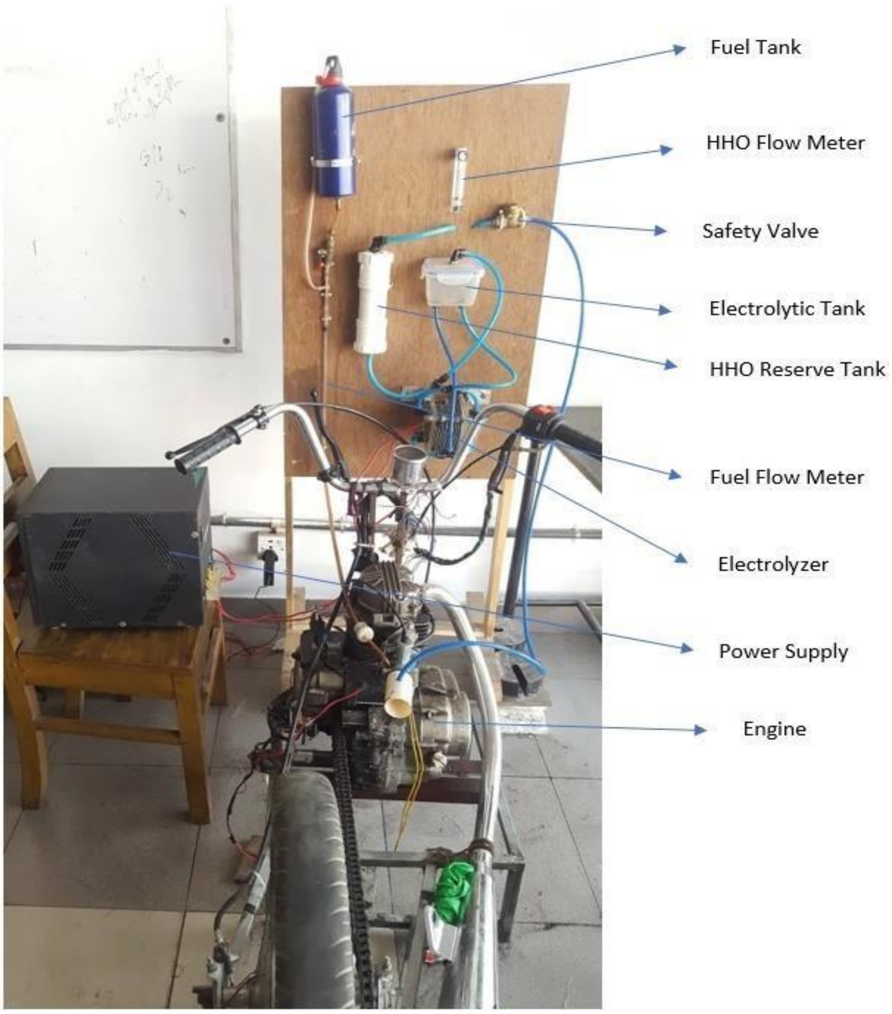

Figure 3. Instrumental Set-up

2.2. Description of the Engine and Measurement Techniques

A single-cylinder, air-cooled spark ignition engine (125 cc engine) was used for this research. The engine specification is given in Table 1 below. A constant load, no load test, and variable Engine rpm (1500–4000 rpm) was performed on this Engine. An exhaust gas analyzer was used to estimate the concentrations of NOx, HC, CO, CO_2, and O_2 in the exhaust stream. The infrared thermometer was used to measure the engine temperature. A flowmeter was used to measure the fuel (gasoline) flow rate. The engine picture is shown in Fig. 3.

Table 1. Engine Description

Displacement	125 cc
Engine Type	Single cylinder, 4-stroke, Air-cooled
Compression power ratio	8.8:1
Maximum torque	9.6 Nm/6500 rpm
Maximum power	7.2 Kw/ 8000 rpm
Ignition type	CDI
Weight	15 kg

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Figure 4. Engine Setup

2.3. HHO Injection Inside Engine
Air was going to the intake manifold through an air filter as shown in Fig. 5 . HHO gas came from the HHO dry cell and went to the intake manifold and mixed with air. Then fuel came from the fuel tank into the carburetor. Air and HHO mixture mixed with fuel in the carburetor. Adding HHO gas to the air/fuel mixture had the immediate effect of increasing the octane rating of any fuel.

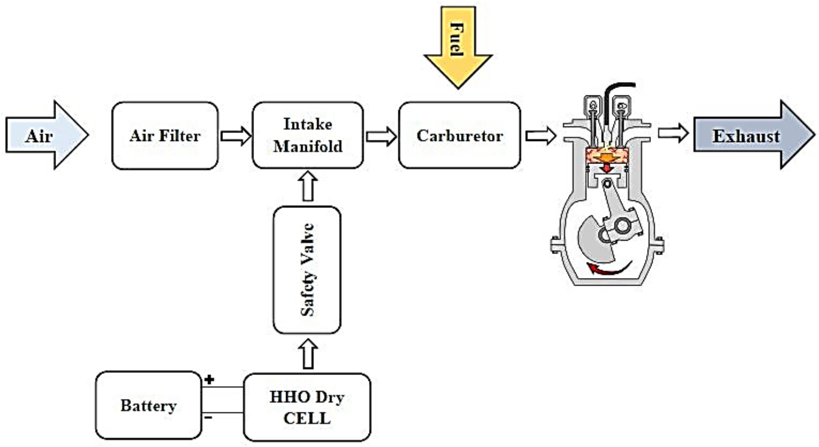

Figure 5. Air, HHO gas, and fuel (gasoline) supply system

2.4. Result and Discussion
Comparisons were drawn between the characteristics found for using only gasoline and using HHO gas with gasoline separately under constant load conditions at different engine rpm

Using only gasoline, CO_2 is the major product of combustion. With the increase of engine RPM, CO_2 production increases. Because in high RPM, the A/F ratio is low, and the amount of Fuel increases. As the engine speed increases, more amount of fuel is introduced to the engine. So, more fuel is burnt at high rpm and more CO_2 is produced.

Using gasoline with HHO gas, the CO_2 production phenomena is almost similar to that of only gasoline combustion. In the fig. 6. which is a representation of experimental data from Table II, we can see that, CO_2 emission was increased by using gasoline and HHO gas. Also, it may be since this HHO contributes to more complete combustion which increases CO_2 emission.

Table 2. Experimatal Data Of CO2 Emmision

RPM	CO_2 (Gasoline) %	CO_2 (Gasoline + HHO) %
1500	3.9	4.2
2000	4.8	5.9
2500	5.9	6.13
3000	6.3	6.77
3500	6.9	7.1
4000	7.5	7.93

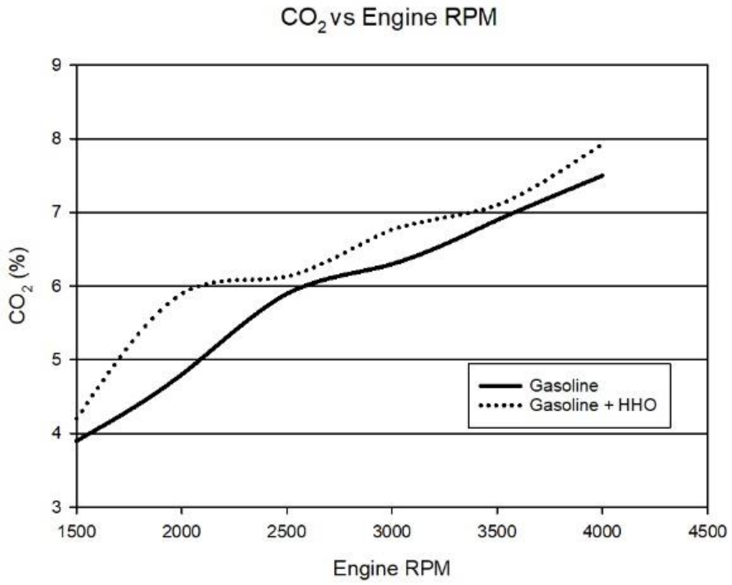

Figure 6. Comparison between CO2 emission due to the use of only gasoline vs gasoline + HHO gas for various engine RPMs

Carbon Monoxide (CO) is the byproduct of incomplete combustion and is generated due to partial burning of fuel. If the A/F mixture does not have enough Oxygen present during combustion, fuel will not burn completely. When combustion takes place in an oxygen-starved environment, there is insufficient oxygen present to oxidize carbon atoms into carbon dioxide (CO_2) and carbon monoxide (CO) forms. In high RPM when the A/F ratio is low then oxygen-starved environment is generally formed. So, the production of CO increases with the rise of engine RPM.

Table 3. Experimatal Data of CO Emmision

RPM	CO (Gasoline) ppm	CO (Gasoline + HHO) ppm
0.12	2.86	4
2000	4.35	3.1
2500	3.91	2.9
3000	4.18	2.6
3500	4.1	3
4000	4.11	3.2

Using gasoline with HHO gas, the production of CO decreases with the rise of engine RPM, which is seen in Fig 7. Because by using HHO gas, the A/F mixture has enough Oxygen present during combustion to complete the combustion.

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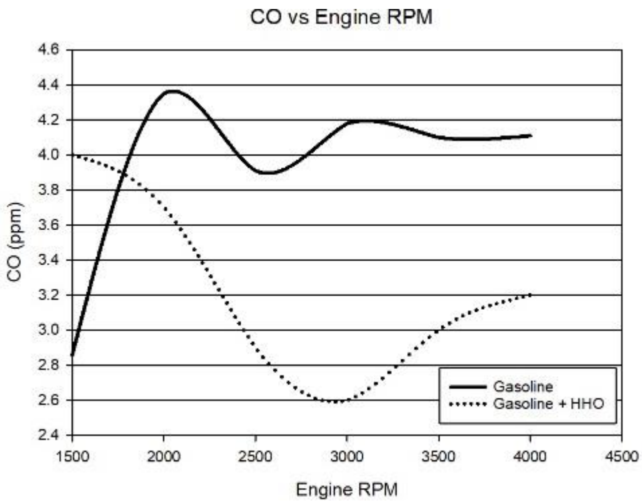

Figure 7. Comparison between CO emissions due to the use of only gasoline 84 0m00m vs gasoline + HHO gas for various engine RPMs

At fixed speed the unburned hydrocarbon increases as the load increases. This is due to more fuel being introduced to achieve the desired engine torque and hence it leads to an increase in HC emission. In Fig. 8, which is a representation of experimental data from Table IV it can be seen that there was a reduction in HC emission when the engine ran with HHO gas with gasoline rather than by only on gasoline. This is again due to the high amount of O_2% from HHO gas injected into the intake manifold which enhances the fuel oxidation process and reduces the HC emission.

Table 4. Experimatal Data of HC Emmision

RPM	HC (Gasoline) ppm	HC (Gasoline + HHO) ppm
1500	183	266
2000	172	156
2500	131.3	93.3
3000	106.3	87.6
3500	97.7	54.4
4000	80	33

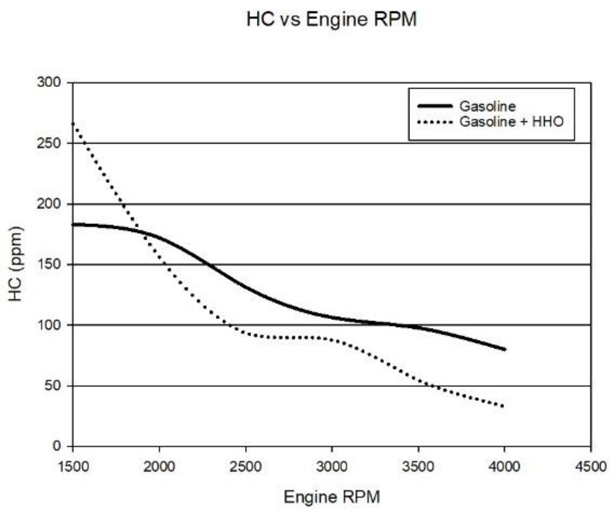

Figure 8. Comparison between HC emissions due to the use of only gasoline vs gasoline + HHO gas for various engine RPMs

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Using only gasoline, Engine temperature increases with the rise of engine RPM. In high temperature Nitrogen reacts with Oxygen and produces NO. So, with the rise of engine RPM, NO production was increased.

When the engine temperature increases with the rise of engine RPM, in that case at high temperature Nitrogen reacts with Oxygen and produces NO and NO_x. So, with the increase of engine RPM, both NO and NO_x production is increased. What is interesting to observe is that, in Fig. 9 as well as in Fig. 10, which is a representation of experimental data from Table V and Table VI respectively, it can be seen that the production of NO and NO_x by using gasoline with HHO gas was much less than the production of NO and NO_x by using only Gasoline. This may be because by using HHO gas with gasoline, the increase in engine temperature was kept lower than by using only gasoline.

Table 5. Experimatal Data of NO Emmision

RPM	NO (Gasoline) ppm	NO (Gasoline + HHO) ppm
1500	13	17.2
2000	43	28
2500	67.3	37
3000	91	44
3500	101.7	48.3
4000	114.3	60.3

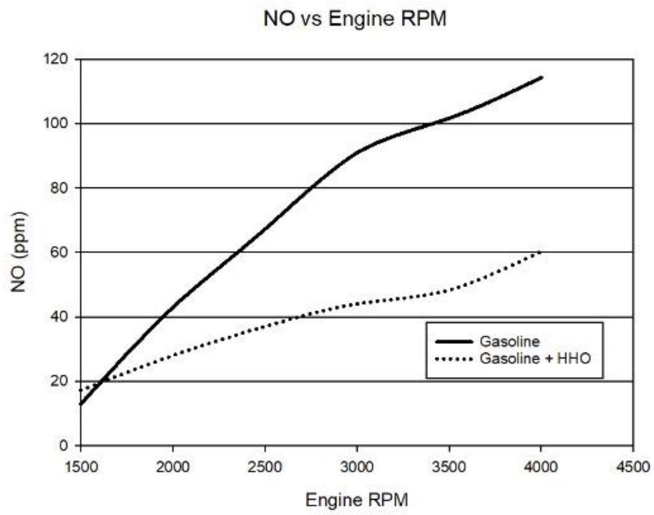

Figure 9. Comparison between NO emission due to the use of only gasoline vs gasoline + HHO gas for various engine RPMs

Table 6. Experimatal Data of NOx Emmision

RPM	NOx (Gasoline) ppm	NOx (Gasoline + HHO) ppm
1500	13.7	18
2000	45.2	29.4
2500	70.7	38.9
3000	95.6	46.2
3500	106.8	50.8
4000	120.1	63.4

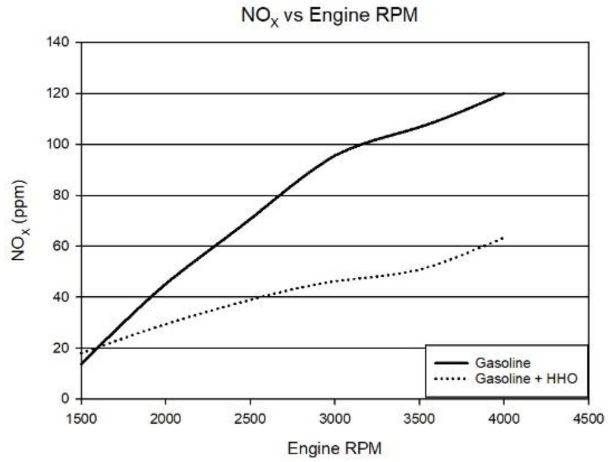

Figure 10. Comparison between NOX emissions due to the use of only gasoline vs gasoline + HHO gas for various engine RPMs

The change of O_2 emission with the engine speed is depicted in Fig. 11. As it is observed, O_2 emission generally decreases as the engine speed rises. As the engine speed rises, more amount of fuel is introduced to the engine. This causes the air-fuel ratio (AFR) to decrease. Since more fuel is introduced, therefore more O_2 is required to oxidize and as a result of this, O_2 emission decreases as shown in Fig. 11. Using Gasoline with HHO, O_2 emission decreases as well which shows a similar pattern in the case of only Gasoline. But O_2 emission is less for using gasoline than HHO as shown in the fig.11.

Table 7. Experimatal Data of O2 Emmision

RPM	O_2 (Gasoline) %	O_2 (Gasoline + HHO) %
1500	13.93	13.83
2000	8.73	13.03
2500	7.69	11.27
3000	7.26	7.83
3500	6.77	7.6
4000	6	6.43

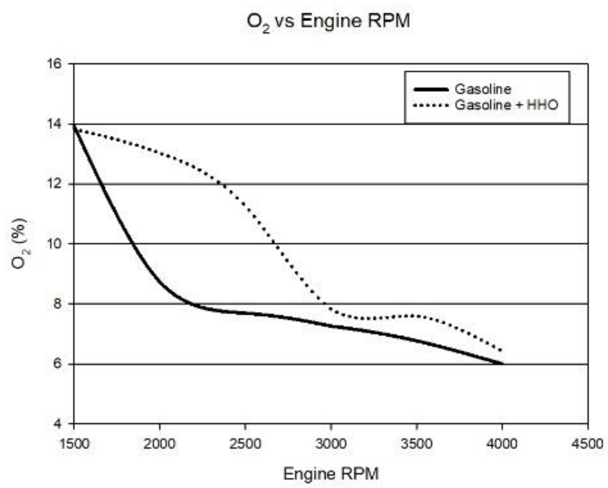

Figure 11. Comparison between O2 emission due to the use of only gasoline vs gasoline + HHO gas for various engine RPMs

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In Fig. 12, derived from Table VIII data, both using only gasoline and gasoline with HHO gas show that as engine RPM rises, more fuel is introduced, leading to increased combustion and heat generation, resulting in higher engine temperatures.

Table 8. Experimental Data of Engine Temperature

RPM	TEMP (Gasoline) ℃	TEMP (Gasoline + HHO) ℃
1500	51.7	50.5
2000	62.6	58.3
2500	77.2	75.3
3000	91.3	86.6
3500	103.3	98.3
4000	106.3	115

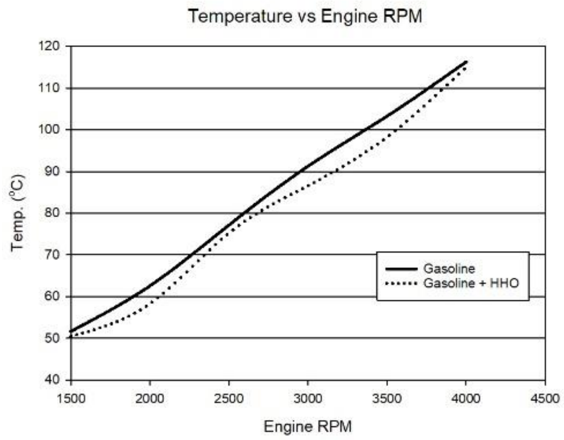

Figure 12. Comparison between Engine Temperature for using only gasoline vs Engine Temperature by using gasoline + HHO gas

In Fig. 13, based on experimental data from Table IX, we observe that increasing engine RPM leads to a decrease in the air-to-fuel (A/F) ratio, resulting in a richer mixture in the combustion chamber. Consequently, higher engine RPM is associated with increased fuel consumption. Notably, when comparing gasoline-only usage with gasoline and HHO gas, the former exhibits higher fuel consumption across most RPM ranges, with an exception at approximately 3000 RPM. However, the fuel consumption for Gasoline+HHO gas becomes lower once again. This anomaly may be attributed to a deviation from the typical trend. On average, using HHO gas results in a maximum 9.58% reduction in fuel consumption.

Table 9. Experimental Data of Fuel Consumption

RPM	Fuel Consumption (Gasoline) ml/S	Fuel Consumption (Gasoline + HHO) ml/S
1500	0.073	0.066
2000	0.081	0.075
2500	0.094	0.087
3000	0.105	0.108
3500	0.105	0.098

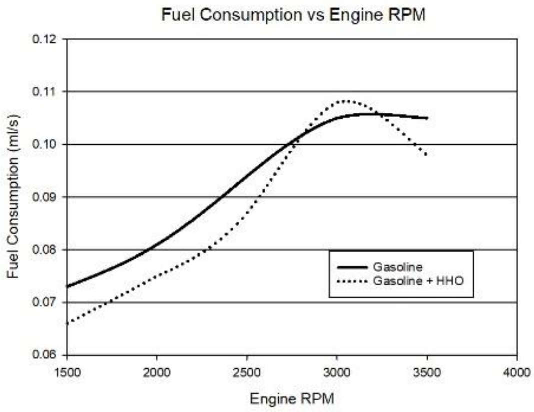

Figure 13. Comparison of Fuel Consumption by using only gasoline vs Fuel Consumption by using gasoline + HHO gas

In summary, the experimental findings reveal significant differences between using gasoline and gasoline with HHO gas as fuels. Both setups exhibit increased CO_2 and O_2 emissions with higher engine RPM, However, the addition of HHO gas contributes to more complete combustion, reducing CO emissions and unburned hydrocarbons. Notably, the introduction of HHO gas also mitigates NO and NOx production, while maintaining lower engine temperatures. Furthermore, This research demonstrates the potential environmental benefits of using HHO gas alongside gasoline in internal combustion engines. In Fig. 14, all the observations are summarized.

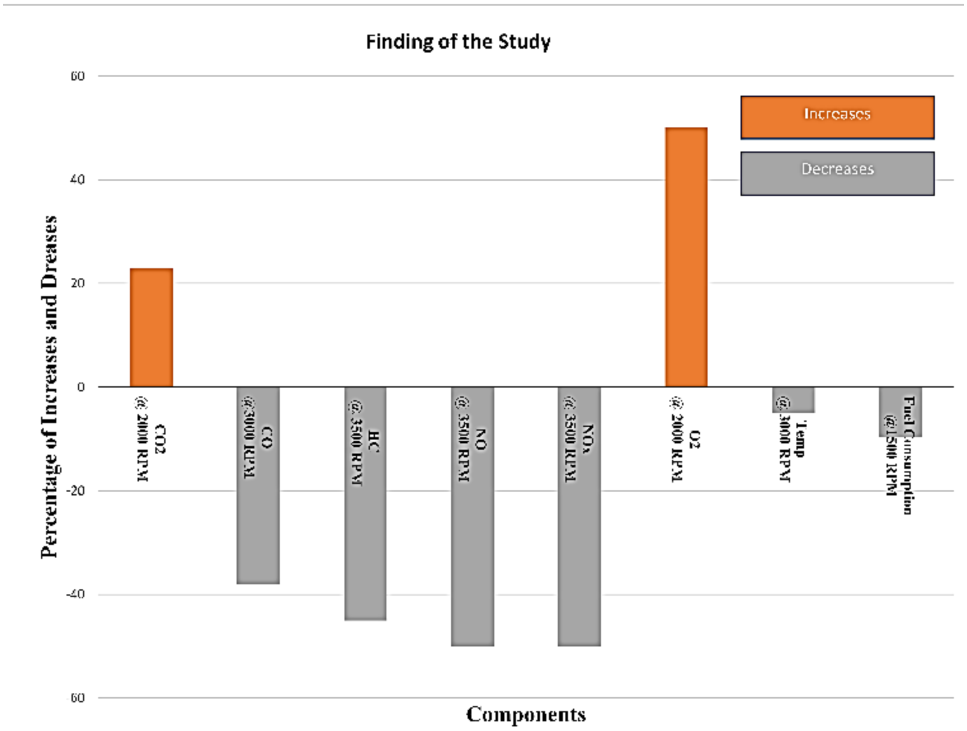

Figure 14. Findings from the Experiment

3. Conclusion

Laboratory experiments were carried out to investigate HHO gas's effect on an SI engine's emission characteristics. A new design of the HHO fuel cell has been implemented to generate the HHO gas required for engine operation. The generated gas was mixed with fresh air in the intake manifold. The

exhaust gas concentrations were sampled and measured using an Exhaust Gas Analyzer. The following conclusions can be drawn,
HHO cells can be integrated easily with existing engine systems. HHO gas was introduced into the air/fuel mixture, consequently reducing fuel consumption by about 9.50%. The concentration of NO, NOx, CO, Engine Temperature, and HC gases were reduced by about 50%,50%,38%, 5% & and 45% accordingly when HHO gas was introduced into the system in load condition. The best available catalyst was KOH, with a concentration of 6 g/L. The proposed design for the separation tank takes into consideration the safety precautions needed when dealing with hydrogen fuel.

4. Acknowledgment

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