
# Experimental investigation of the effects of HHO gas on the performance and emissions of a single-cylinder gasoline engine (PRODIT)

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**ABSTRACT**

The aim of this experiment was to create an innovative and simple HHO gas production system to investigate its effect on engine performance and exhaust emissions and to determine whether hydroxyl gas could be a viable and sustainable solution for reducing fuel consumption and pollutant emissions. Compared to various hydrogen production processes, electrolytic hydrogen is cheaper and has a lower environmental impact when it is produced by the electrolysis of water. A hydrogen generator was designed and built to produce gas HHO by electrolysis of distilled water in the presence of a catalyst (NaOH) as an electrolyte, using a pulse-width modulation (PWM) production system to control the amount of gas. Tests were carried out on a single-cylinder, four-stroke petrol engine (PRODIT GR306/0001). Gas was added to the engine's air intake manifold at different flow rates. Tests are conducted at 2000 rpm and compression ratios(11:1)under various loads. Test results show an improvement in engine performance through an increase in thermal efficiency at best case (12%), a reduction in fuel consumption by (15.3%), and a reduction in all exhaust emissions (CO2, CO, HC, and O2). It was also noted that the exhaust gas temperature is lower when operating on dual fuel compared to pure gasoline.

**Keywords:** HHO gas, Engine Performance, combustion, fuel, renewable.

## 1.Introduction

For a long time, fossil fuels such as gasoline and diesel have been the main source of energy for both the transportation and power generation sectors. Because fossil fuels have limited potential and due to their negative environmental impacts, the worldwide engine community is increasingly interested in developing alternative fuels that are better for the environment [1]. Interest in alternative fuels began after the oil crisis in the 1970s. However, it has recently increased due to concerns about rising prices, air quality, and greenhouse gases. With the rise in oil prices, alternative fuels are becoming more competitive [2]. Fossil fuels in liquid form currently provide about 65 percent of the world's energy requirements [3].According to the Hydrogen Council, a global hydrogen energy initiative made up of several energy and transportation companies. Approximately 25% of passenger cars and 20% of non-electric rail transport could be powered by hydrogen by 2050. This could lead to a 20% reduction in daily transport fuel consumption [4,5]. Due to its unique properties, such as low ignition energy, fast flame propagation speed, and wide working range, hydrogen is the ideal choice for use as an alternative fuel for gasoline engines. The mixture of air and hydrogen gas creates a combustible mixture that can be burned in a gasoline engine. The massive post-combustion combustion results in lower flame temperatures, which is directly related to reduced heat transfer to the walls, improved engine efficiency, and lower NOx emissions[6,7,8]. Hosking notes that currently LPG remains the best alternative fuel. However, once hydrogen production increases, availability increases, and prices fall, hydrogen will replace LPG as a promising alternative fuel. This is mainly due to the low emission of harmful gases and the high energy density of the hydrogen structure [9]. Previous research reveals that when hydrogen gas is used as a fuel booster in the combustion process, engine efficiency increases, and it has the potential to significantly reduce pollutants and fuel consumption. Despite the many advantages of using hydrogen in IC engines, there are still difficulties in production, storage and transportation [10]. Several researchers have conducted various experiments on internal combustion engines using HHO gas under different operating conditions and presented their ideas.

**Al-Rousan et al. [11]** conducted an experimental study to determine the effect of HHO on the Honda G200, a 197 cc, single-cylinder engine. Tests were conducted with a constant load and variable speed from 1000 to 2300 rpm. The HHO gas produced by the electrolysis process is mixed with fresh air before being fed into the carburetor. Exhaust gases were analyzed using an exhaust gas analyzer. With the addition of HHO to the fuel-air mixture, the emissions (NOx, NO, CO, and $CO_2$) decreased by 54%, 50%, 20%, and 40%, respectively. Fuel consumption decreased by 20 to 30%. A lower exhaust gas temperature was also noted. The concentration of oxygen content increased by 20% over the speed of 1900 rpm.

**Abdullah [12]** studied the effect of adding HHO gas produced from a hydrogen production cell. HHO is used to enhance combustion in the Sinjai gasoline engine, model LJ276MT-2, 644 cc, 2-cylinder. The study was conducted at 2000–5000 rpm. Tests yielded the following results: an increase in torque of 19.87%, an increase in engine power of 20.14%, an increase in average effective pressure of 19.87%. .improvement in thermal efficiency of 12.39% , and a reduction in SFC of 36.44%. Emissions (CO, $CO_2$, and HC) decreased by 28.756%, 21.303%, and 45.039%, respectively, compared to the premium fuel used in the experiment.

**Sharma et al. [13]** used a four-cylinder gasoline engine of 1197cc. To study the effect of adding HHO gas on engine performance at variable loads from 0% to 100%. The results showed the following: Engine braking power improved by 11.5% on average. Average engine fuel consumption decreased by 6.35%, and average thermal efficiency increased by 10.26%. The temperature of the engine exhaust gases decreased by 4%. NOx is also reduced due to the complete combustion of the fuel.

**Babaria et al. [14]** studied the effect of HHO gas on the combustion process of a Honda 135cc, four-stroke, gasoline engine. When HHO gas is added to the engine. Thermal efficiency improved by 5%, and fuel consumption decreased by 20%. Carbon monoxide and hydrocarbon emissions decreased. Engine power increased by 5.7%.

**Shajahan et al. [15]** conducted HHO gas injection with a fuel-air mixture at 3,600 rpm through the intake manifold of the Honda GK200 single-cylinder, 197cc, under various loads ranging from 1 to 4 kg. To evaluate engine performance and emission characteristics. When HHO gas was added to the mixture, the thermal efficiency increased from 28% to 35% due to the higher flame velocity of the hydrogen. Fuel consumption has been reduced by 25 to 35%, CO concentration has been reduced by 7 to 11%, and hydrocarbon concentration has been reduced by nearly 50%. Oxygen concentrations increased by 20%.

## 2.Experimental setup and procedure

The experiments were carried out in the Internal Combustion Engines Laboratory, Department of Mechanical Engineering, College of Engineering, Thi-Qar University, Iraq. Figure (1) shows a schematic diagram of the experiment setup. Tools and equipment for the pilot unit are shown below.

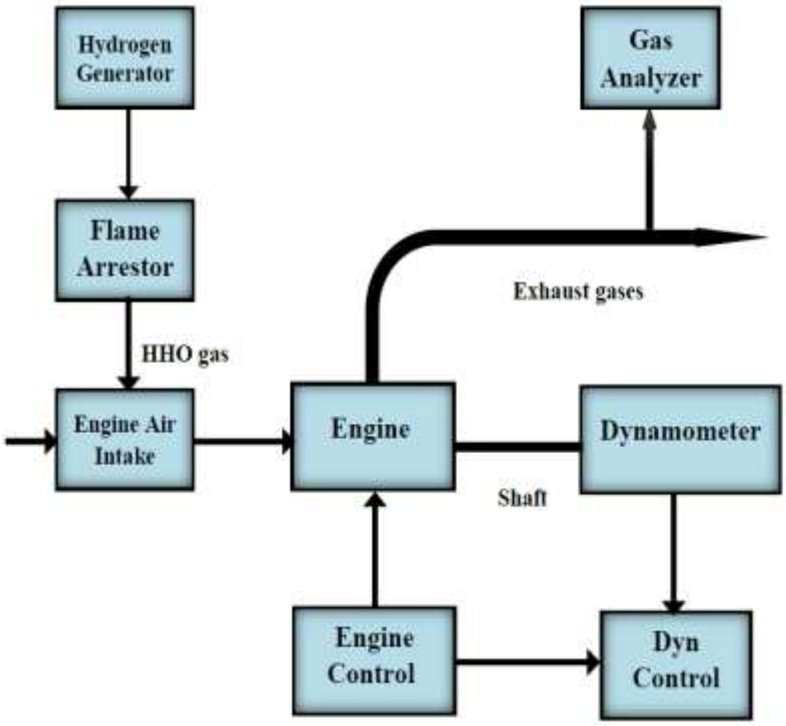


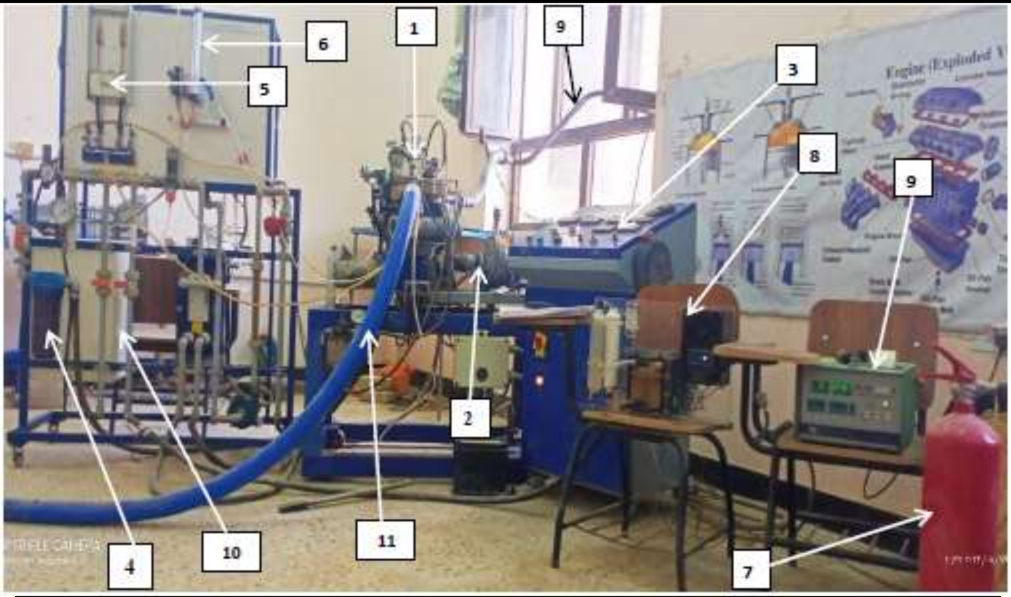

Figure (1) Schematic diagram to the experimental setup

**2.1 Experimental setup**

Tests were performed on a single-cylinder, water-cooled, four-stroke petrol engine with a displacement of 541cc (PRODIT GR306/0001), whose specifications are given in Table1, connected to a hydraulic dynamometer to simulate various loads. Engine brake power, engine torque and speed, air and fuel flow rate, and exhaust gas temperature were measured, from which other parameters were calculated. The experiments also included measuring exhaust emissions (CO, $CO_2$, $O_2$, HC) using an exhaust gas analyzer. Figure (2) shows a photograph of the experimental platform with other equipment.

Table (1): Engine specifications

| | |
|---|---|
| Manufacture | PRODIT |
| Cycle Otto or Diesel | four stroke |
| Diameter | 90mm |
| Stroke | 85mm |
| Swept volume | 541cc |
| Compression ratio | 4–17.5 |
| Max. power output | 4kW at 2800 rpm |
| Max. torque | 28N·m at 1600 rpm |
| Cooling type | Water cooled |
| No load speed range | 500–3600 rpm |
| Load speed range | 1200–3600 rpm |




| | | |
|---|---|---|
| 1. Engine | 2. Dynamometer | 3. Control panel |
| 4. Engine cooling unit | 5. Fuel engine unit | 6. Air processing system |
| 7. Foam extinguishers | 8. HHO generator | 9. Exhaust |
| 10. Orifice meter | 11.Intakemanifold | 12.Gas Analyzer |

Figure (2) A photograph of the laboratory unit

### 2.2 Hydrogen generators

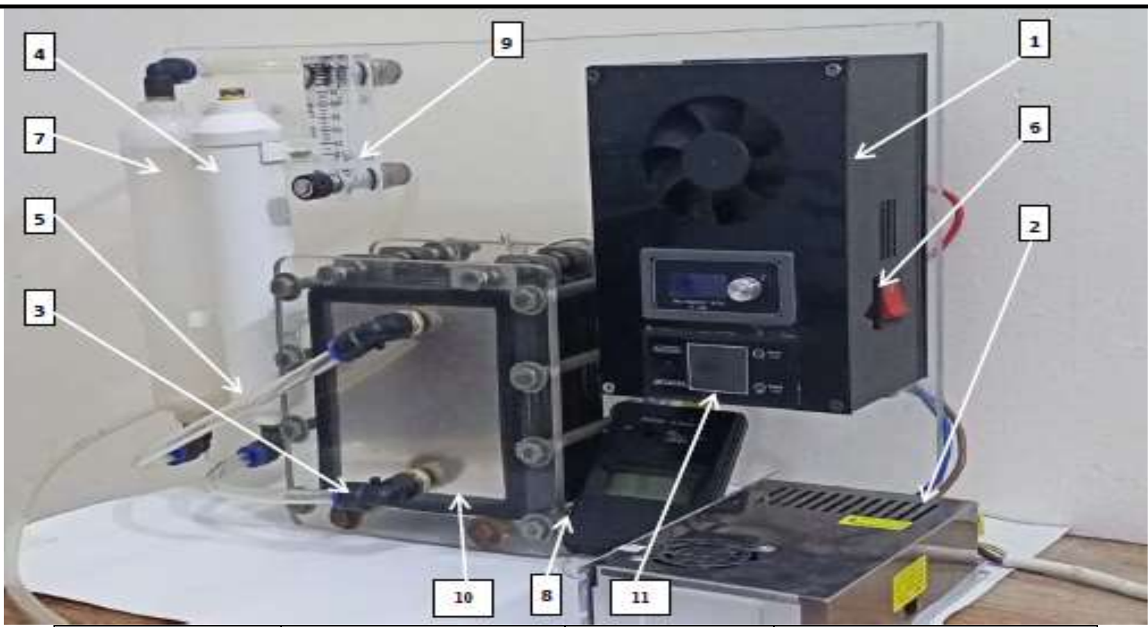
The basic idea of water electrolysis is to allow direct electric current to flow between two electrodes in the presence of an electrolyte to increase the electrical conductivity of the water. A water molecule is oxidized at the positive electrode and reduced at the negative electrode, resulting in oxygen and hydrogen gas[16]. as shown in the general decomposition reactions in the following equations:

$(Cathode)\ 2H_2O + 2e^- \rightarrow H_2 + 2OH^-$ ....(1)

$(Anode)\ \ 2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$ ....(2)

$(Total)\ H_2O + \ electrical\ energy \rightarrow H_2 + \frac{1}{2}O_2$ ....(3)

The components of the HHO generator subsystem include a water electrolyzer, DC power supply, flame arrester, electrical safety lock, bubble tank, PWM circuit, and HHO gas flow meter from 0 to 1 LPM. Depending on the amount of gas required, the generator may contain one or more cells. Electric current is the driving force in this system. Another important component of the analytical process is the electrolyte, or catalyst, to produce HHO gas. It is a conductive medium for free ions. It is called a catalyst reformer because it stimulates or accelerates gas generation. Figure (3) shows the main parts of the system.




| | | | |
|---|---|---|---|
| 1. PWM | 2. Power Supply | 3. Fittings | 4.The Water Reservoir |
| 5. PVC Tubing | 6. Emergency Stop | 7. Bubbler | 8. Thermocouples |
| 9. Flow Meter | 10. Dry Cell | 11. Digital voltage and current meter | |

Figure (3) Hydrogen generators system

**2.3 Experimentation Fuels**

The tests were carried out using Iraqi gasoline produced by the (Iraqi Ministry of Oil) with hydrogen gas produced by electrolysis of water shown in Table 2.

Table (2) the properties of used fuels[17,18,19, 20].

| Properties | Gasoline | Hydrogen |
|---|---|---|
| Normal state | Liquid | Gaseous |
| Chemical formula | various | $H_2$ |
| Density at NTP [kg/m$^3$] | 740 | 0.085 |
| Lower Heating Value [MJ/kg] | 42.9 | 120 |
| Stoichiometric AFR [kg/kg] | 14.7 | 34.3 |
| Octane number | 85 | <130 |
| Boiling point at I bar [ºC] | 25-215 | −252 |
| Heat of vaporization [kJ/kg] | 130-350 | – |
| Flammability limits in air [λ] | 0.2-1.6 | 10-0.14 |
| Adiabatic flame temperature [ºC] | 2002 | 2480 |
| Energy per unit mass of air [MJ/kg] | 2.95 | 3.37 |
| Carbon content (mass%) | 84 | 0 |

**2.4 Experimental procedure**

The tests were carried out under stable conditions, and the engine was heated until a steady state was reached. The first set of experimental tests started with pure gasoline, on the basis of which the comparison will be made. Tests were conducted at 2000 rpm, C.R=11:1 and under various engine loads (0, 2, 4, 6, 8, 10) N.m. The tests were repeated three times, and average values were taken to reduce experimental uncertainties. HHO gas was added at volumetric flow rates of 0.3, 0.6 and 1 LPM, respectively, by mixing with the air entering the combustion chamber. With a fixed amount of liquid fuel used for each test point 20cc. Certain safety precautions are taken in the laboratory. To provide safe working conditions.

## 4. Results and discussion

### 4.1 Engine Performance characteristics

#### 4.1.1 Brake thermal efficiency (ɳbth)

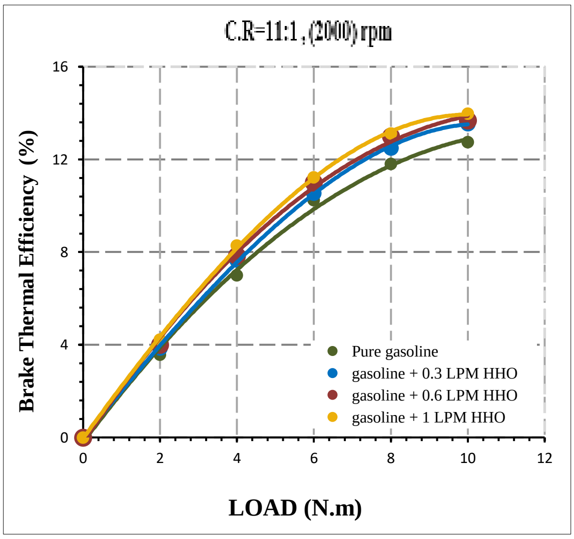
Figure (4) shows that the brake thermal efficiency rate improves when using dual fuel, as it increases by 6%, 9.1%, and 12%, respectively, for flow rates of HHO gas (0.3, 0.6, and 1) LPM, respectively, compared to pure gasoline. It was observed that when the flow of HHO gas increased, the brake thermal efficiency improved due to the improvement in the combustion process. The temperature of the HHO gas stimulates the cleavage of the benzene molecules, which raises the reaction rate and flame velocity, thus enhancing the combustion efficiency[21]. The faster combustion of hydrogen results in a shorter combustion period and, thus, a higher cylinder temperature, which contributes to higher thermal efficiency. The primary benefit of HHO is that it enhances the octane rating of any gasoline added to it, thereby improving the characteristics of low-grade fuels and shifting ignition to top dead center with the same confidence as higher-octane fuels[22].

#### 4.1.2 Brake specific fuel consumption (BSFC)

Figure (5) shows the variance in brake specific fuel consumption (BSFC). It is noted that when the HHO gas is increased to the engine, the fuel consumption of the brakes decreases. This is due to the fact that HHO acts as a gasoline booster, resulting in improved combustion and increased combustion efficiency. From the experimental results obtained when HHO gas was added to gasoline fuel as an additional fuel, the brake specific fuel consumption rates decreased by 6.9%, 10.6%, and 15.3%, respectively, when HHO gas was added at mixing rates of 0.3, 0.6, and 1 LPM for HHO gas over respectively compared to pure gasoline

#### 4.1.3 Exhaust gas temperature

The hydrogen combustion process only produces water vapor, which contributes to a lower exhaust gas temperature (EGT). Moreover, the presence of HHO reduces fuel utilization and the phenomenon of lean mixture, resulting in lower exhaust gas temperatures[22]. Laboratory results show that when the engine is running in pure gasoline mode, the exhaust gas temperature is higher than in dual fuel mode. It has also been observed that EGT increases with increasing load because more fuel is burned to meet the required energy requirements. Figure (6) shows the variation in EGT, where the exhaust gas temperatures decrease by about 0.8%, 1.6%, and 3%, respectively, when adding HHO gas (0.3, 0.6, and1) LPM, respectively, compared to pure gasoline. According to previous research, a 4% decrease in EGT was observed when using a mixture of HHO and gasoline as a result of an improvement in the fuel combustion process, which led to a significant decrease in NOx emissions in the exhaust gas[13]. It was also found in other research that adding HHO to a gasoline engine reduces EGT [11].



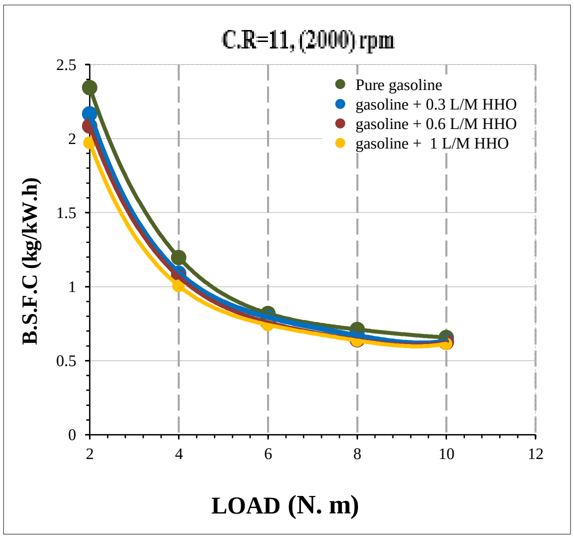



Figure (4) Variation in BTE versus loads Figure (5) Variation in BSFC versus loads

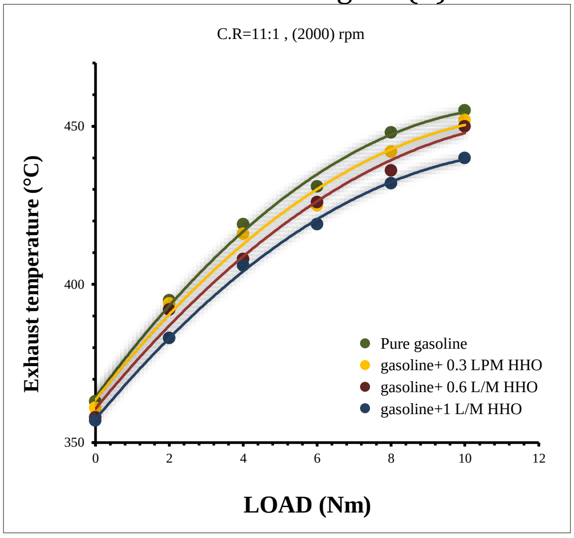



Figure (6) Variation in EGT versus loads.

## 4.2 Emission characteristics

### 4.2.1 Carbon monoxide CO emissions

Carbon monoxide is a toxic gas that poses serious threats to human health and therefore must be reduced. The effect of adding HHO gas in varying proportions to the engine as a fuel enhancer was examined, as the results show that it reduces carbon atoms and reduces the amount of air that increases the concentration of CO emissions that depend on the engine combustion efficiency and the fuel-to-air ratio. Carbon deficiency in HHO significantly inhibits the formation of CO. In addition, the excellent chemical qualities of HHO gas, such as wide flammability and fast flame speed, accelerate the combustion process of the mixture and ensure complete combustion of the gasoline [15].

CO is the main component that results from rich combustion due to excess fuel compared to the amount of air consumed. Figure (7) shows the variation in CO emissions, as it decreases when HHO gas is added due to the optimization of the combustion process. The results shows a decrease in CO emissions by 8.7%, 17.7%, and 29.5%, respectively, when HHO gas was added at rates (0.3, 0.6, and 1) LPM, respectively, compared to pure gasoline.

Experimental results show high concentrations of CO emissions in pure gasoline mode, which indicates incomplete combustion for many reasons. When HHO gas is added, CO emissions decrease. This is due to the fact that HHO gas contains additional oxygen, which helps in the oxidation of CO to $CO_2$ [17].

### 4.2.2 Carbon dioxide $CO_2$ emissions

Experimental results show a decrease in carbon dioxide emissions due to the good combustion properties of hydrogen when it is added as a fuel booster . This is due to the lack of carbon in the hydrogen molecule, which reduces the amount of carbon in the cylinder. When fuel mixture and HHO gas are used, $CO_2$ emissions are reduced due to the higher hydrogen-to-carbon ratio and higher temperature inside the combustion chamber[17].

The engine produces less $CO_2$ when operating in dual fuel mode, which indicates better fuel combustion compared to pure gasoline. The results also show an increase in $CO_2$ emissions with increasing load at a constant speed, due to the engine consuming more fuel. Lower $CO_2$ emissions are a good indicator of combustion quality. $CO_2$ emission rates decrease by 7.4%, 13.5%, and 24.3%, respectively, at HHO gas mixing rates 0.3, 0.6, and 1 LPM, respectively, as shown in Figure (8) compared to pure gasoline.

### 4.2.3 Hydrocarbon HC emissions

Unburned hydrocarbon emissions arise from the incomplete combustion of hydrocarbon fuels. HC in exhaust gases are measured in parts per million (ppm) or as a percentage by volume. HC emissions are a measure of engine inefficiency but not a significant indicator of pollutant emissions.

Blending hydrogen reduces UBHC emissions because hydrogen contains no carbon and reduces fuel consumption, resulting in fewer carbon atoms in the cylinder and improved combustion. The combustion of hydrogen raises the temperature and leads to the oxidation of the HC formed from the injected fuel [23]. Oxygen-enriched HHO reduces hydrocarbon emissions by fuel oxidation, resulting in shorter cooling distance, wide ignition range, and improved combustion efficiency [22].
Experimental results show that hydrocarbon emissions decrease with increasing loads due to higher cylinder temperatures, which leads to more oxidation of HC. Figure (9) shows a decrease in HC content of 9.7%, 16%, and 23%, respectively, when HHO gas was added at flow rates of (0.3, 0.6, and 1) LPM, respectively.

### 4.2.4 Oxygen $O_2$ emissions

Oxygen emissions are measured to evaluate combustion characteristics, although they are harmless. The air/fuel ratio in an engine can be calculated by measuring the oxygen content in the exhaust. Experimental results show the effect of mixing HHO in a gasoline engine on the exhaust gas $O_2$ content. The oxygen content in the exhaust gas decreases when the HHO gas is increased because the actual amount of air inside the cylinder decreases due to the decrease in the density of hydrogen. In addition, hydrogen consumes more oxygen during combustion than gasoline.

Through the results, Figure (10) shows the effect of mixing HHO gas on the oxygen content in the exhaust. The oxygen content decreases when HHO gas rates of 0.3, 0.6, and 1 LPM are added, by about 0.6%, 1.3%, and 1.6%, respectively, compared to pure gasoline.

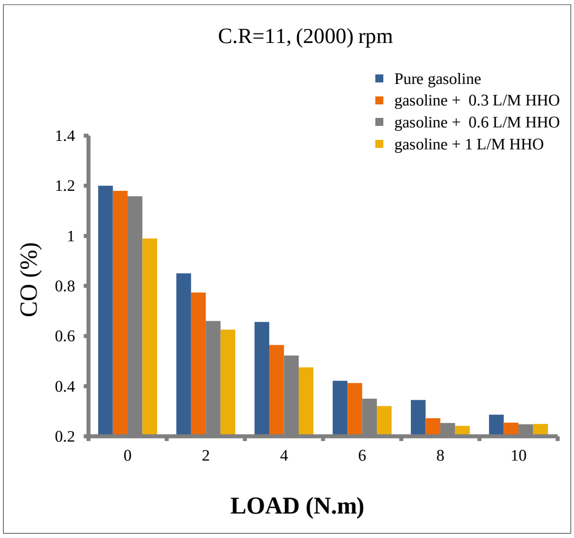



Figure (7) Variation in emissions CO with engine loads

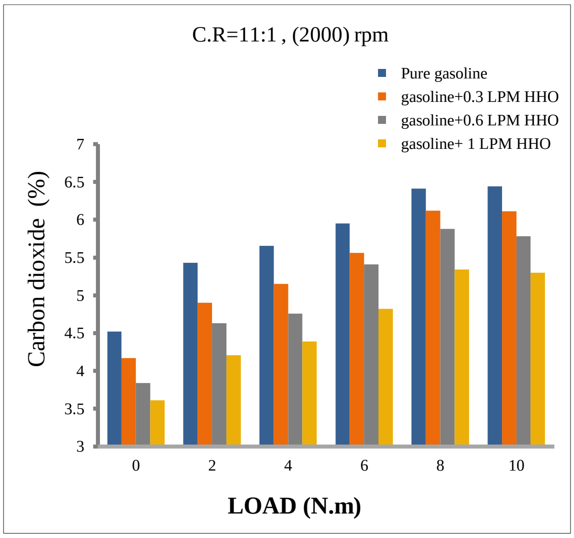



Figure (8) Variation in $CO_2$ emissions with engine loads

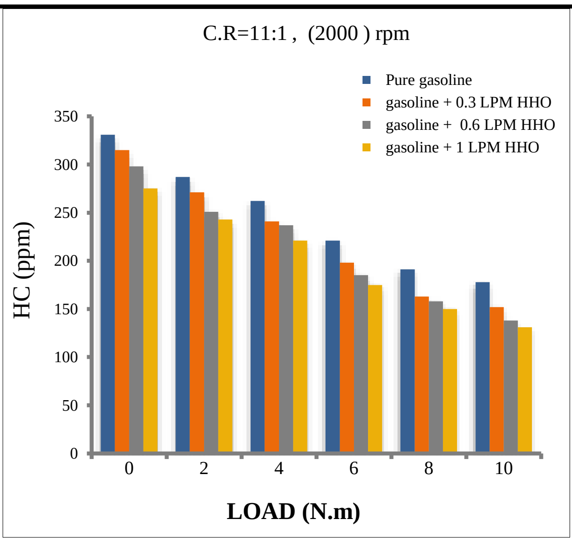



Figure (9) Variation in HC emissions with engine loads

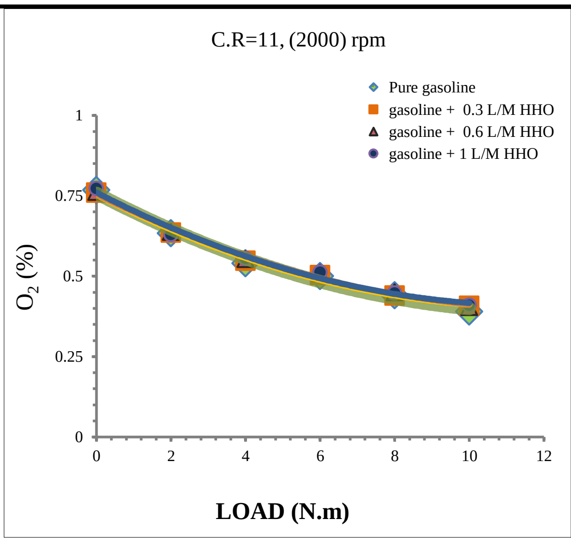



Figure (10) Variation in oxygen $O_2$ content with engine loads

## CONCLUSION

The aim of this research is to study the effect of adding hydroxyl gas at varying rates (0.3, 0.6, and 1) LPM, respectively, as an additional fuel under different loads at a constant speed in a gasoline engine. To check engine performance and exhaust emissions. The results were compared with the case of pure benzene. Conclusions can be drawn from the current study:

1. A gasoline engine can be successfully produced to operate on dual fuel (HHO+gasoline) and a dual fuel engine is ideal for all applications, whether in vehicles or in other energy applications.
2. When the gasoline engine runs on dual fuel, engine performance improves and exhaust emissions decrease.
3. The new design of the hydrogen generator with pulse width modulation (PWM) technology contributed to controlling the amount of gas required to be added to the engine.
4. The brake thermal efficiency of the engine improves at its best when adding 1LPM of HHO gas at a ratio by 12%.
5. Brake specific fuel consumption decreases at best by 15.3% when adding LPM of HHO gas.
6. All exhaust emissions decreased ( $CO$,$CO_2$,HC, and $O_2$ ) respectively at their best when adding 1 liter of HHO gas by (29.5%,24.3%,23%, 1.6%) respectively compared to pure gasoline fuel.
7. Exhaust gas temperature is lower in dual fuel mode compared to pure gasoline. In the best test case decreased by 3%.

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**NOMENCLATURE**

| **Symbol** | **Description** | **Unit** |
|---|---|---|
| CO | Carbon monoxide | % |
| $CO_2$ | Carbon dioxide | % |
| HC | hydrocarbons | Ppm |
| NOx | Nitrogen oxides | % |
| ICE | Internal combustion engines | - |
| g/L | Gram per liter | - |
| NaOH | Sodium hydroxide | - |
| KOH | Potassium hydroxide | - |
| HHO | hydroxyl gas | - |
| SFC | Specific fuel consumption | kg/hr) |
| UBHC | Unburned hydrocarbon | - |
| BSFC | Brake specific fuel consumption | kg/Kw.hr) |
| BTE | Brake thermal efficiency | % |
| LPM | liter per minute | - |
| N.m | Newton meters | - |