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Experimental Investigation on the Effect of using Oxy-Hydrogen Gas on Spark Ignition Engines Performances, and Emissions Characteristic

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***Abstract*- The target of this work was to study the effect of adding HHO to gasoline fuel on engine performance and emissions. HHO gas production per input power was achieved by designing, manufacturing, and optimizing the HHO cell. The optimized parameters were the amount of HOH added to the Gasoline as the experimental Study is done by measuring the thermal efficiency and exhaust emission effect in many cases. First case Neat Gasoline and the remaining cases after adding HOH in different percentages of 5, 10, and 15 L/ min and then repeating the experimental tests with three different commercial Octane Boosters. The used engine is a Honda commercial OHV engine, air-cooled, four-stroke, and single-cylinder. Additionally, the Gasboard exhaust gas analyzer was used to monitor the emissions of NOx, HC, and CO. The results indicated that the impacts of HHO and gasoline fuels on engine performance metrics like braking power, brake-specific fuel consumption, brake thermal efficiency, and exhaust emissions such as CO, NOx, CO2, and exhaust gas temperature were evaluated at different engine loads (lighting) (EGT). Except for CO and HC emissions in comparison to neat petrol operations, the results revealed that adding HHO-gasoline combination with additives is the most successful in boosting engine performance and offering a more ecologically acceptable attitude toward exhaust emissions.**

Keyword: Gasoline engine; Octane poster additives; Emissions; Engine performance; Oxy-Hydrogen HHO

I- INTRODUCTION

Working to improve the characteristics of the internal combustion engine performance and emissions has grown in importance in recent years because to fuel depletion and environmental pollution [1-3]. Even a new technology for enhancing combustion properties has been applied to the engine fuel system [4-6]. Hydrogen burns and diffuses more quickly than gasoline, reducing the time it takes for fuel to burn and increasing engine thermal efficiency [7]. In addition, because hydrogen is so widely flammable, hydrogen engines may operate in lean conditions, which reduces NO_x emissions because the combustion temperature is lower [8-12]. On the contrary, pure hydrogen engines at stoichiometric conditions always produce less engine power and more NOx the high temperature of the flame and low volume energy density of hydrogen, NOx emissions occur [13-15]. Furthermore, the limited availability of hydrogen infrastructure and the high costs associated with hydrogen generation and storage limit the widespread use of hydrogen engines [1, 16].

In contrast, hydrogen-blended engines use a negligibly tiny amount of hydrogen and have the potential to perform better in terms of emissions and combustion [17, 18]. Experimental research on the effect of hydrogen addition on the performance of a CNG engine was investigated [19, 20]. The test findings showed that, because of the shorter duration of combustion, raising the hydrogen blending quantity reduced engine cyclic variation[21]. In the meantime, CO and HC emissions dropped with the addition of hydrogen since it improved the air-fuel combinations' ability to burn [22, 23]. The combustion and emissions characteristics of a hydrogen-enriched natural gas engine were also researched by Ma et al.[24]. He discovered that as the hydrogen addition fraction increased, the engine's low burn limit was also expanded. Additionally, the engine's thermal efficiency was increased following the addition of hydrogen for a specific operating state. Ji et al.[25] Carried out a series of tests to find out how adding hydrogen affected the performance of a petrol engine at idle and under typical driving situations. The test results demonstrated that the addition of hydrogen could increase engine thermal efficiency, reduce toxic emissions from gasoline engines, and ease cyclic variation, especially under lean and light load conditions.

Even though hydrogen-blended engines used less hydrogen than pure hydrogen engines, issues with onboard storage and hydrogen recharging persisted. The onboard Not only does a hydrogen storage system add weight to automobiles. Also poses safety risks, according to earlier studies. In recent years, a workable answer to the hydrogen supplement in automobiles has been the hydrogen generator that generates hydrogen by water electrolysis [7, 26-28]. Additionally, in addition to The electrolysis gas, hydrogen, also includes oxygen a combustion stimulant that helps fuel-air mixtures burn quickly and completely [29, 30]. As a result, it appears that the hydrogen-oxygen combinations, also known as hydroxygen, can boost engine performance even more. The normal hydroxygen is a mixture with an oxygen-to-hydrogen mole proportion of 1:2 because the full combustion of 2 mol hydrogen uses 1 mol oxygen[29].

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According to Uygur et al [31, 32], the improvement in The flame speed of methane-air mixtures caused by the addition of 10% of the standard hydroxide was equivalent to the addition of 20% pure hydrogen. The increased engine fuel economy is also a result of the addition of hydroxygen. The effectiveness of a compression ignition engine coupled with the typical hydroxygen was studied [33]. A water electrolytic hydroxygen generator powered by a 24 V external power supply produced oxygen and hydrogen in the experiment. The test findings demonstrated that when the hydroxygen-blending fraction grew, engine thermal efficiency increased and CO and HC emissions dropped.

Andrea et al [34] investigated the impact of the addition of hydroxygen on the combustion and emission performance of gasoline engines employing premixed hydrogen-oxygen-air mixtures with a mole ratio of oxygen-to-hydrogen of 1:2. He determined that the addition of hydroxygen did not affect the engine's performance under the stoichiometric state. Furthermore, owing to the greater NOx emissions increased with the addition of hydroxygen, regardless of combustion temperature or oxygen content[35]. Even though some studies have reported the effect of hydroxygen addition on engine combustion and emissions characteristics, only a few papers have been published that have quantitatively examined the effect of hydroxygen addition on the performance of a gasoline engine under lean conditions. Furthermore, due to the low ignition energy of hydrogen [7], the premixed hydroxygen mixes that are typically utilized in prior research increase the possibility of backfiring in the intake manifolds.

Therefore, there is a critical need to create and evaluate innovative processes for adding hydroxygen to cylinders. To investigate the impact of hydroxygen addition on improving the combustion and emissions performance of a gasoline engine, a customized spark ignition engine with 4 hydrogen injectors mounted beneath the original petrol injectors and an oxygen injector placed at the intake plenum was used in this experiment[29, 36-38]. To investigate the impact of hydroxygen addition on improving the combustion and emissions performance of a gasoline engine, a customized spark ignition engine with 4 hydrogen injectors mounted beneath the original petrol injectors and an oxygen injector placed at the intake plenum was used in this experiment [8].

To manage the opening and closing of the injectors for fuel, oxygen, and hydrogen, a hybrid electronic control unit (HECU) was employed. The engine was tested at a typical city driving speed of 1400 rpm, with manifold absolute pressure (MAP) of 61.51 kPa. In addition, three standard hydroxygen volume fractions of 0%, 2%, and 4% have been introduced in the intake manifold. To compare the effects of conventional hydroxygen and hydrogen additions on improving gasoline engine performance [1].

II- ENGINE SETUP AND EXPERIMENT PROCEDURE

The design and construction of the experimental test rig are introduced as shown in figure 1[39-41]. An experimental study will be done in many cases. Neat Gasoline operation and then after adding a different percentage of HHO of 5L / min, 10 L/min, and 15 L/min will be applied at different engine loads. The last stage of the experimental work is repeating the same test conditions after adding three different boosters of Octane. These were known commercially by Abro, Liqui Moly, and Thermol. P. By studying the effect of adding HHO with three different additives on the performance of the engine such as brake power, brake thermal efficiency, EGT, and BSFC. Also, exhaust emission such as NO_x, CO, CO2, and UHC parameters was measured at different engine loads at fixed engine speeds.

The different materials used in manufacturing the setup are commercially available. The present experimental setup has been designed and assembled in the internal combustion engine and combustion devices laboratory, Faculty of Engineering, Tanta University, Egypt.

Fig. 1. Experimental test rig is a 3D diagram.

A. Engine and test bed description

Experimental engine conducted on Honda commercial OHV engine Air-cooled, four-stroke, OHV Single Cylinder. With maximum output AC 5.5 KVA. Table 1 describes the experimental engine's characteristics. Before adding the new

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gasoline, the motor's and gas tank's fuel lines were cleaned. Following the cleanup cycle, the motor was driven with fresh fuel for a short period to clear away any residue [42, 43]. The leftover ex-fuel, whenever the motor became steady at rapid with low burden, the information was begun to record until the motor become almost unsteady under the high burden [44, 45].

Table 2 lists the fuel characteristics of gasoline and compressed natural gas. figure 2 illustrates the experimental test diagram with all components. To stop backflow from occurring behind the CNG bottles, a check valve is utilized. Following the check valve, CNG is sent through an ex-proof pipeline to the regulator. The constituents (HHO, CNG, and air) inside the intake manifold are mixed very effectively when a mixing chamber is used before it. These results in higher fuel efficiency, increased engine stability, and decreased emissions. Figure 3 shows that the flow meters measure and regulate the amount of hydrogen and compressed natural gas (CNG) gas sent to the engine. In a mixing chamber, a certain quantity of CNG and hydroxyl gases are combined as shown in figure 4. The percentages of the mixture were calculated by averaging the results of the three tests that each experiment underwent three times. The total average of HHO gas was adjusted for this experiment to be 5, 10, and 15 LPM (Liter per Minute), while the total average of CNG gas was set to be 10 cm.

The second stage of this experimental setup will be done after adding three different Booster Octane (Liqui Moly, Abro, Thermal p) at 5 L / m of HOH and study the effect of adding Booster octane in (CNG, HHO, and air) Mixture in Engine Performance and different emissions.

Table 1. Test Engine Specification

Model Number	GX390
Maximum AC Output	5.5KVA
Rated AC Output	5.0KVA
DC Output (Generator/Charger)	8.3A
Method of Starting	Hand Cranking
Type of generator	D-AVR
Rated Voltage	240 (V)
Rated Frequency	50 (Hz)

Table 2. Gasoline fuel properties

Description	Gasoline (H/C=1.87)
Molecular weight(g/moll)	~110
Mass density (kg/N_Am^3)	720-780 (liquid)
The mass density of liquid H_2 at 20 K(kg/N_Am^3)	-
Boiling point(K)	310-478
Higher heating value(MJ/kg)(assumes water is produced)	47.3
Lower heating value(MJ/kg)(assumes steam is produced)	44.0
Flammability volume) limits(%	1.0-7.6
Deniability limits (%volume)	1.1-3.3
Diffusion velocity in air (m/s)	0.17
Ignition energy (ml)	0.24
flammability limit	n/a

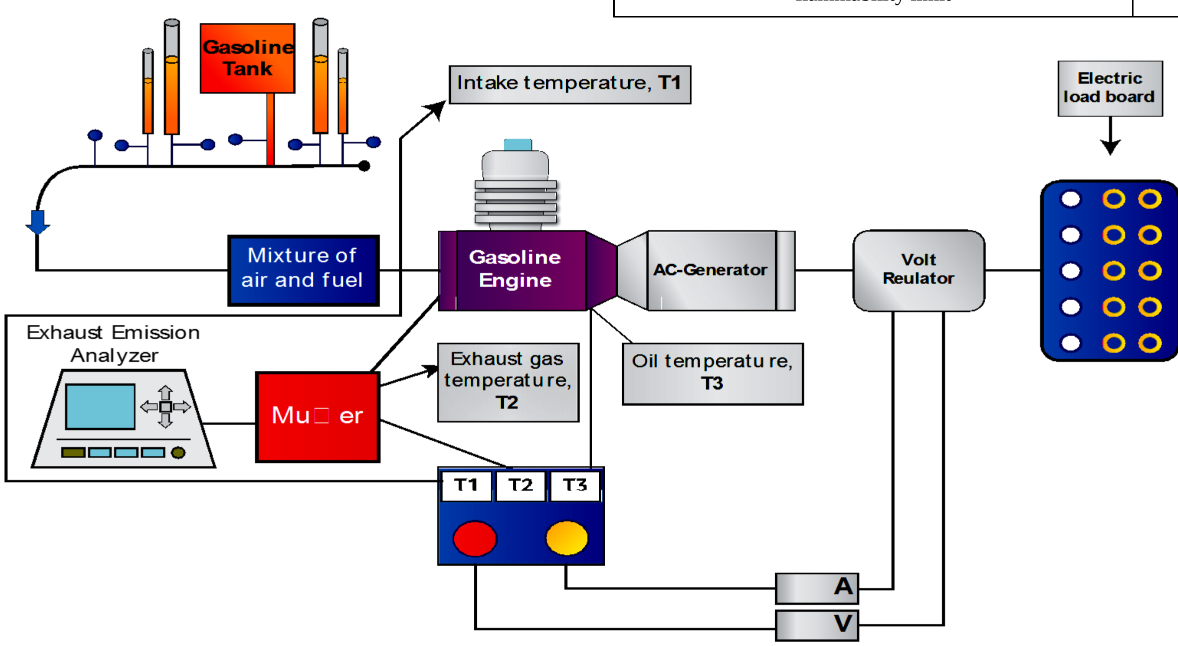

Fig. 2. Experimental diagrams with clarification of all components.

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Fig. 3. Pressure gauge regulator with the Fuel tank

Fig. 4. Test engine side view to present the air flow rate measurement with electric voltage load panel

III- RESULTS OF THE EFFECT OF DIFFERENT HHO GAS ADDITIVES ON SI ENGINE BEHAVIOR

Under the subsections in terms of engine performance and emissions, respectively, experimental data are reported. The primary goal of this experimental investigation was to determine what would happen if gasoline fuel was mixed with (HHO) gas and (HOH +Booster Octane). The experimental study was done in engines at different loads by using a variac transformer. The experimental test is repeated in many stages the first stage is Gasoline and the remaining case after enriching Gasoline with 5 Liter/min, 10 Liter/min 15 Liter/min of HHO respectively finally experimental test will be done after adding three different Octane Booster at 5 l / m HOH (ABRO, liquid Moly, THERMOL) to the mixed fuel (HOH, Gasoline). All experimental study was done without modification on the test engine. Moreover, the main target of this experimental test is to study the effect of adding HOH and Additives on engine performance and exhaust emissions, especially in comparison with neat gasoline fuel results.

A. Engine performance

Engine performance analysis has been presented in the next figures which show the brake thermal efficiency, brake-specific fuel consumption, and engine exhaust gas temperature at different engine loads at a fixed speed of 3000rpm.

a. Brake thermal efficiency

Figure 5 shows that gasoline fuel enriched with 5 Liter/min HHO fuel performed 11.52% better than plain gasoline, and gasoline fuel enriched with 10 Liter/min HHO fuel performed 19.3% better than pure gasoline. Similar results are obtained with gasoline enriched by 15 L/min HHO, with an average of 25.46% improvement in engine torque output. The improvement in engine torque output is likely due to the higher heating value of hydrogen, higher flame speeds, and better combustion of both molecular hydrogen and molecular oxygen. In comparison to the low calorific value of straight gasoline [46].

b. Brake Specific fuel consumption

Brake with 5 L/min of HHO fuel, the specific fuel consumption of HHO B10 enrichment was on average 17.37% greater than clean gasoline fuel. In addition to the advantages of HHO fuel, improvements of 23.11 and 26.32 in the case of 10 L/min and 15 L/min, respectively, may be attributed to the new fuel mixture (HOH + Gasoline), which contains some oxygen and encourages more thorough combustion of the biodiesel than neat Gasoline fuel. Better thermodynamic efficiency can be achieved in the combustion chamber by using pure hydrogen or HHO. When compared to ordinary liquid fuels, hydrogen has a higher

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heating value and flame speed[24]. As a result, as demonstrated in Figure 5, the two hydrogen-enriched fuels employed in this study had higher brake torque outputs than straight gasoline.

c. Exhaust Gas Temperature (EGT)

Figure 7 shows the fluctuations in exhaust gas temperature with load for Gasoline with hydrogen enrichment. It was found that adding HOH with different quantity exhaust gas temperature also reduced. At 5 l/m HOH enrichment fuel, the exhaust gas temperature for hydrogen enrichment was 590℃, compared to 608℃ for Neat Gasoline fuel. In addition, 554, 527 in case of 10 L/M, and 15 L/M of HOH mixture. The HHO-induced decrease in exhaust temperature, As the percentage of hydrogen increases at low speeds, the temperature of the exhaust gas tends to drop, indicating better combustion and cleaner gases [47].

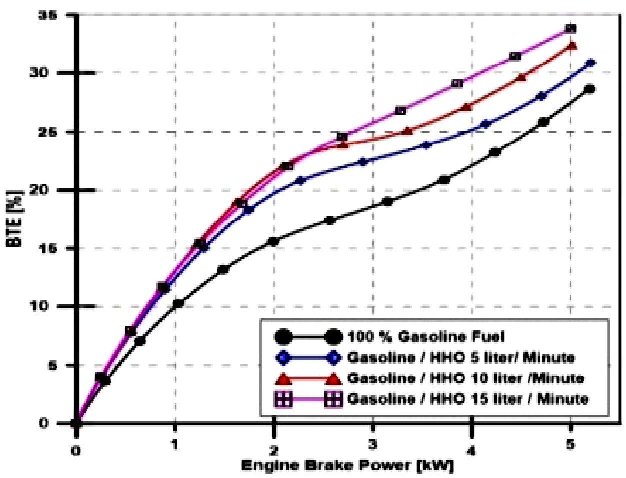

Fig. 5. Overall thermal efficiency improvements with HHO over pure petrol fuel at different loads.

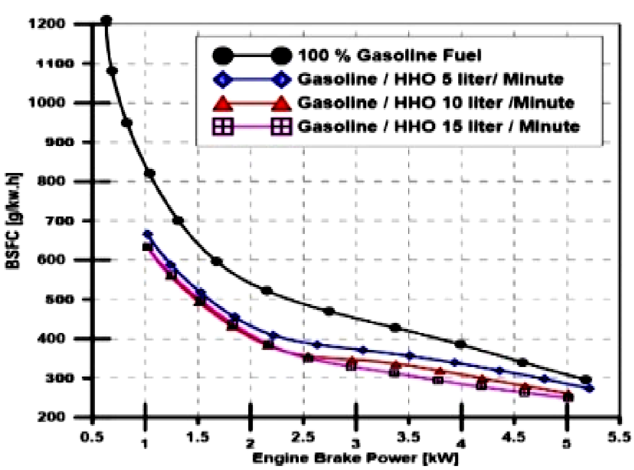

Fig. 6. Specific fuel consumption improvement with HHO over pure petrol fuel at different loads

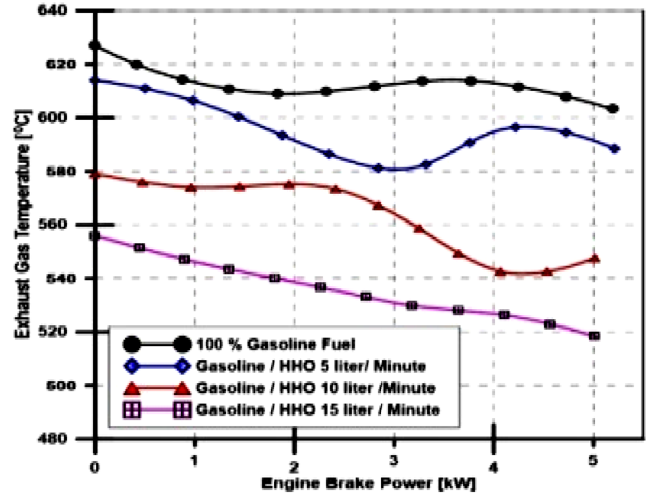

Fig.7. Exhaust gas temperature improvements with HHO over pure petrol fuel at different Loads.

B. Engine emissions

Figures 8, 9, and 10 shows the effect of supplying HHO gas to a gasoline engine on carbon monoxide CO, CO2 unburned hydrocarbon HC, and nitrogen oxide NOx emissions, respectively.

a. Carbon Dioxide

As shown in figure 8, the fuel-to-air ratio of the engine has a considerable impact on CO_2; therefore utilizing a blend of HHO gas lowers the amount of CO in the exhaust since it uses less gasoline. 29.8% and 52.6, respectively, reduce in CO2 emissions at 5L /M and 10 L/M of HOH were recorded. More improvement after adding 15 l/m as a deduction will be 55.7. One of the main causes of CO_2 reduction is the absence of carbon in hydroxyl gas. A broad spectrum of flammability and high Engine operation at Concentration drops down quickly under heavy loads[48].

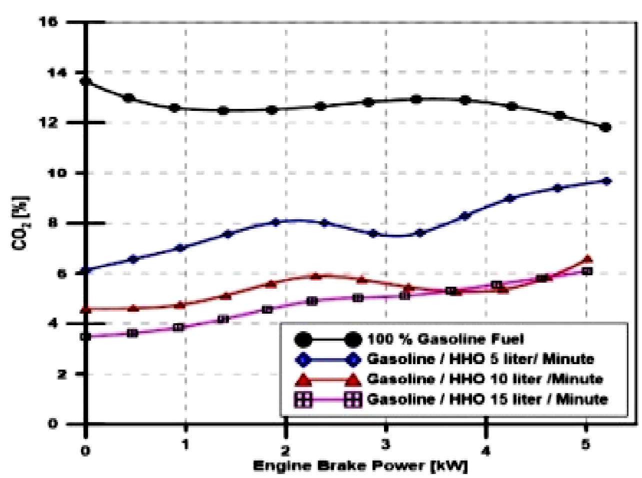

Fig. 8. Impact of varying the engine dynamometer load on CO2 emission

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b. CO emission

As shown in figure 9 when compared to the Neat Gasoline fuel operation, CO emission levels increased by 32%. The decreased O2 content in the cylinder may assist to explain why CO does not entirely oxidize to CO2 during HHO induction. The mixture in the injection spray's outer zones is insufficient to sustain flame propagation. As a result, as engine speed increases, the local temperature lowers and the CO oxidation processes freeze[49].

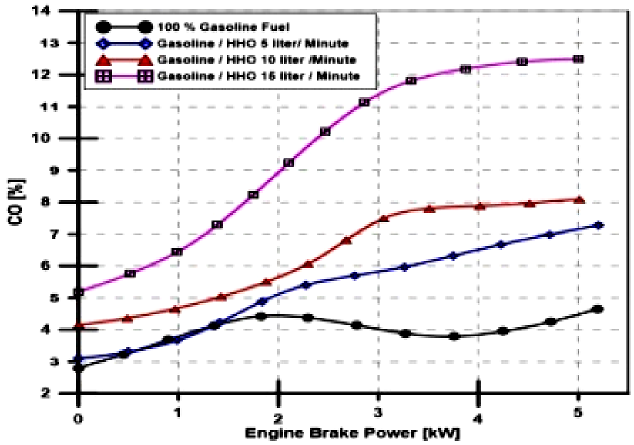

Fig. 9. Effect of varying the engine dynamometer load on NOx emission

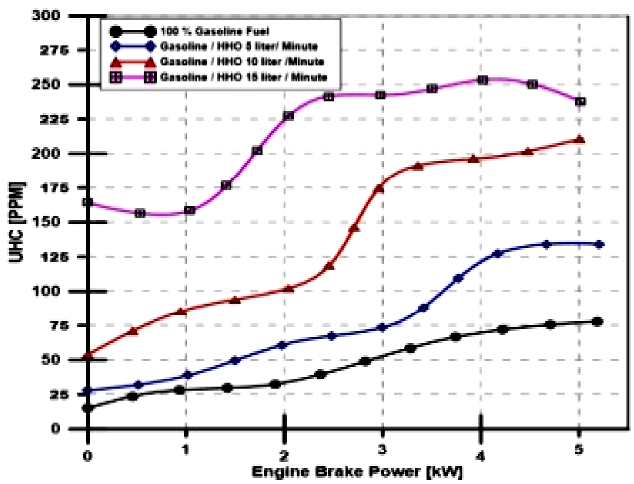

Fig. 10. Impact of varying the engine different load on HC emission

c. Hydro Carbon HC

Figure 10 demonstrates that as the load grows, so does the number of unburned hydrocarbons. This is because more gasoline is necessary to provide the desired engine torque, resulting in higher HC emissions[50]. When HHO is added, however, HC emissions increase by 65%, 110%, and 166% for (5, 10, and 15) L/M, respectively. Because of the large amount of hydroxy present, proper air cannot be introduced into the cylinders. This stops gasoline from completely burning.

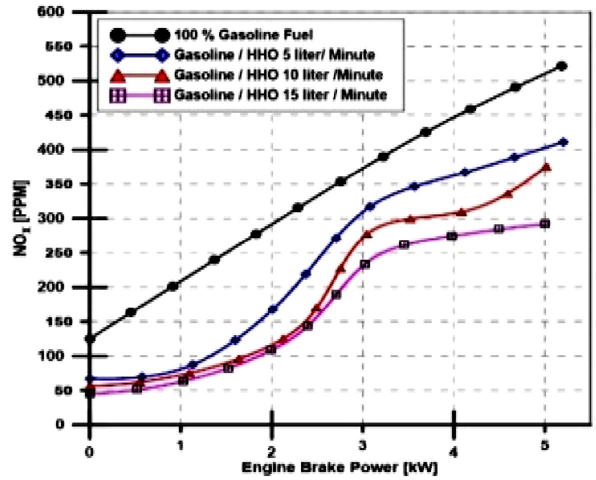

Fig. 11. Impact of varying the engine dynamometer load on NOx emission

d. NOx emissions

The high flame temperature and extra air typically increase high NO_x emissions. When HHO is added to the intake manifold, the amount of gasoline is reduced, resulting in a lean mixture and, ultimately, a lower flame temperature. Lower NO_x emission results as seen in Figure 11[51].

IV- EFFECT OF HHO GAS WITH DIFFERENT KINDS OF OCTANE BOOSTER ADDITIVES ON SI ENGINE BEHAVIOR

When mixing fuel additives with gasoline, it is crucial to assess engine performance exhaust emissions like a key sign that the fuel blend is suitable for a SI engine's efficient operation. The second stage for our experimental study is to repeat all experimental setups after adding three different fuel additives (ABRO, liquid Moly, thermol. p) to (HHO+ Gasoline) at 5 L / minute). All experimental examination was carried out without any changes to the test engine. The primary goal of this experimental test is to investigate the effect of adding HOH and Additives mix on engine performance and exhaust emissions, particularly when compared to neat gasoline fuel results.

A. Engine performance

The shown figures demonstrated in this subsection contain brake thermal efficiency, brake power, and brake-specific fuel consumption.

a. Brake thermal efficiency

Variations versus engine loads are shown in figure 12. The illustrated data were the Gasoline fuel enriched with 200 ppm of three different types of Octane booster with 5 L/ minute of HHO gas. The obtained results of the BTE were 20.7% better than neat Gasoline. However, in the case of using ABRO and 15.4 % in the case of LIQUI MOLY and

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improvement reached the peak in the case of adding THERMOL P by the total percentage of improvement by 59.6% This is because the fuel has a higher octane number and heating value when compared to other fuel samples[52].

b. Brake Specific fuel consumption

The brake Specific fuel consumption SFC is a measurement of how much fuel is used to generate 1 kilowatt of electricity in an hour. Figure 1 of HHO þ B10 enrichment with three different Octane boosters compared to neat gasoline was decreased by 24.3 %, 21.2,24.2 in thecase of adding (ABRO, LIQUI MOL, THERMAL P) respectively this decrement happened due to SFC reduced for an increase in brake power [53].

B. Engine emissions

Figures 13, 14, and 15 demonstrate the effects of providing the gasoline engine with (HHO+ Booster octane additives) gas on carbon monoxide CO, CO2, nitrogen oxides NOx, and unburned hydrocarbon HC.

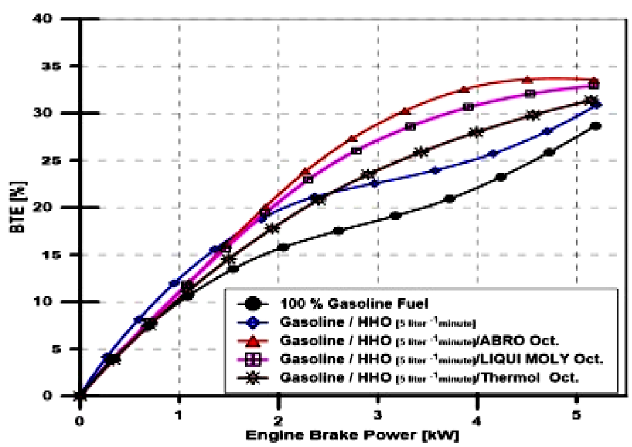

Fig. 12. Overall thermal efficiency improvements after adding HOH with Octane booster additives at different loads

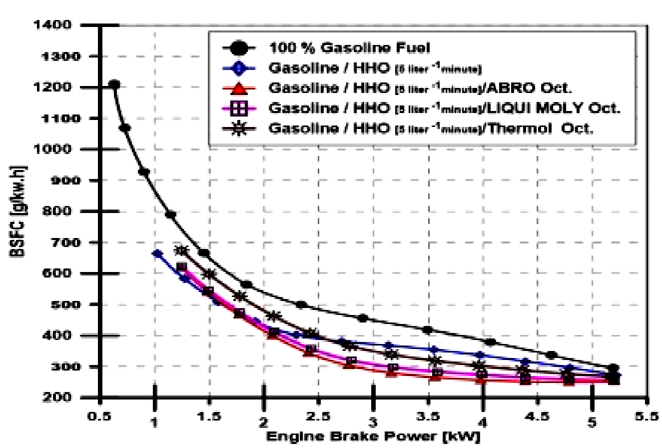

Fig. 13. Specific fuel consumption improvement after adding HOH with Octane booster additives at different loads

In summary, the experimental test demonstrates that while utilizing (gasoline + HOH + booster Octane additives), the concentrations of CO and HC drop but the concentration of NOX increases, as shown in Figure.

a- Carbon Dioxide

As shown in figure 14, CO_2 is decreased in the case of using Abro additives by the percentage of 8.9 %. in the case of using LIQUI MOLY and Thermal P it is noticed that the CO_2 emissions were reduced by respectively 23.6 %, and 21.1% this is due to the complete combustion which leads to less carbon dioxide emissions [54].

a. CO emission

As shown in figure 15 when compared to Neat Gasoline fuel operation, CO emission has a huge reduction that can reach 58 % in the case of Liqui moly reduction due to less oxygen in themixture[53].

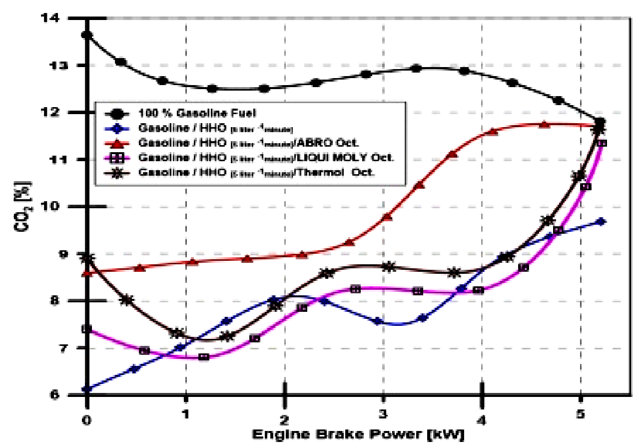

Fig. 14. Impact of varying the engine dynamometer load on CO2 emission

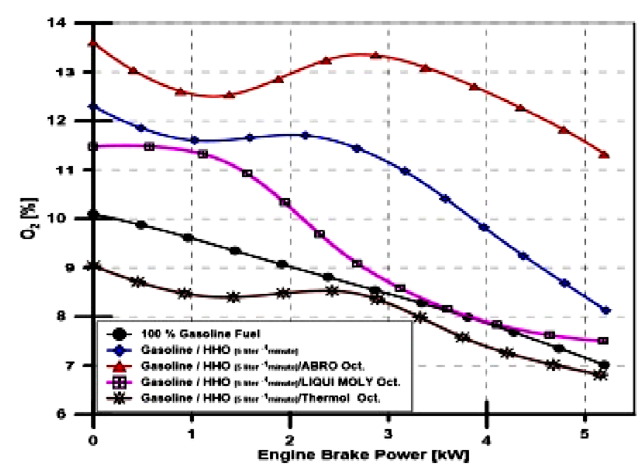

Fig. 15. Impact of varying the engine's different loads on CO emission

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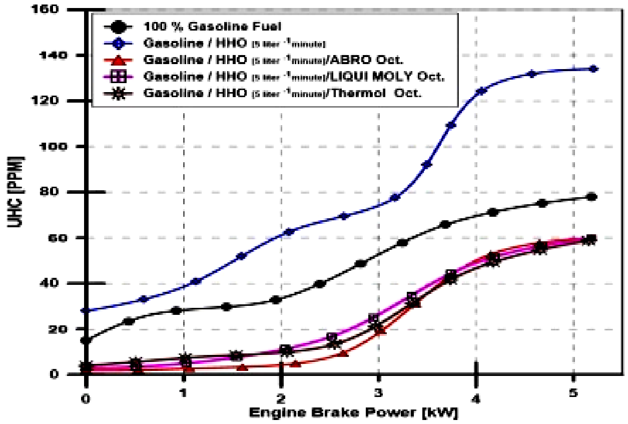

Fig. 16. Impact of varying the engine's different load on HC emission

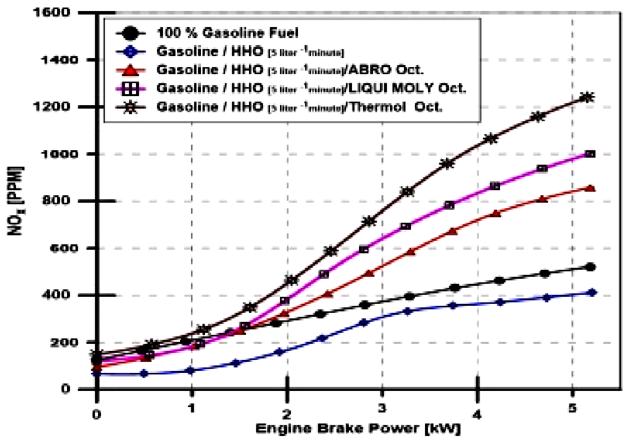

Fig. 17. Impact of varying the engine dynamometer load on NOx emission

b. Hydro Carbon HC

In figure 16, it is obvious that as the load grows, the amount of unburned hydrocarbon decreases. Hydrocarbon emissions are caused by incomplete combustion or by releasing unburned fuel into the environment. Case of adding booster Octane additives with different types it is enhancing the combustion process which leads to less HC emission[55]. The total reduction in HC emission can be 41 %, 42%, and 53 in the case of the three different Octane booster additives as shown in figure 16.

c. NOx emissions

Figure 17 illustrates The mean reason for NO_X emission in spark ignition engines is due to the reaction of Nitrogen with Oxygen at high temperatures. As shown in figure 17 there is increasing in NO_x emission at 5 L/m of HOH and after adding 200 imps of Octane booster by 61 % in the case of Abro and 47 %.

V- CONCLUSION

The performance and emissions of an experimental engine run on a Honda commercial OHV engine with an air-cooled, 4-stroke, OHV single cylinder have been examined in laboratory tests. To produce the HHO gas necessary for engine functioning, a new HHO fuel cell architecture has been implemented. In the intake manifold, the produced gas and fresh air are combined. The gas analyzer has been used to sample and measure the exhaust gas concentrations. One can infer the following conclusions.

- The HHO cell is simple to integrate with current engine systems.
- When HHO gas is added to the air/fuel combination, the engine's thermal efficiency rises by up to 10%, resulting in a 34% decrease in fuel consumption.
- When HHO is added into the system by various percentages, the concentration of NOx has been lowered to nearly 15%, 18%, and 14% accordingly.
- HOH hurts increasing CO and HC emissions. Hydrogen and oxygen work together to achieve complete combustion. Carbon dioxide, carbon monoxide, and unburned hydrocarbons are all reduced by a net amount in exhaust gas emissions. When NOx emissions are taken into account, several outcomes are identified. There were some occasions where NOx emissions increased and others where NOx emissions decreased. KOH was determined to be the optimum electrolyte for the formation of HHO gas at an average concentration of 6 grams/liter.

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Conflicts of Interest: The authors declare that there is no conflict of interest.

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