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Experimental Investigation for Improving Performance and Emissions of Gasoline Engine by Adding HHO Gas

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ABSTRACT

Decreasing the emission pollution linked with petrol combustion is gaining a great interest world-wide. Lately, HHO has been inserted to internal combustion engines as a novel clean source of energy. The effect of different HHO addition into intake manifold on the gasoline engine performance and emissions had evaluated experimentally and compared in this research. The purpose of this work is improving the performance and emissions of gasoline engine. The experimenters were performed on an air-cooled single cylinder gasoline engine with and without HHO. With the same engine loads (25%, 50%, 60%, 75% and 80%) and constant engine speed (2000 rpm) at various HHO addition into intake manifold (VR=0.037, 0.045, and 0.052) and without HHO, the engine performance parameters (BSFC and BTE) and exhaust emissions (CO, CO_2, HC, and NO_X) were measured. The results pointed out that: BSFC decreased, BTE incremented, CO minimized, CO_2 slight increased, HC reduced and NO_X diminished with increasing HHO addition at overall operation conditions when compared to gasoline fuel (without HHO).

Keywords: HHO Gas, HHO Addition, Gasoline Engine Performance and Emissions.

Abbreviations

BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
CO	Carbon Monoxide
CO_2	Carbon Dioxide
HC	Unburned Hydrocarbon
HHO	Hydroxy Gas or oxyhydrogen (Brown's Gas)
NO_X	Nitrogen Oxides
ppm	Parts per Million
rpm	Revolutions per Minute
VR	Volume Ratio $=V_{HHO} / V_{air}$ (inlet of the intake manifold - measured by orifice flow meter)

1.INTRODUCTION

Nowadays, the energy crisis, climate and air pollution are major global problems, there is a global concern toward reduction consumption of fuel and emissions for internal combustion engines is encourages researchers to find alternative solutions that would not request a substantial amendment in engines design. One of these solutions is to use hydrogen to improve engine performance and reduce emissions. Hydrogen is a universal, light and highly reactive fuel produced through a chemical process known as electrolysis. This method uses an electric current to separate hydrogen and oxygen in water. Hydrogen is the most abundant element in the universe, but on Earth it does not appear pure in nature and requires energy to separate. The most common method is to extract hydrogen from water, which consists of two hydrogen atoms and one oxygen atom to produce a gaseous fuel, HHO in which case the hydrogen production process is free of carbon and any air pollutants, thus becoming energy without emitting carbon dioxide into the atmosphere, which helps in reducing global warming.

Elkassaby et al [1] studied the influence of hydroxy gas addition on gasoline engine performance and emissions used two catalyst materials, potassium hydroxide and sodium hydroxide. Sa'ed and Ammar [2] carried out the influence of hydroxy gas on combustion emissions in gasoline engines. It was found that after adding HHO gas to the fuel, nitrogen oxides and carbon dioxide decreased by about 50% and 20%, respectively. Effect of introduced hydroxy gas into the intake manifold of gasoline engine has been studied [3, 4]. T. Nabil [5] investigated an efficient use of HHO gas in deferent types of gasoline engines, and found a fuel consumption reduced by 16.3 % for 1300CC engine and 14.8 % for 150CC engine. HHO gas decline the exhaust emissions by 24.5 % and 33 % decreased in CO and 21 % and 27.4 % reduced in HC for 1300CC and 150CC engines successively. The performance and emissions of diesel engines were studied with and without the use of HHO gas used dry and wet cells [6, 7]. K. Aydın et al [8, 9], carried out the effect of adding HHO gas with diesel fuel or bio-diesohol fuel on performance and emissions in CI engines. Performance and emission characteristics of HHO gas as a fuel for diesel engine had been investigated by [10, 11]. M. Jorge [12], investigated the influence of addition of H2 on diesel engine performance. S. Liu et al [14] studied the combustion stability of shale gas engines using HHO. F. Salek et al [15] investigated experimentally, energy assessment and betterment of hydroxy generator coupled with a gasoline engine. Y. Karagöz et al [16] investigated the influence of H2 and O2 addendum as a mixture on performance and emissions of gasoline engine. C. Ji et al [17, 18] carried out the influence of H2 addition on combustion and emissions of a gasoline engine at lean conditions and also different H2 volume fractions in the hydroxygen.

From the previous review, the effect of adding HHO gas in different percentages has not been widely studied on engine performance and emissions. So that, the objective of this work is to carry out experimental investigation of the performance and emissions of a gasoline engine with addition HHO into intake manifold in different percentages (VR=0.037, 0.045 and 0.052) compared with gasoline fuel at different engine loads (25%, 50%, 60%, 75% and 80%) and constant engine speed (2000 rpm).

2. EXPERIMENTAL SET-UP AND TEST PROCEDURE

The gasoline engine used in the current experimental study; its specifications are shown in **Table No. 1**. Schematic diagram and the pictorial view of the experimental set-up and its components are shown in **Figure 1**.

Table 1. Specifications of the used Gasoline Engine

Type of cooling	Air cooling
Power	5.3 kW
Compression ratio	9
Bore & Stroke	62 & 49.7 mm
Type	4 stroke
No. of cylinder	1

The gasoline engine is directly connected to an electrical dynamometer with a maximum power of 15 hp. The engine output is controlled by adjusting the excitation field voltage (applied on the electrical dynamometer) and for this it is said that the engine operates at a certain load (percentage of the maximum torque). The values of the excitation field voltage vary with the change of load during test. The accuracy of the optical tachometer device used to measure engine speed is ±0.01%. Carbon monoxide (CO), carbon dioxide (CO_2), unburned hydrocarbons (HC) and nitrogen oxides (NO_X) were obtained by extracting a continuous sample of exhaust gases through the exhaust pipe. The exhaust gases were then fed into the gas analyzers (IR Infrared industries – FGA4000XDS Model) and measured by the sensors with accuracies ±0.01%, ±5 ppm, ±5 ppm and ±0.2% for CO, NO_X, HC and CO_2 respectively.

The plan is designed for the experimental study on performance and emissions of gasoline engine using hydroxy (HHO) gas with gasoline fuel and comparing with gasoline fuel. HHO gas introducing into the intake manifold of the engine: HHO gas is injected directly in intake manifold of the gasoline engine without engine modification. HHO gas was used as a supplementary fuel in engine. Various parameters such brake specific fuel consumption (BSFC), brake thermal efficiency (BTE), carbon monoxide, nitrogen oxides, unburned hydrocarbon and carbon dioxide as function of engine loads (25%, 50%, 60%, 75% and 80%) and constant engine speed (N=2000 rpm), without HHO and with HHO in different percentages (VR=0.037, 0.045 and 0.052) were recorded during experimental tests. **Table No. 2** shows main properties of the gasoline fuel and hydrogen gas.

Table 2. Properties of Fuel [19, 20, 21]

	Gasoline	**Hydrogen**
Density (kg/m^3)	723.5 -791.3	0.089
heating value (MJ/kg)	43.4 - 46.7	120-141.7
Flammability limits in air (vol%)	1.4 -7.6	4 -76

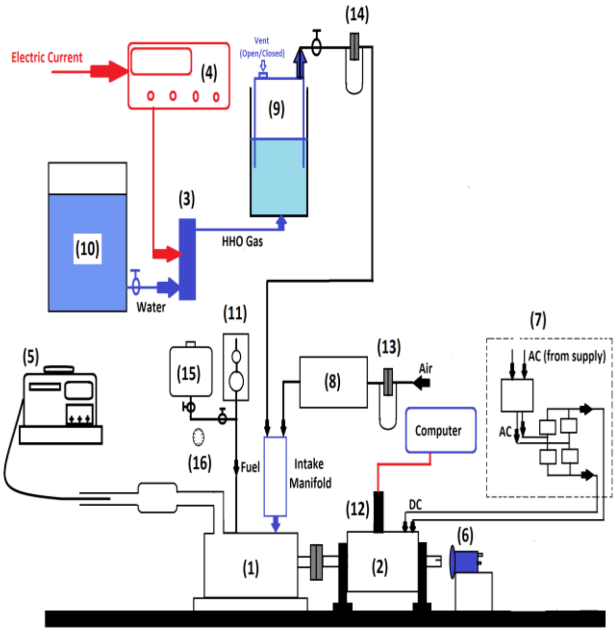

Figure 1-a. Schematic diagram of the experimental setup

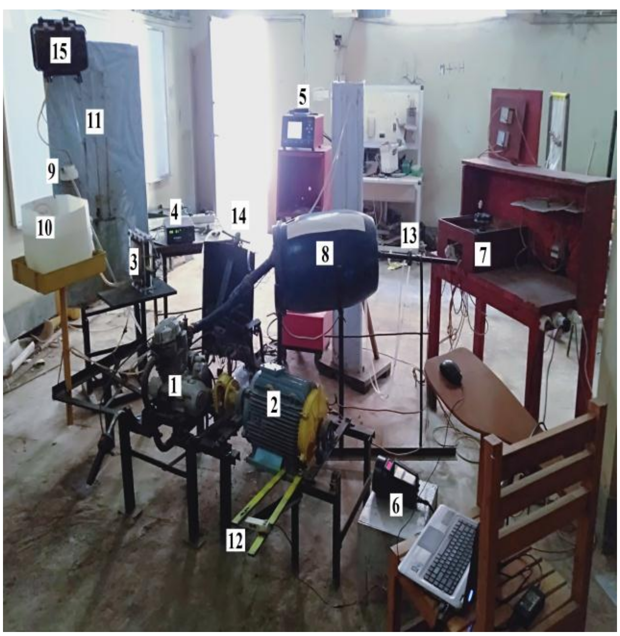

Figure 1-b. The pictorial view of the experimental set-up

(1) Petrol Engine; (2) Electrical Dynamometer; (3) HHO Dry Cell; (4) Power Supply; (5) Exhaust Gas Analyzer; (6) The Optical Tachometer; (7) Voltage Regulator; (8) Air Box; (9) HHO Tank; (10) Water Tank; (11) Fuel Consumption Rate Device; (12) Load Cell; (13) Orifice Air Flow Meter; (14) Orifice HHO Flow Meter; (15) Petrol Tank and (16) Stop Watch.

Figure 1. Schematic diagram and the pictorial view of the experimental Set-up

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Performance of Gasoline Engine

Brake specific fuel consumption is the ratio of a mass flow rate of the fuel supplied to the gasoline engine to the brake power obtained at a crankshaft and it indicates how efficiently the fuel is used to produce brake power. Where, brake power is the amount of power available at the crankshaft of the engine. It is also given by the product of the torque available at the crankshaft and the angular speed of the crankshaft. The BSFC says how effectively the amount of fuel get converted into brake power, where the rate of fuel consumption increases and the BSFC decreases with increasing of engine load. **Figure 2** illustrates the BSFC vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The BSFC reduced by about 4.6%, 9.1 %, 9.1%, 10% and 7.4% at 25%, 50%, 60%, 75% and 80% of engine load successively and VR=0.037. At VR=0.045, BSFC decreased by about 22.3 %, 26 %, 25.6%, 25% and 24.5 % at 25%, 50%, 60%, 75% and 80% of engine load respectively. While, BSFC minimized by about 27.4%, 31%, 28.6%, 30.8% and 32.3% at 25%, 50%, 60%, 75% and 80% of engine load successively and VR=0.052. The addition of HHO to the engine helps to improve the combustion process [1, 5] and thus reduce fuel consumption.

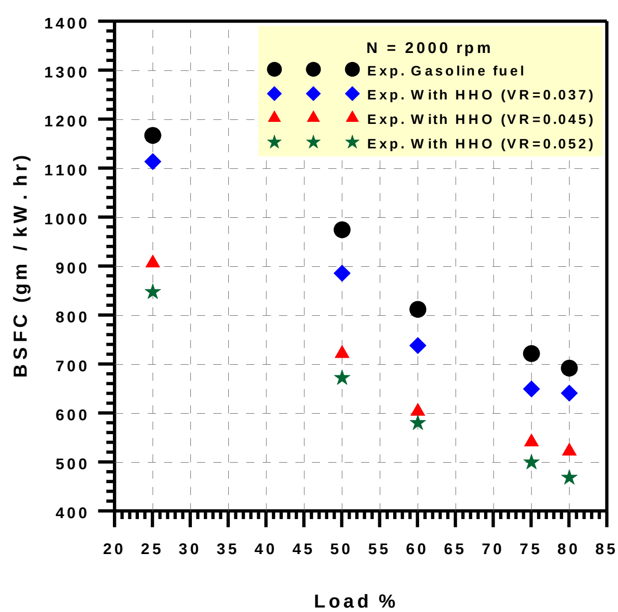

Figure 2. BSFC versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

The brake thermal efficiency is the ratio of the brake power at the gasoline engine crankshaft to the power generated by the fuel combustion. The brake thermal efficiency shows the amount of power taken by the gasoline engine crankshaft out of total power generated by the fuel combustion. **Figure 3** shows the BTE vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The BTE increases by about 12.3%, 17.9 %, 17.9%, 19.1% and 15.7% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.037. At VR=0.045, BTE rise by about 38%, 44.7%, 44.2%, 43% and 42% at 25%, 50%, 60%, 75% and 80% of engine load successively. While, BTE raise by about 47.6%, 55.4%, 50.1%, 54.8% and 58.4% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.052. As a result of addition of HHO, the combustion process has improved. Introducing hydroxy gas into the engine improved BSFC and BTE because of the better features of HHO gas compared with gasoline fuel, where hydroxy gas increased the octane rating of gasoline [3, 4].

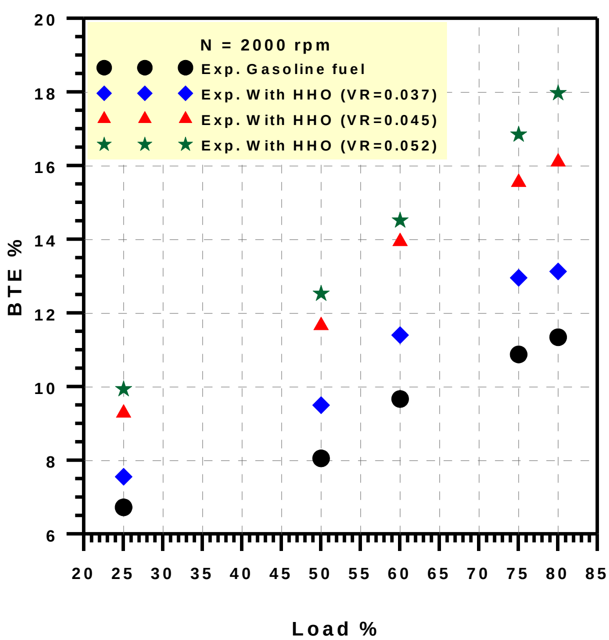

Figure 3. BTE versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

3.2 Gasoline Engine Gas Emissions

Carbon monoxide is a poisonous, colorless, tasteless, odorless, flammable gas that is slightly less dense than air. Carbon monoxide consists of one carbon atom and one oxygen atom connected by a triple bond. It is the simplest molecule of the oxocarbon family. In coordination complexes the carbon monoxide ligand is called carbonyl. It is a key ingredient in many combustion processes. **Figure 4** shows carbon monoxide concentration vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The carbon monoxide concentration minimized by about 19.7%, 18.4%, 21.3%, 14.5% and 11.2% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.037. At VR=0.045, CO concentration decreased by about 33.8 %, 31.6%, 31.9%, 32.5% and 31.6 % at 25%, 50%, 60%, 75% and 80% of engine load successively. While, CO concentration reduced by about 38%, 34.9%, 34.8%, 35% and 33.3% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.052. Because of utilization of hydroxy gas with interior oxygen content, it improves the combustion process of the gasoline engine [1, 5, 14].

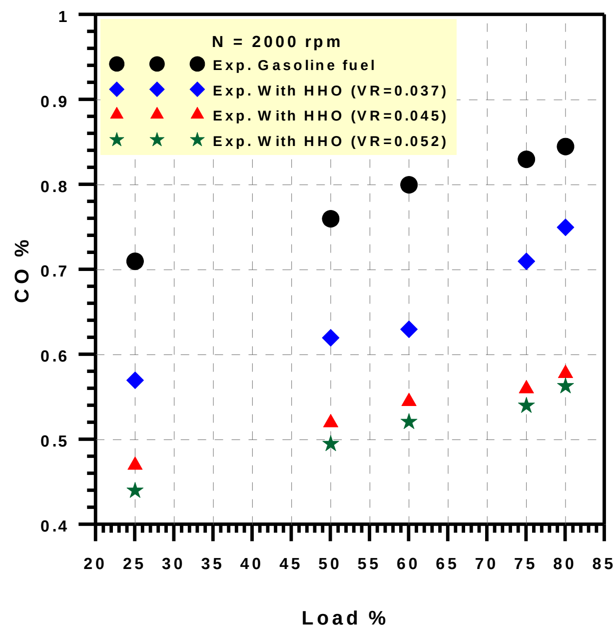

Figure 4. CO emissions versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

Unburned hydrocarbons are one of the main pollutants emitted from internal combustion engines and cause many environmental and health problems; It depends on the detailed chemical composition and toxic nitrogen oxides (NOx) and the consequence of incomplete combustion of the hydrocarbon fuel. **Figure 5** presents HC concentration vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The hydrocarbons concentration reduced by about 13.2%, 14%, 13.7%, 13.6% and 12.3% at 25%, 50%, 60%, 75% and 80% of engine load successively and VR=0.037. At VR=0.045, HC concentration decreased by about 32.6 %, 34.4%, 36.2%, 31.5% and 33.6% at 25%, 50%, 60%, 75% and 80% of engine load successively. While, HC concentration minimized by about 42.2%, 40.9%, 42%, 36.3% and 37.1% at 25%, 50%, 60%, 75% and 80% of engine load successively and VR=0.052. HC concentration appears because of the increase of the fuel oxidation [3, 5] and decrease with HHO addition.

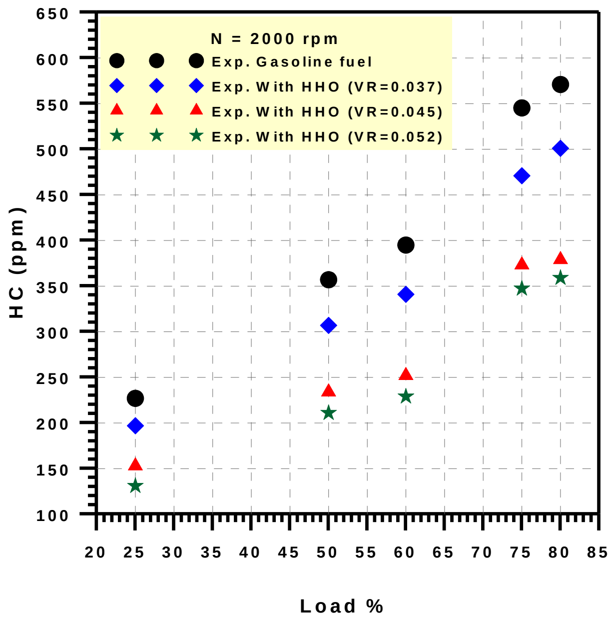

Figure 5. HC emissions versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

Nitrogen Oxides are a family of poisonous, highly reactive gases. These gases are usually produced from the reaction between nitrogen and oxygen during combustion of fuels at high temperatures. **Figure 6** shows the nitrogen oxides concentration vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The nitrogen oxide concentration decreased by about 15.1%, 18.3%, 28.7%, 28.7% and 20.8% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.037. At VR=0.045, NO_X emissions minimized by about 36 %, 39 %, 40.6%, 37% and 38.5% at 25%, 50%, 60%, 75% and 80% of engine load successively. While, NO_X concentration reduced by about 44%, 43.7%, 45.4%, 40% and 40.8% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.052. NO_X concentration reduced may be because of the drop in flame temperature as a result of introducing HHO into the intake manifold results in minimize the amount of gasoline fuel which leads to lean mixture [1, 4].

On the contrary, in **Figure 7** illustrates carbon dioxide concentration vs. engine load and constant engine speed with HHO addition in different percentages compared with gasoline fuel. The CO_2 concentration increased by about 0.53%, 0.065 %, 0.77%, 0.56% and 0.63% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.037. At VR=0.045, CO_2 emissions increased by about 1.18 %, 1.4 %, 1.29%, 1.38% and 0.9 % at 25%, 50%, 60%, 75% and 80% of load of engine successively. While, CO_2 emissions raise by about 1.4%, 1.5%, 2.5%, 1.7% and 1.8% at 25%, 50%, 60%, 75% and 80% of engine load respectively and VR=0.052. CO_2 concentration reduced because of shorter combustion time [2, 3].

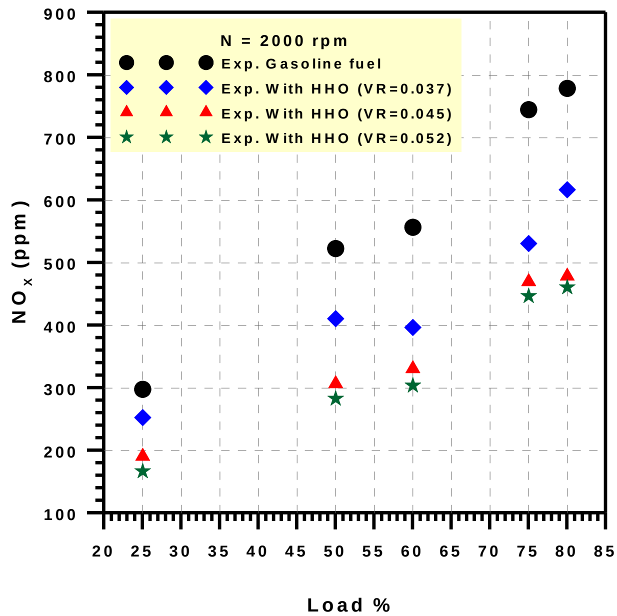

Figure 6. NO_X emissions versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

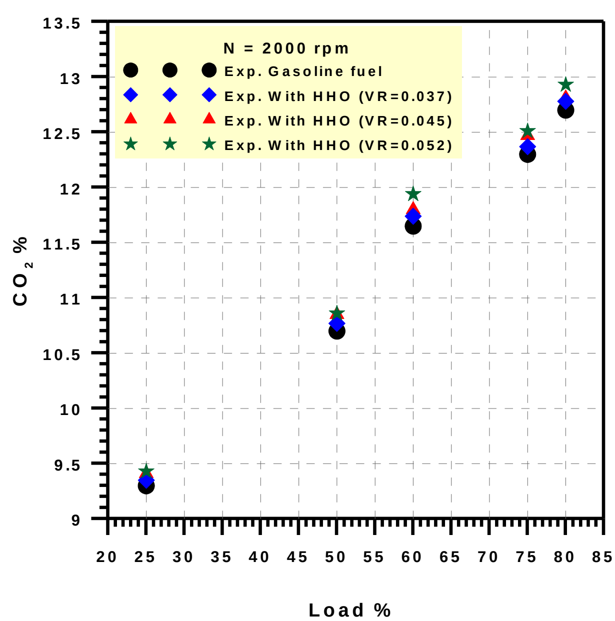

Figure7. CO_2 emissions versus engine load at HHO addition in different percentages compared with gasoline fuel at constant engine speed

4.CONCLUSIONS

An experimental investigation of the performance and the exhaust gas emissions of a gasoline engine with addition HHO in different percentages compared with gasoline fuel were conduced. The percentages of augmentation and diminution in the BSFC, BTE, CO, HC, NO_X and CO_2 at operation conditions with addition HHO in diverse percentages compared with gasoline fuel are clarified as follows:

- BSFC reduced with increase engine load at constant engine speed. In general, the BSFC decreased from 4.6% to 10%, 22.3 to 25.6 and 27.4 to 32.3 at VR=0.037, 0.045 and 0.052 respectively.
- BTE augmentation with increase engine load at constant engine speed. In general, the BTE rise from 12.3% to 19.1%, 38 to 44.7 and 47.6 to 58.4 at VR=0.037, 0.045 and 0.052 successively.
- CO concentration minimizes with increase engine load at constant engine speed. In general, the CO emissions diminution from 11.2% to 19.7%, 31.5 to 33.8 and 33.4 to 38 at VR=0.037, 0.045 and 0.052 respectively.
- CO_2 concentration rises with increase engine load at constant engine speed. In general, CO_2 emissions augmentation from 0.53% to 0.78%, 0.87 to 1.4 and 1.4 to 2.5 at VR=0.037, 0.045 and 0.052 successively.
- HC concentration decreases with increase engine load at constant engine speed. In general, the unburned hydrocarbon minimized from 12.3% to 14%, 31.5 to 36.2 and 36.3 to 42.3 at VR=0.037, 0.045 and 0.052 respectively.
- NO_X concentration reduces with increase engine load at constant engine speed. In general, the NO_X emissions diminish from 15.1% to 28.7%, 35.9 to 40.6 and 40 to 44 at VR=0.037, 0.045 and 0.052 successively.

The percentages of augmentation and diminution in the measured variables are shown in the figures in the appendix.

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APPENDIX

$$\text{Percentage } \mathit{increase\ or\ decrease\ in\ Item} = \left| \frac{\%Item_{WithoutHHO} - \%Item_{With\ HHO}}{\%Item_{WithoutHHO}} \right| * 100$$

Item (BSFC, BTE, CO, HC, NO_X and CO_2), at the same load and VR.

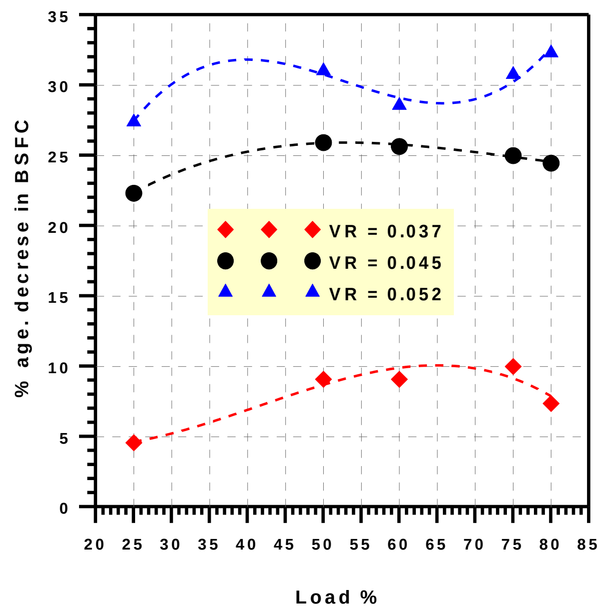

Figure A.1. %age. reduce in BSFC for gasoline engine with HHO compared without HHO

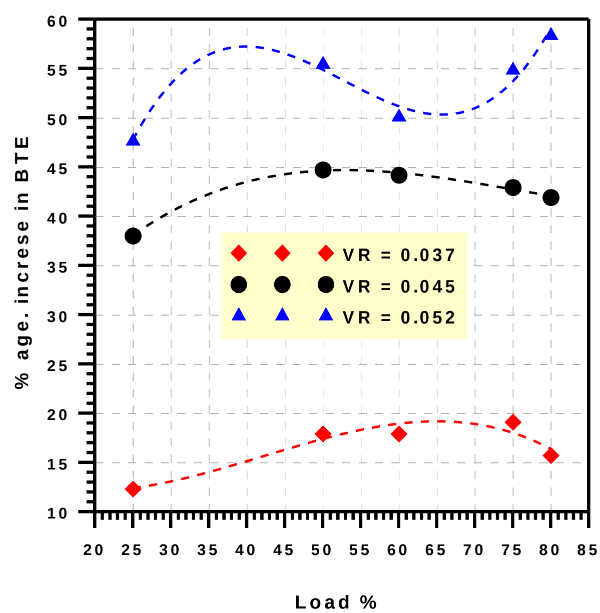

Figure A.2. %age. increment in BTE for gasoline engine with HHO compared without HHO

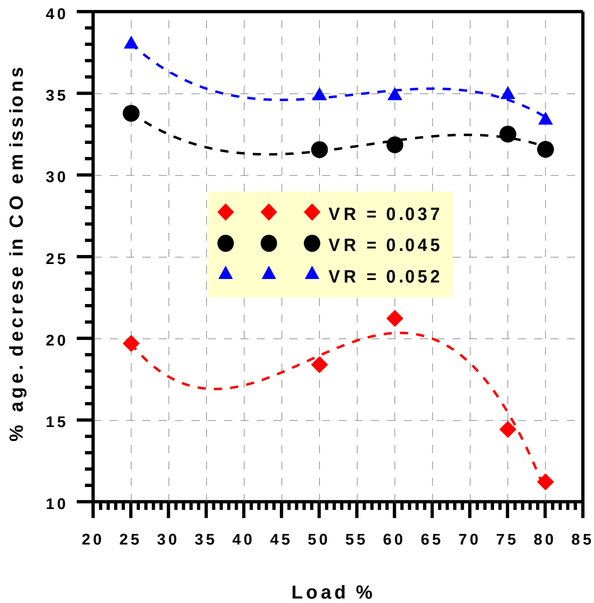

Figure A.3. %age. decrease in CO emissions for gasoline engine with HHO compared without HHO

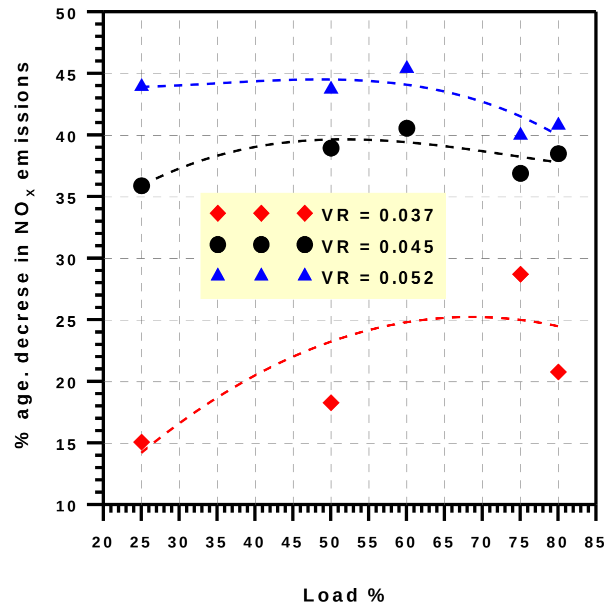

Figure A.5. %age. reduce in NO_X emissions for gasoline engine with HHO compared without HHO

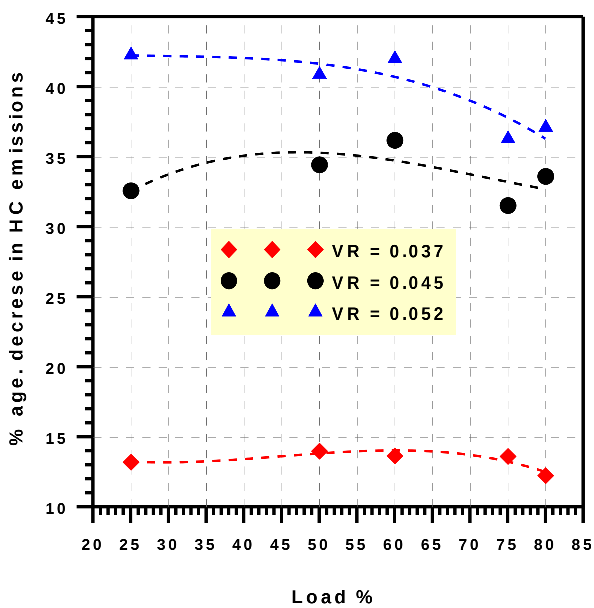

Figure A.4. %age. minimize in HC emissions for gasoline engine with HHO compared without HHO

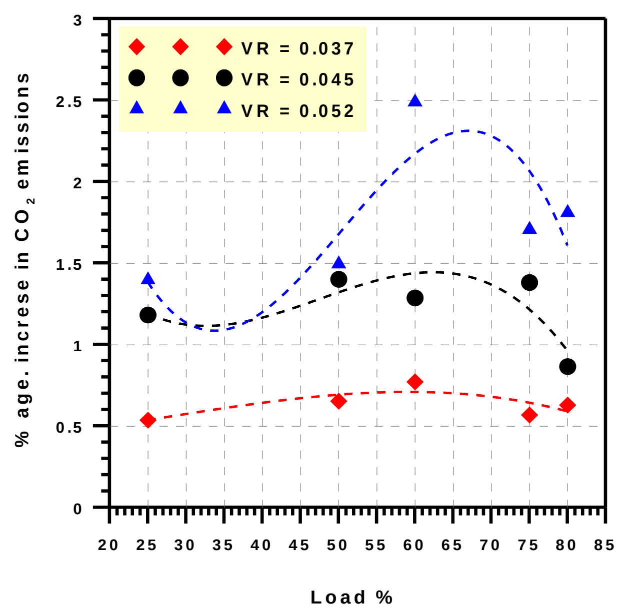

Figure A.6. %age. rise in CO_2 emissions for gasoline engine with HHO compared without HHO