Investigating the Effect of Oxyhydrogen on the Performance of a Compression Ignition Engine

Ahmed M. Rashad

Mechanical Power Department, MTC

Kopry Elkoba, Cairo, Egypt

rashada30@yahoo.com

***Abstract*-Evaluating the performance enhancement of a diesel engine through the addition of Oxy-hydrogen (HHO) gas generated through water electrolysis has been investigated by several researchers. The outcomes were claimed to be very promising. It is thought however that the results need more investigation. This study is carried out to evaluate the influence of adding HHO gas into the inlet air on the performance of a direct injection diesel engine. The experimental work is carried out under constant speed with varying load and amount of introduced HHO generated through water electrolysis. In this work the results contrary to many publication showed that, the thermal efficiency increases only at low loads and the brake specific fuel consumption consequently decreases at low loads too (up to 23% of maximum load). Using oxyhydrogen; the maximum engine power decreases with increasing electrolyte concentration. The maximum reduction in maximum power was (3.8 % to 7.6). An explanation for the results was attempted**.

Keywords- Oxyhydrogen; Thermal Efficiency; Fuel Consumption

I. INTRODUCTION

Many researches have been directed towards the investigating of alternative fuels to reduce pollutants emission without sacrificing performance and fuel economy. Among the various probable alternative fuels, hydrogen is found to be the most promising due to its clean burning and better combustion properties [1, 2].

It was found that the addition of hydrogen improves the engine thermal efficiency and reduces the specific fuel consumption (sfc), however, the volumetric efficiency decreases [1, 3]. In other research it was found that, indicated efficiency slightly increases with hydrogen enrichment at 15 Nm load. At lower load on the other hand, the efficiency decreases. Specific energy consumption increases with hydrogen flow rate at 5 and 10 Nm load, but it decreases at higher loads. Maximum cylinder pressure decreases with hydrogen enrichment at 5 and 10 Nm, but slightly increases at higher load [4]. It is reported that hydrogen reduces smoke emissions at part loads. At the full rated load, reduction in smoke levels is limited; this was believed to be due to the lower amounts of excess air available in the cylinder [5]. Studies have shown that added hydrogen in percentages as low as 5-10% percent of the hydrocarbon fuel can reduce fuel consumption. The theory behind this concept is that the addition of hydrogen can extend the lean operation limit, improve the lean burn ability, and decrease burn duration. Finally, the hydrogen-fueled internal combustion engines inherently suffer from a loss in volumetric efficiency due to the displacement of intake air by the large volume of hydrogen in the intake mixture. For example, a stoichiometric mixture of hydrogen and air consists of approximately 30% hydrogen by volume, whereas a stoichiometric mixture of fully vaporized gasoline and air consists of approximately 2% gasoline by volume [6].

The potential for improved efficiencies and reduced emissions with hydrogen-fueled internal combustion engines appears quite promising. Still there are doubts that the hydrogen-fueled internal combustion engine can serve as a near-term option for a transportation power. The long-term future of the hydrogen-fueled internal combustion engines is hard to predict, as is the future of the hydrogen economy itself [6].

The problems associated with the production and storage of pure hydrogen currently limits the application of pure hydrogen in diesel engine operation. Common duct water electrolyzers that generate a hydrogen oxygen mixture for injection into internal combustion engines is promoted as a method for improving and reducing emissions as well as the brake thermal efficiency and fuel consumption [7-9]

Presence of oxy-hydrogen gas during combustion process was found to decrease the brake specific fuel consumption and increase the brake thermal efficiency [8, 9].

Electrolysis is an electrochemical process in which electrical energy is the driving force of chemical reactions. Water electrolysis breaks the chemical bond of H_2O; $2H_2O \rightarrow 2H_2 + O_2$. The resulting gas mixture is commonly referred to as HHO. Various types of catalysts are used and potassium hydroxide was reported to be best suited for this application because of its ability to remain unchanged during electrolysis [10]. A heavy-duty diesel engine was tested at one low load steady-state condition (24.5% of the maximum load), Measurements showed that the mixed fuel of (diesel fuel + 60 L/min of HHO mixture) reduced the brake specific fuel consumption (BSFC), by an amount of 12.6% [11].

Investigations showed that HHO flow rate had to be reduced in relation to engine speed below 1750 rpm due to the long opening time of intake valves. The excessive volume occupation of oxyhydrogen in cylinders prevents correct air-fuel mixture to be formed and consequently decrease volumetric efficiency. Decreased volumetric efficiency influences combustion efficiency which had negative effects on engine torque and exhaust emissions [12].

The present work was done to investigate the role of HHO gas on the performance of compression ignition engines. The aim was to determine the limits of the effect of the HHO.

II. EXPERIMENTAL WORK

The experimental work has been performed to investigate and clarify the effect of adding oxyhydrogen (HHO) gas on the engine performance. Potassium hydroxide (KOH) solution with concentrations (5%, 10% and 15%) was used as an electrolyte in an oxyhydrogen generator. Cell characterization tests showed that volumetric flow of HHO increases linearly with both voltage and current [12]. So the oxyhydrogen flow rate is increased by increasing the feeding current of the oxyhydrogen generator. Every test was carried out at three feeding electric current (at 5 % KOH concentration the electric current values were 9 amperes, 13 amperes and 20 amperes, at 10 % KOH concentration the electric current values were 7 amperes, 11 amperes and 17 amperes and at 15 % KOH concentration the electric current values were 18 amperes, 20 amperes and 23 amperes).

A single cylinder, direct injection diesel engine (type Deutz-F1L-511), was used in the present work. Main engine specifications are listed in Table 1. Fig. 1 shows the schematic drawing for the test rig and the locations of the measuring devices which are shown in Table 2.

TABLE 1 MAIN SPECIFICATIONS OF DEUTZ-F1L-511 DIESEL ENGINE

Type	**Deutz**
Model	F1L – 511
Combustion chamber	Open type
Bore	100 mm
Stroke	105 mm
Displacement	825 cm^3
Compression ratio	17 : 1
Cooling system	Air cooling
Number of cylinders	One – vertical
Starting	Electrical

Engine external load is carried out by Leroy Somer alternator (type LSA 37). The generator set is supplied with a control unit, which contains calibrated gauges to measure the current and voltage of each phase during the engine operation at various loads.

The output brake power (N_b), in Watt, is calculated as follows:

$$N_b = V_{phase} I_{phase} \cos\Phi$$

Where,

V_{phase} voltage of the phase (Volt)

I_{phase} current of the phase (Ampere)

Φ resistive angle

Generator is loaded by a set of electric lamp bank. Exhaust temperature is measured by a calibrated K- type thermocouple instrument. The engine fuel consumption at steady state operation is evaluated by recording the time of consuming a certain mass of fuel.

The brake specific fuel consumption (BSFC) will be:

$$BSFC = \frac{\overset{o}{m}_f (1000)(3600)}{N_b} \qquad (2)$$

Where,

$\overset{o}{m}_f$ rate of fuel consumption (g/s)

Where brake thermal efficiency (η_{th}) can be calculated such as:

$$\eta_{th} = \frac{N_b}{\overset{0}{m}_f \times Hv} \tag{3}$$

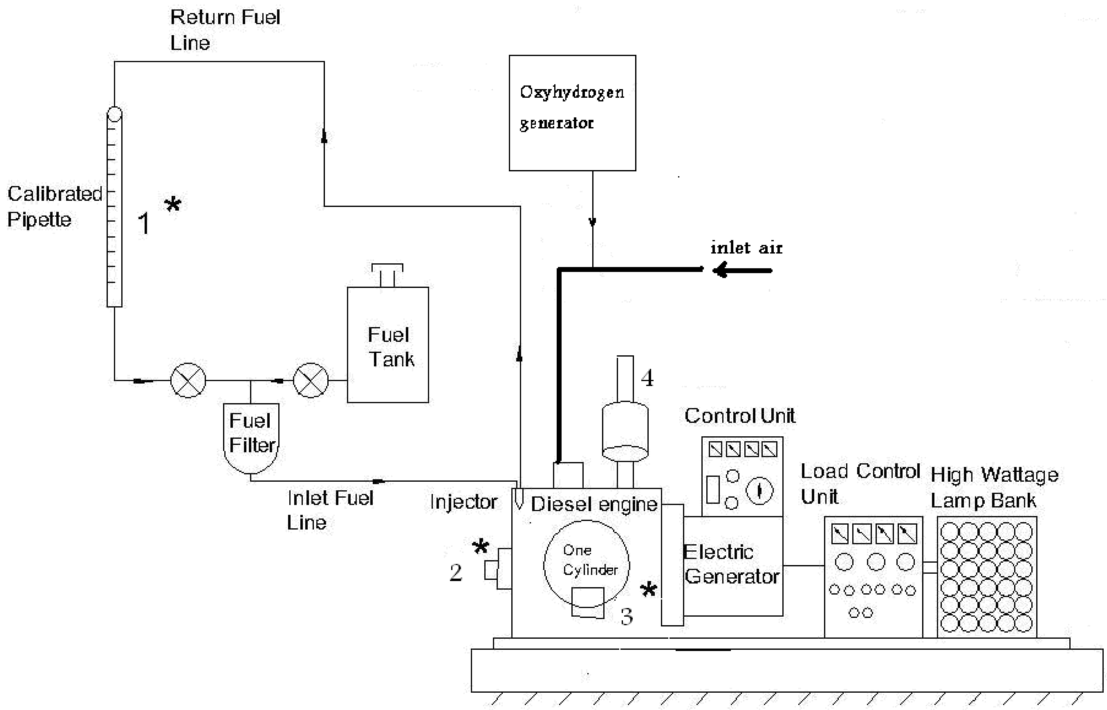

Fig. 1 Schematic drawing for the location of the measuring devices

TABLE 2 LOCATION NUMBER AND NAMES OF THE MEASURED PARAMETERS

Location	Measured Parameter
1	Fuel flow rate
2	Engine speed & crank angle
3	In-cylinder pressure
4	Exhaust gases temperature

III. RESULTS AND DISCUSSION

Figures from 2 to 10 show the effect of HHO on the brake specific fuel consumption, brake thermal efficiency and the exhaust temperature at different concentration of the electrolyzer (5 %, 10 %, and 15% by mass).

A. Effect of HHO on the Maximum Power

The figures show that the maximum engine power decreases for all KOH concentrations and this can be explained as follows: in diesel engines; at full load the excess air factor decreases; this means that the amount of air available for combustion decreases. Part of this air is used to burn HHO which releases less energy at combustion than hydrocarbon fuel. Also the remaining air is not enough to burn all the hydrocarbon fuel. In addition, the loss in volumetric efficiency due to the displacement of intake air by the large volume of oxyhydrogen in the intake mixture; influence the combustion efficiency [13].

B. Effect of HHO on the Brake Specific Fuel Consumption (BSFC)

Figs. 2, 5 and 8 show the effect of HHO on the brake specific fuel consumption (BSFC) at different KOH concentrations. The figures show that; at low load (up to 20% of maximum load); the BSFC decreases (up to 14 %) with addition of HHO for all KOH concentrations. At high loads the BSFC was not significantly affected. This could be explained as follows: oxyhydrogen (HHO) is admitted into the intake at the expense of the intake air. At low load the excess air factor (a) is high; hence there is enough air to burn HHO and the diesel fuel. This leads to increase the power output at low load and consequently the BSFC decreases. At high loads the excess air factor is reduced as HHO is admitted at the expense of intake air. This means that the amount of air available for burning diesel fuel is lowered dramatically. As a result; the amount of diesel fuel burnet is reduced and also the output power. So the BSFC was not significantly affected.

The figures show also that the BSFC decreases with increasing electrolysis current at no load only. But there were no significant change at part load and full load.

C. Effect of HHO on the Brake Thermal Efficiency (BTE)

Figs. 3, 6, and 9 shows the effect of HHO on the brake thermal efficiency (BTE) at different KOH concentrations. The figures show that the increase in BTE was significant only at low load (up to 20 % of full load). The maximum increase in BTE was about 18% (at up to 20 % of full load). At part and high loads there was no significant change in the brake thermal efficiency.

D. Effect of HHO on The Exhaust Temperature

Figs. 4, 7 and 10 show the effect of HHO on the exhaust temperature, the figures show that the exhaust temperature decreases with addition of HHO. This may be due to the low calorific value of HHO compared to diesel fuel and the reduction of the amount diesel fuel burnt at higher loads.

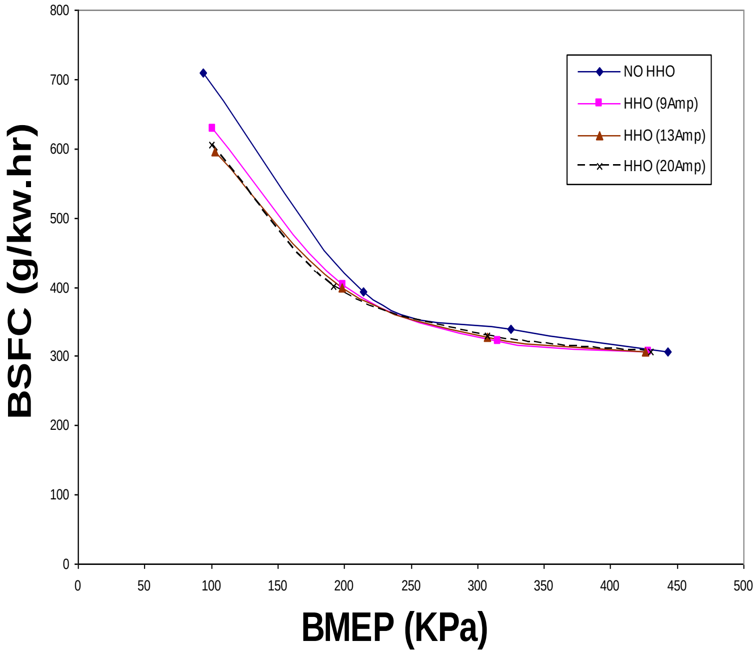

Fig. 2 Effect of HHO on specific fuel consumption (KOH 5%)

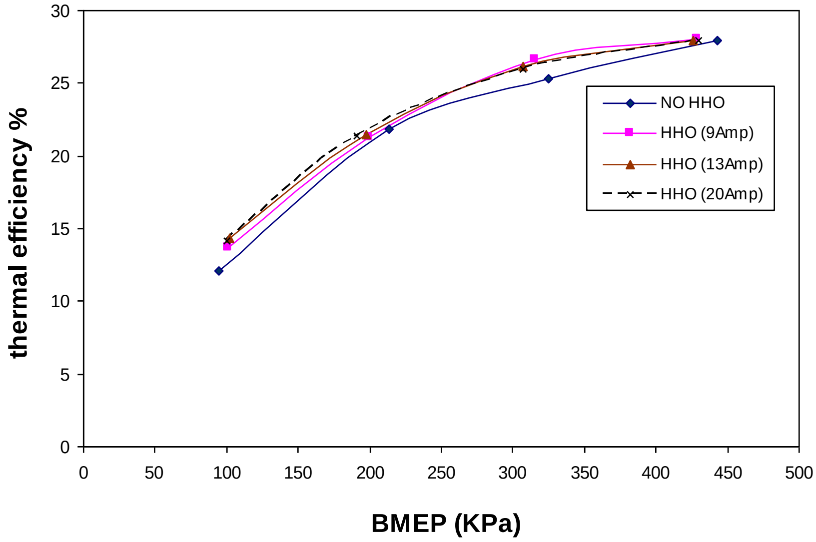

Fig. 3 Effect of HHO on brake thermal efficiency (KOH 5%)

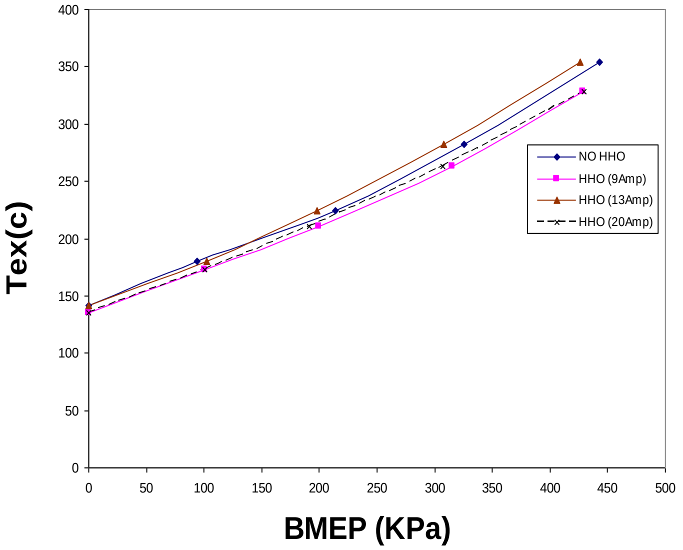

Fig. 4 Effect of HHO on exhaust temperature (KOH 5%)

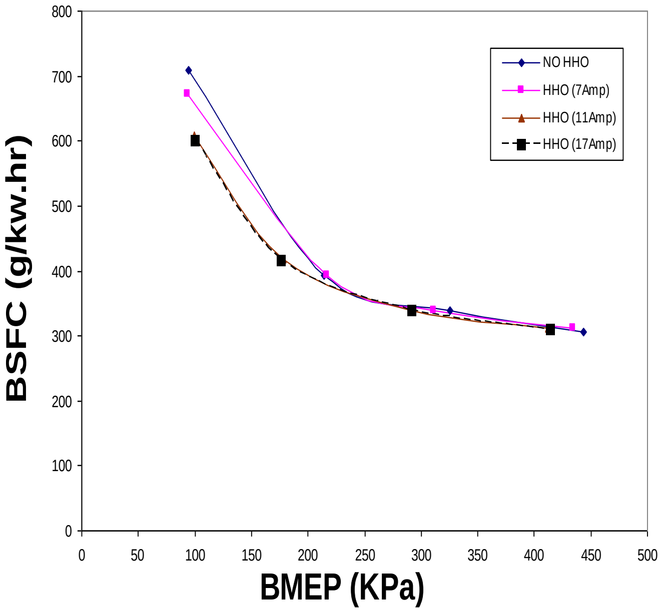

Fig. 5 Effect of HHO on specific fuel consumption (KOH 10%)

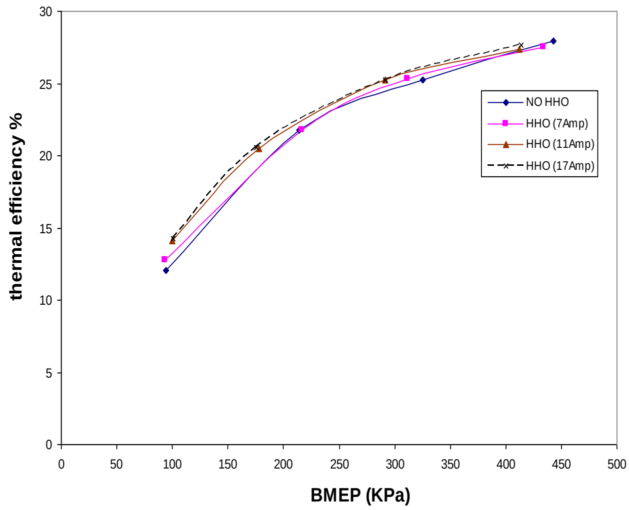

Fig. 6 Effect of HHO on brake thermal efficiency (KOH 10%)

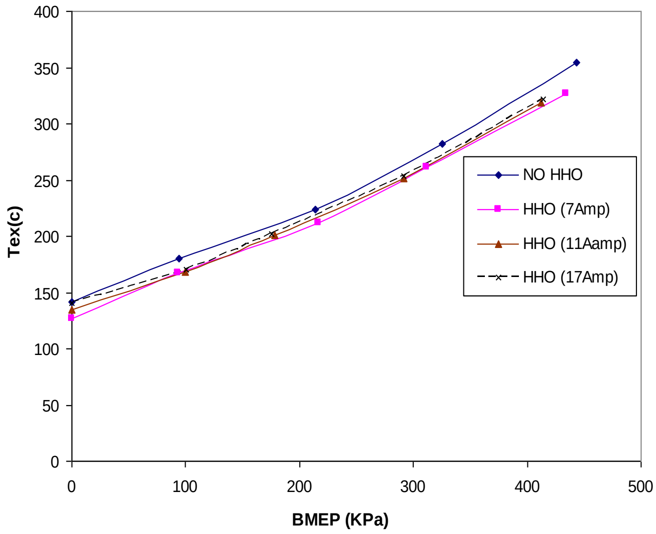

Fig. 7 Effect of HHO on exhaust temperature (KOH 10%)

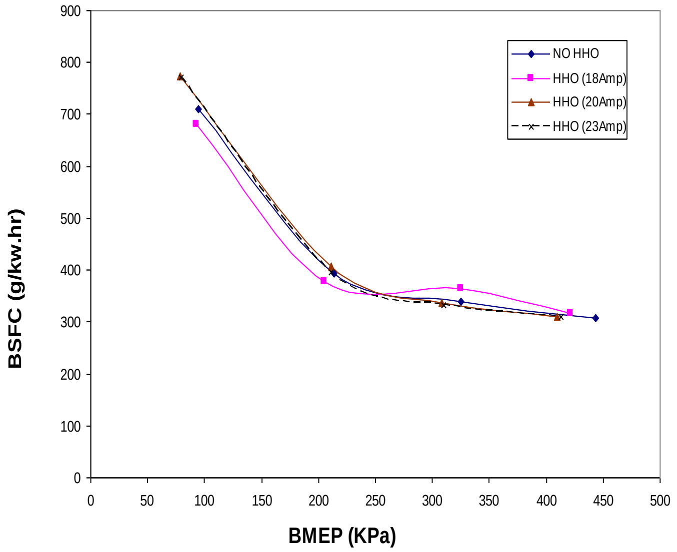

Fig. 8 Effect of HHO on specific fuel consumption (KOH 15%)

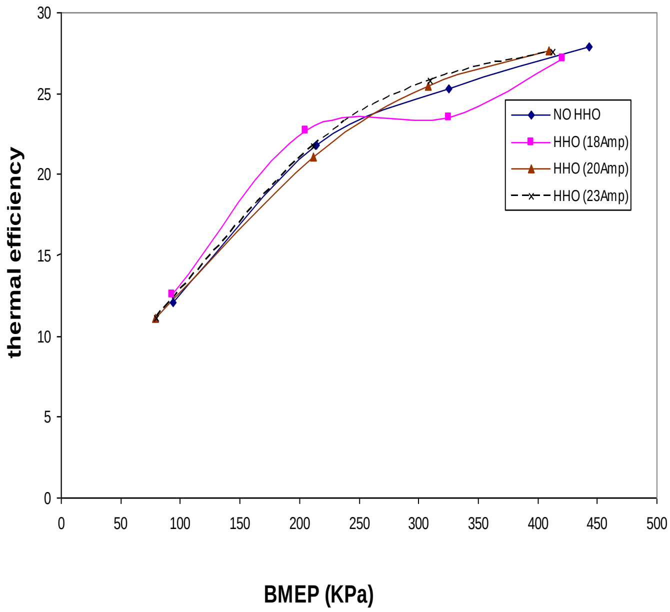

Fig. 9 Effect of HHO on brake thermal efficiency (KOH 15%)

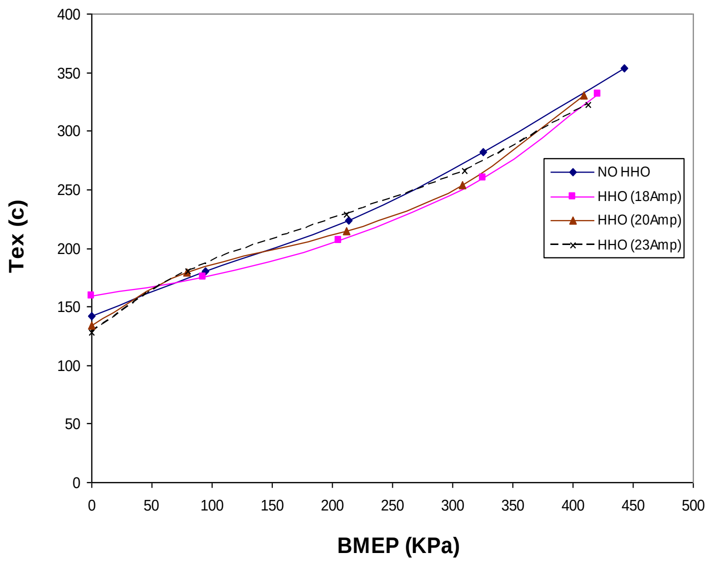

Fig 10 Effect of HHO on exhaust temperature (KOH 15%)

IV. CONCLUSIONS

1. The maximum power of the engine decreased with using HHO. This may be due to the lower amounts of excess air available in the cylinder, and the loss in volumetric efficiency due to the displacement of intake air by the large volume of oxyhydrogen in the intake mixture.

2. The specific fuel consumption decreased at low load (up to 20%) but at higher loads the decrease in the specific fuel consumption was not noticed.

3. The brake thermal efficiency was noticed to increase at low loads only. At high loads no increase in the thermal efficiency was noticed

4. The exhaust temperature decreased using HHO

5. It is thought that using HHO in diesel engines may not have good impact on the engine performance; where it reduces the maximum engine power and doesn't have noticeable effect on the specific fuel consumption and thermal efficiency at medium and high loads

6. According to the obtained results and the detailed study of the previous works, it can be concluded that, adding oxyhydrogen can only improve the performance of the internal combustion engines at low loads

7. More intensive work is needed to clarify and judge the influence of HHO on the performance of the internal combustion engines. The work should be done to clarify and judge the influence of HHO on the specific fuel consumption, thermal efficiency, …etc.

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