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Experimental Investigation of the Effect of Injection of Oxy-Hydrogen Gas on the Loading characteristics of Diesel Engine

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Abstract: *Oxy-Hydrogen generator, which produces a mixture of hydrogen and oxygen by water electrolysis has many advantages over using pure hydrogen as an additive fuel in Internal combustion engines due to the elimination of aboard storage problems of hydrogen. In this paper, an experimental exploration was carried out in order to study the effect of addition of oxy-hydrogen gas intake air manifold on loading performance characteristics of a diesel engine at different operating conditions. The experimental work was performed on a test rig comprising a four stroke 5.67 liters water-cooled diesel engine. Instrumentation included devices for measuring engine speed, load, exhaust temperature, fuel consumption and inlet air flow rate. Tests were conducted at a speed of 1500 rpm and different engine load at different oxy-hydrogen generator supplied currents and different electrolyte concentrations. The addition of H_2O_2 gas reduces the specific fuel consumption at all percentage of electrolyte concentration and all values of oxy-hydrogen generator supplied current. Fuel saving ranging from 1.62 at 10 A to 6.47 % at 26 A at 5% electrolyte concentration while at 25 % of electrolyte concentration the fuel saving ranged from 6.47 at 10 A to 13.29 % at 26 A. volumetric efficiency decreases by about 4.5 % when the supplied current is 26 A at 5 % electrolyte concentration and about 5.5 % when the supplied current is 26 A at 25 % electrolyte concentration.*

Keywords: *diesel engine- Loading characteristics- Oxy-hydrogen addition.*

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I . Introduction

Oxy-hydrogen gas is a mixture of hydrogen and of oxygen with percentage by volume (2:1) bonded together molecularly. It is generally produced by electrolysis by passing an electric current through water, it divides into hydrogen and oxygen that ascend from the liquid water as gas. This gas is called Browns gas, HHO or (H_2/O_2). It may be introduced into the air intake manifold to be used as an additive to conventional engine fuels. H_2O_2 gas has the advantages of highly flammable much more than gasoline and gas oils. The Oxy-hydrogen explosion is so fast that it fills the combustion chamber at 3 times faster than gasoline explosion. At atmospheric pressure Oxy-hydrogen auto ignition takes place s at about 570^{o}C. It has very high diffusivity. This ability to disperse in the air is considerably greater than gasoline and gas oil. At atmospheric temperature and pressure H_2O_2 gas can burn when it is between about 4% to 94% hydrogen by volume. Oxy-hydrogen has very low density result in a storage problem. A amount of 241.38 KJ of energy (LHV) is released for every mole of H_2 burned [1]

The majority of previous works paying attention on the use of untainted hydrogen as an fuel additive [2-6]. It improved the combustion progression due to its better combustion characteristics compared to conventional diesel fuels. Also, It was reported that hydrogen increases the engine thermal efficiency and reduces the volumetric efficiency [2-6]. Addition of untainted hydrogen as a fuel additive brings aboard storage problems of hydrogen into concern. Viable solution to this problem is to produce H_2O_2 aboard by water electrolysis and utilized it in the form of a mixture of hydrogen and oxygen gases [1].

Few researches have been done on this concept. Some of these works were conducted to improve the thermal efficiency of petrol engines such as Amman A. Al-Rousan [7], A.M.Falhat, et al. [8] ,Tuan Le Anh, et al. [9] and EL-Kassaby et al. [10]. Some others worked to enhance the performance of diesel engines. Bari and Esmaeil [11] performed experimentations on four cylinder direct injection diesel engine. The experiments were carried out under steady speed of 1500 rpm with three different power level. The result showed that with introduction of H_2O_2 gas at different percentage into diesel engine, the brake thermal efficiency was found to increase with increasing of engine load. The brake specific fuel consumption of engine was reduced as the engine load increased. It was also noticed that adding H_2O_2 further than 5% does not have considerable effect on engine performance. The HC, CO and CO_2 emissions were found to be reduced while NOx was increased owing to higher temperature achieved during combustion process.

Ali Can Yilmaz,el al. [12] produced H_2O_2 gas with different electrolytes NAOH (aq), NACL (aq) and KOH (aq.), with various electrode designs in a leak proof plexi-glass reactor. The engine used was four cylinder, four stroke diesel engine. Results showed that there was 19.1 percentage increase in engine torque when H_2O_2 system was used compared to diesel operation where as 14% gain was achieved on specific fuel consumption using hydroxyl gas. Also about 13.5% reduction in CO emission and 5% reduction in HC but experiment showed that at low engine speed with constant H_2O_2 flow rate turned into disadvantage for torque ,CO,HC, and SFC this is because of long opening time duration of intake valve at low speed which cause excessive air replacement by H_2O_2 in cylinder which prevents proper air to be taken into combustion chamber due which volumetric efficiency decreases that influenced combustion efficiency which had adverse effect on performance parameter.

Dahake et al. [13] carried out some experimentations on single cylinder four stroke diesel engine, it was seen that, the oxy-hydrogen gas enrichment resulted in considerable enhancement in performance and reduction in emission parameters except the exhaust gas temperature and NO emission which increases with increase in load. The thermal efficiency of diesel engine was found to increase when enriched with oxy-hydrogen gas. The exhaust gas temperature seems to be increased causing increase in NOx. Carbon monoxide (CO) and hydrocarbon (HC) were reduced marginally due to better combustion with oxy-hydrogen gas and absence of carbon. The purpose of this work is to examine the effect of the addition of H_2O_2 gas on the performance characteristics of a diesel engine joined to a hydraulic dynamometer. experimentations were carried out at a steady speed of 1500 rpm with adding of different quantities of H_2O_2 gas corresponding to changing the oxy-hydrogen generator supplied current of 10, 18 and 26 A with different electrolyte concentration of 5, 15 an 25 % at different loading of 11 kW, 22 kW, 33 and 44 kW corresponded to brake mean effective pressure of 1.56, 3.12, 4.68 and 6.24 bar respectively.

II EXPERIMENTAL WORK

Experimental Setup:

The experimental work was conducted on a complete rig (available in the laboratory of mechanical power and energy at the Military technical college) for testing naturally aspirated as well as turbochargerd diesel engines. The test rig includes the engine and all the instrumentation necessary for measuring and recording the operating parameters. An on-line data acquisition system is furnished to improve the speed and accuracy of data collection and recording. A transport diesel engine of type Mercedes-Benz with an open chamber is used. This is a four stroke 6-cylinder with 97 mm bore, 128 mm stroke, and 17: 1 compression ratio. Detailed engine specifications are given in appendix (A).

Engine external loading was carried out by an ELZE /Heenan hydraulic dynamometer. The fluid used was water with which the maximum breaking power could reach 170 kW at 4000 rpm. The engine and dynamometer shafts were directly coupled through a cardan shaft. The test rig is fully instrumented in order to acquire experimental data as well as to monitor the engine operating conditions. Figure (1) gives a general scheme of the complete test rig showing numbered locations where important pickups and transducers concerning our experimental work are positioned. a list of these locations and the corresponding measured parameter at each is given table (1).

The engine speed is measured using shaft encoder. Also it was measured and monitored frequently using a hand held digital tachometer model Lutron DT-2234 . The fuel consumption of the engine was calculated by recording the time required for consumption of a fixed volume of fuel and using the following equation.

$$\dot{m}_f = \frac{V_f \rho_f}{t} \quad (1)$$

A standard orifice of 60 mm diameter is mounted at the air surge tank entrance with a U-tube manometer which is fitted downstream the settling chamber to measure the air pressure drop across the orifice as shown in figure (1). The air flow rate is calculated from the orifice area and the manometer reading.

$$\dot{m}_{air} = C_d A_{orifice} \sqrt{\frac{2\Delta p}{\rho_{air}}} \quad (2)$$

A thermocouples type K (NiCr-Ni), which is connected to a digital read out is used to measure the temperature of the exhaust manifold

The oxy-hydrogen gas, H_2O_2, was produced by water electrolysis using an oxy-hydrogen generator specially designed and manufactured. The characteristics of the generator is measured as shown in figure (2). To simplify the experimental setup, the H_2/O_2 generator was supplied by 12 V from separate power supply. Actuality it will be generated from the battery/alternator array of the engine. The power essential to generate the H_2/O_2 mixture is incorporated as an input energy to the engine. The produced mixture is subsequently conceded through a drier bottle before it is introduced to the engine through the air intake manifold. Explosions anywhere in the line were suppressed by flame arrestors installed into the H_2/O_2 line. The supplied current is measured by clamp ampere (Lutron CM-9940)

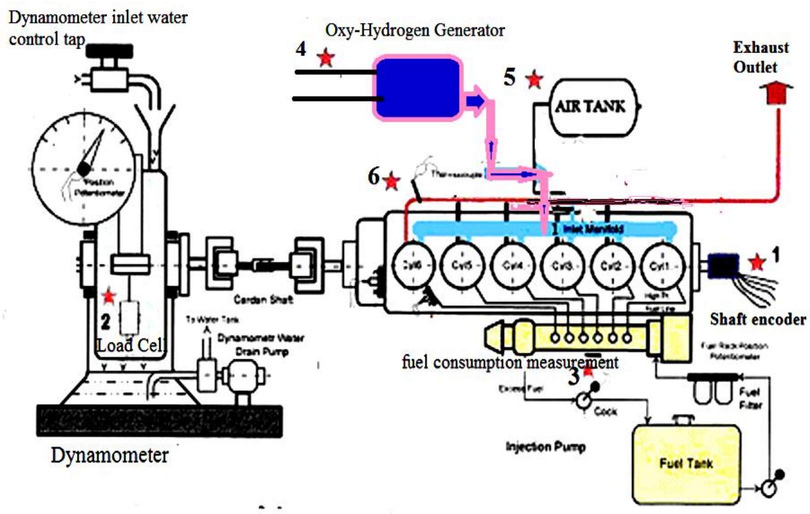


Figure 1: Schematic of test rig, *i point of measurements of the ith parameter

Test procedure

Measured parameters included engine speed, engine power (calculated from the dynamometer reading) , fuel consumption and inducted air mass flow rate. The tests were conducted on the diesel engine with and without introducing the oxy-hydrogen gas. One oxy-hydrogen generators was used in these tests whose characteristics is given in figure (2) and its specifications were given in Appendix B. All the measured parameters were measured under three values of the oxy-hydrogen generator supplied current namely 10A, 18 A and 26 A for three values of electrolyte concentrations namely 5%, 15% and 25%. Table (2) lists the tests conducted to explore the diesel engine performance with and without oxy-hydrogen gas under different operating conditions (constant speed and variable load).

Table 1: List of measuring locations and the parameter measured at each (Relevant to Figure (1))

Location	Measured Parameter	Measuring device
1	Engine speed	Shaft encoder digital tachometer model lutron DT-2234
2	Brake torque	ELZE /Heenan hydraulic dynamometer
3	Fuel consumption	Recording the consumption time of fixed volume
4	HOH generator supplied current	clamp ampere (Lutron CM-9940)
5	The air pressure drop across the orifice	U-tube manometer
6	Exhaust temperature	A thermocouples type K (NiCr-Ni)

Table 2: Measured parameters and operating settings at which measured parameters were recorded

Measured parameters	operating settings at which measured parameters were recorded					
	Engine Speed (rpm)	**% of load to engine full load**	**HOH generator Supplied current**	**electrolyte concentration %**		
• Engine speed • Dynamometer reading • Fuel consumption • HOH generator supplied current • The air pressure drop across the orifice • Exhaust temperature	1500 rpm	0 %	**10A**	**5%**	**15%**	**25%**
		20 %				
		40%				
		60%				
		80%				
		0 %	**18A**			
		20 %				
		40%				

60%	
80%	
0 %	
20 %	
40%	**26A**
60%	
80%	

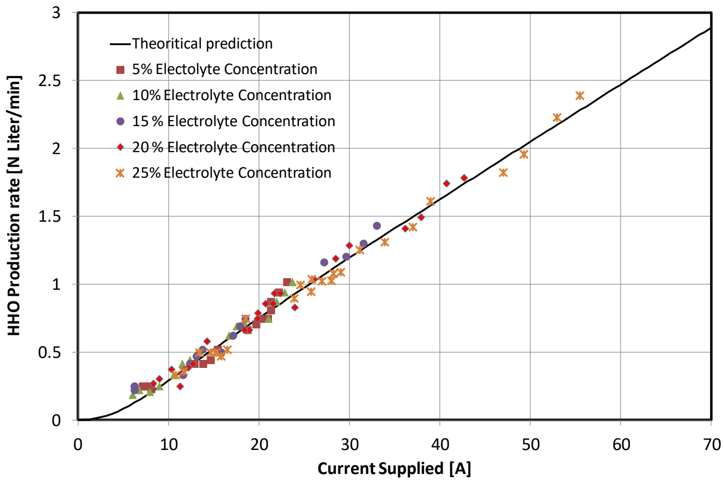


Figure 2: H_2O_2 production rate of the oxy-hydrogen generator used in this work [14]

III . RESULTS AND DISCUSSIONS

Brake Specific Fuel Consumption

The brake specific fuel consumption,   is inversely proportional to the engine indicated efficiency and engine mechanical efficiency by the equation

$$g_e = \frac{3600}{\eta_e H_l} \quad (3)$$

$$g_e = \frac{3600}{\eta_i \eta_m H_l} \quad (4)$$

where

g_e : specific fuel consumption [gm/kW.hr]
η_e : effective thermal efficiency
η_i : indicated thermal efficiency
η_m : mechanical efficiency
H_l : lower heating value of the fuel [MJ/kg]

The brake specific fuel consumption (BSFC) was shown to reduce as the engine loading increases due to the increase of engine mechanical efficiency which is in direct proportional to the output engine power.

It is well known that increasing the oxy-hydrogen generator supplied current increases the amount of Oxy-hydrogen gas admitted to the engine cylinder. The volumetric flow rates of oxy-hydrogen gas admitted to the engine were 1.3 L/min, 0.7 L/min and 0.3 L/min corresponds to 26A, 18 A and 10 A respectively based on the theoretical prediction and experimental measurements carried out [14].

Figure (3) show the variation of fuel consumption saving with brake mean effective pressure at different oxy-hydrogen generation supplied current for electrolyte Concentration of A: 5 % ; B: 15 % C: 25 %. The figures revealed that, adding a small quantity of H_2/O_2 into the air intake reduced the BSFC despite of the engine loading level at all supplied currents and electrolyte concentrations. This is owing to homogeny in hydrogen mixture creation with air follow-on in better combustion charateristics. Higher flame speed of hydrogen assists to have more complete combustion and maximum pressure nearer to TDC producing further work [11].

The results show that the fuel saving percentage is higher for small load namely 11 kW for all concentrations level. This can be attributed to greater hydrogen energy contribution at low load and lesser energy share at modest load. The fuel saving percentage tends to increase at higher load (44 kW) owing to the enhance of the hydrogen flame speed at excess air factor of (1.5:1.7) [15].

It was shown that the fuel saving increases with the increase of the oxy-hydrogen generator supplied current due to the increase of the percentage of the oxy-hydrogen gas admitted to the engine cylinders as discussed earlier. These findings match with the results of Saravanan et al [4] and Bari et al [11] . Bases and acids were documented to modify the nonconductive character of untainted water. These compounds have a great reducing consequence on the overvoltage value of oxy-hydrogen generator [16:19] by enhancing the aqueous electrolyte compounds ionic conductivity. However, the concentration of acidic and alkali aqueous solutions are restricted in practice due to the extremely corrosive activities of electrodes. Yuvaraja et al [18] concluded that the hydrogen evolution steadily increases with increase in electrolytic concentration. This may be attributed to the increase of current that passes through the electrodes which depends on the electrodes conductance and electrolyte concentration which causes a greater number of effective ionic collisions per unit time. This leads to the increase of fuel saving percentage with the increase of electrolyte concentration.

A

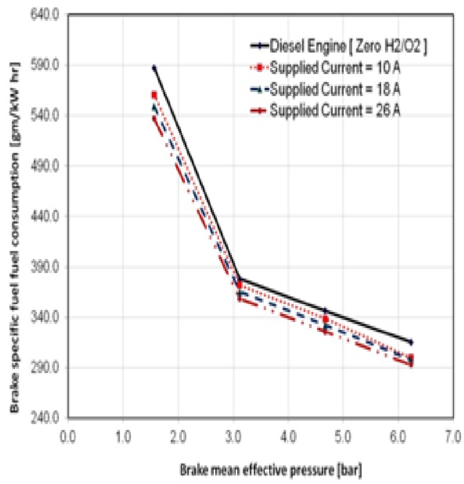


Figure 3: Effect of brake mean effective pressure on the brake specific fuel consumption (bsfc) at different oxy-hydrogen generation supplied current for electrolyte Concentration of A: 5 % ; B: of 15 % C: 25 %

Brake thermal efficiency

The brake thermal efficiency is conversely proportional to the brake specific fuel consumption as indicted by eq. 1 and 2. The change of brake thermal efficiency with the engine loading level for different Oxy-hydrogen generator supplied Currents namely 10A, 18 A and 26 A and different electrolyte concentration 5 %, 15 % and 25 % are revealed in figure (4 A, B and C) respectively.

It is clear from the figure that, despite of the value of engine loading, the rising the supplied current (% addition of H_2/O_2 mixture) result in the increasing of the break thermal efficiency of the engine. The flame speed of hydrogen is nine times faster than the flame speed of gas oil fuel [20]. Therefore, burning gas oil in the company of hydrogen will outcome faster and more comprehensive combustion which will result in higher maximum pressure nearer to TDC and therefore, result in a higher effective pressure.

Excess Air Factor

Figure (5) depicts the variation of excess air factor with different percentage of H_2/O_2. It was expected that when the H_2/O_2 mixture was introduced with the intake air it will occupy a volume and replace some air result in reduced quantity of air induced to the engine causing a reduction of the excess air factor. Instead, the excess air factor was shown to increase with increasing H_2/O_2 which may be explained by the fact that the inducted mixture contains oxygen and hydrogen as well. Also it was shown previously that increases of the induced H_2O_2 decrease the specific fuel consumption especially at small loads which increase the excess air factor. This increase in excess air factor enhances the combustion characteristics resulting reduced fuel consumption and increased thermal efficiency as described earlier.

The increases in excess air factor were from 1.29 at full load when running with pure fuel to 1.33 at 26 A supplied current and 5 % electrolyte concentration and, from 1.32 to 1.36 at 26 A supplied current and 25 % electrolyte concentration at full load. These values indicate that the effect of added H2O2 gas did not significantly affect the excess air factor especially at full load.

Volumetric Efficiency

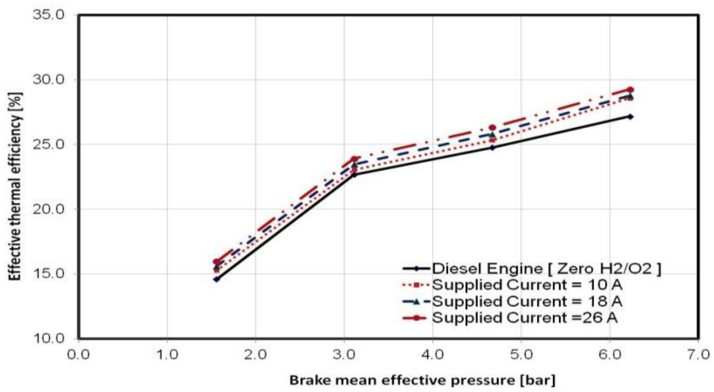
Figure (6) illustrated The consequence of H_2O_2 induction rate on volumetric efficiency. It was noticed that regardless of the engine loading level, the volumetric efficiency was shown to decrease by about 4.5 %

when the supplied current is 26 A at 5 % electrolyte concentration and about 5.5 % when the supplied current is 26 A at 25 % electrolyte concentration. This may be attributed to the following. A constant speed naturally aspirated diesel engine operates with almost constant air induction rate. The rate of inducted air is shown to decrease with increasing of the engine loading owing to the increase of engine temperature resulting in a decrease of inducted air density. The maximum decrease in volumetric efficiency was found to be about 3% in the loading range under consideration. However, at a constant load, the quantity of induced air decreased when oxy-hydrogen induction rate was increased with the increase of supplied current and electrolyte concentration as shown in figure (6) and resulted in decrease of volumetric efficiency. The decrease of the inducted air rate leads to improper combustion affecting obviously the emission characteristics. These results agreed with what was obtained in previous works [6,21]

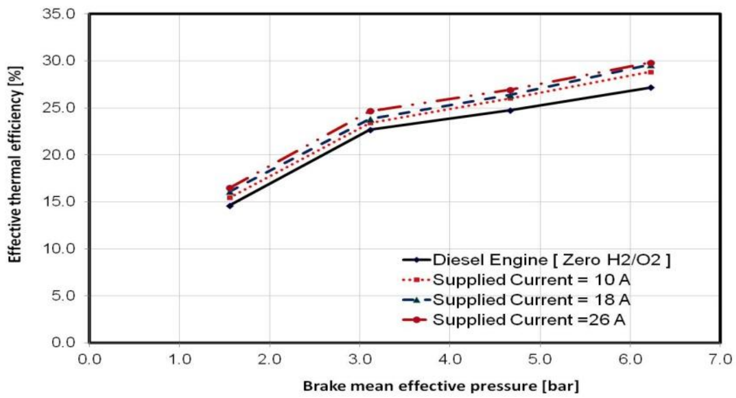
Exhaust Temperature

The exhaust temperature is shown to decrease with increasing the supplied current (amount of added oxy-hydrogen gas) at all power output This is owing to the decrease of specific fuel consumption as the amount of oxy-hydrogen decreases. Also the excess air factor was shown to increase with the increase of admitted oxy-hydrogen gas which has a coolant effect. The exhaust temperature was shown to decrease for the same supplied current with increase of electrolyte concentration. The maximum temperature decrease was about 80^{o}C at medium to high load, 26 A and 25 % electrolyte concentration.

A



B



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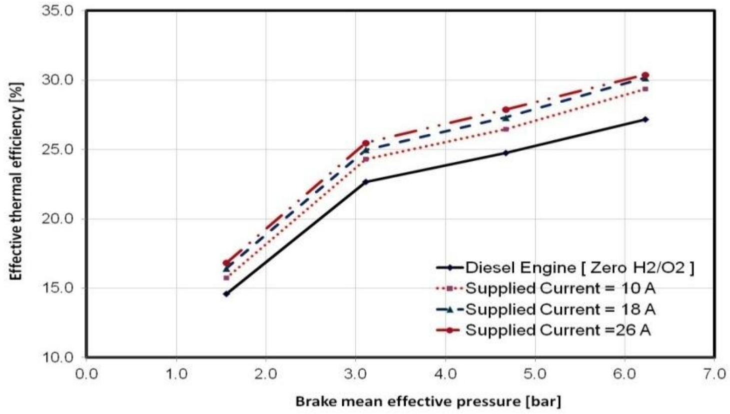
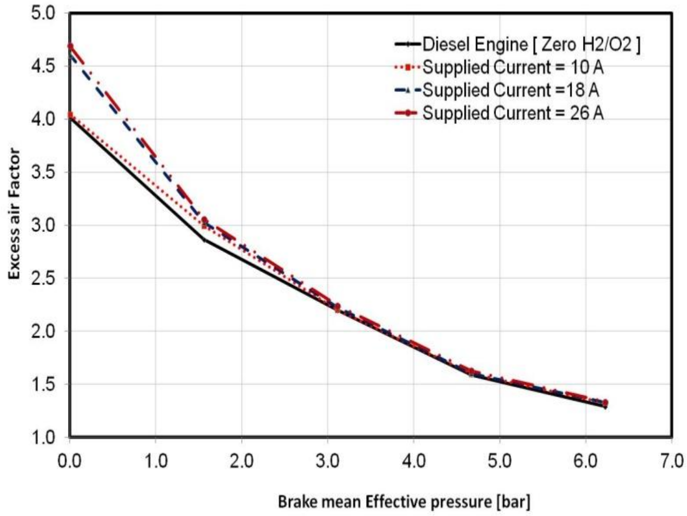
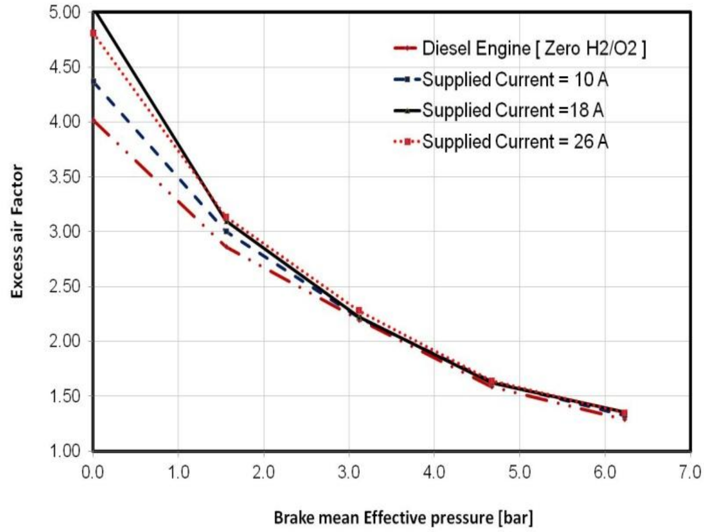


Figure 4: Effect of brake mean effective pressure on brake thermal efficiency at different oxy-hydrogen generation supplied current at different oxy electrolyte Concentration of A: 5 % ; B: of 15 % C: 25 %

A



B



C

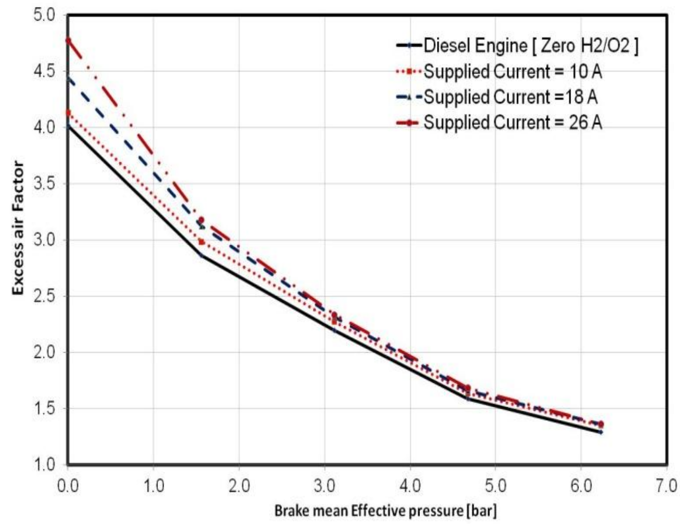


Figure 5: Effect of brake mean effective pressure on excess air factor at different oxy-hydrogen generation supplied current for at different oxy electrolyte Concentration of A: 5 % ; B: of 15 % C: 25 %

A

B

C

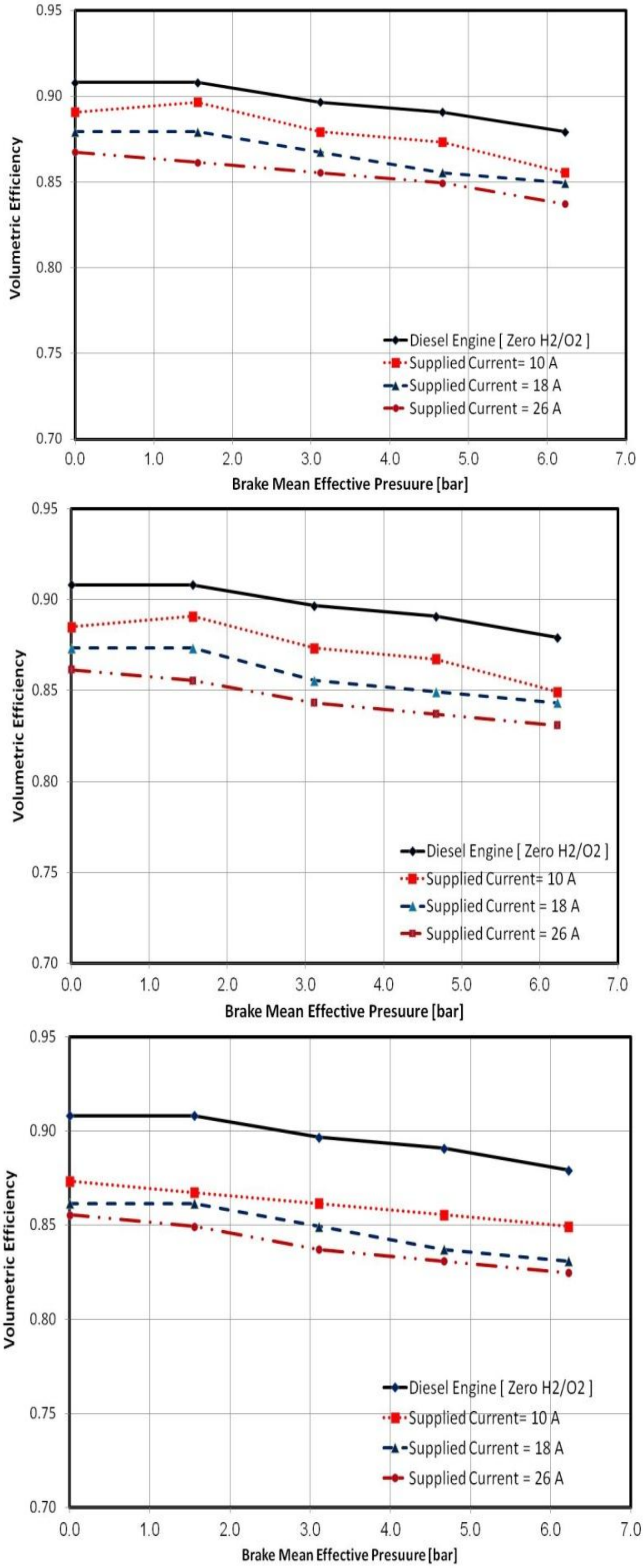


Figure 6: Effect of brake mean effective pressure on the volumetric efficiency at different oxy-hydrogen generation supplied current at different oxy electrolyte Concentration of A: 5 % ; B: of 15 % C: 25 %

A

B

C

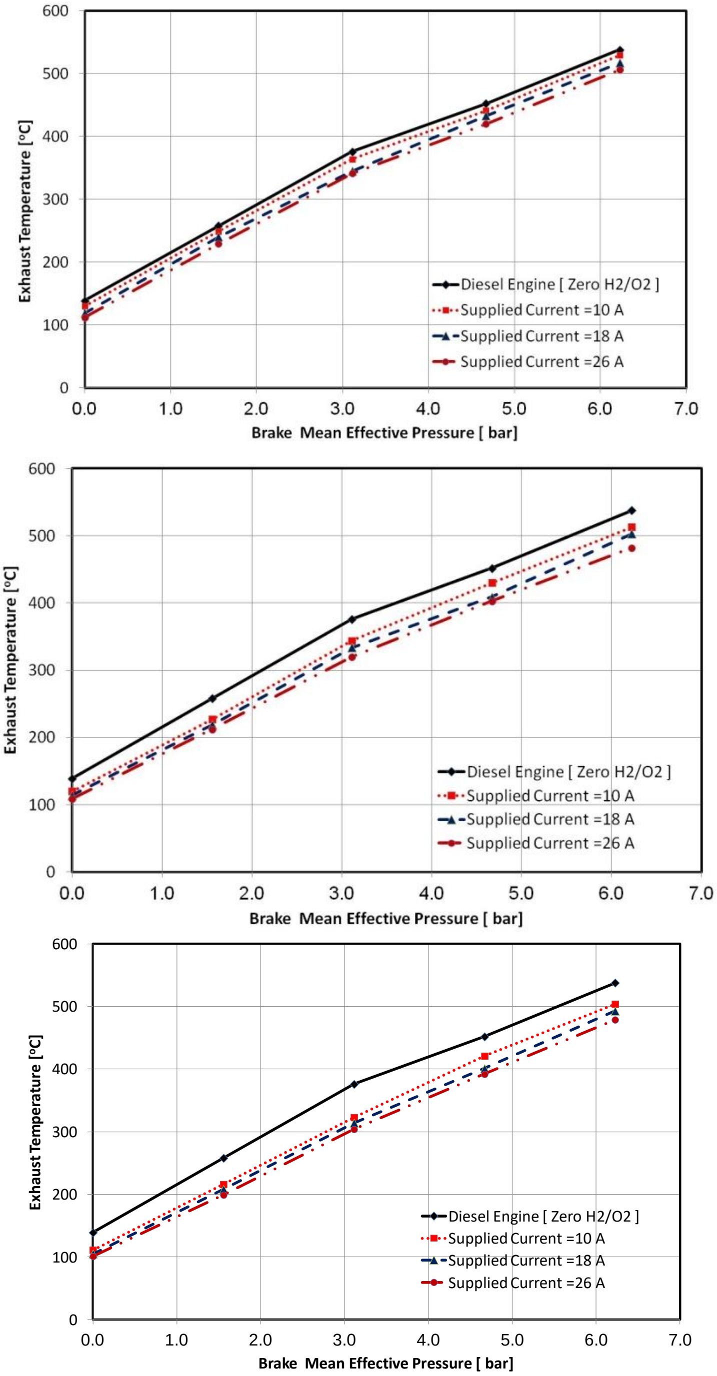


Figure 7: Effect of brake mean effective pressure on the exhaust temperature at different oxy-hydrogen generation supplied current at different oxy electrolyte Concentration of A: 5 % ; B: of 15 % C: 25 %

IV. Conclusions

The consequence of using a small quantity of H_2O_2 mixture as an fuel additive on the loading performance characteristics of a four-cylinder diesel engine were instigated. The H_2O_2 gas was produced using water electrolysis. The hydrogen flame speed is about nine times higher than flame speed than diesel so it has the capability to improve overall combustion characteristics, generating higher maximum pressure nearer to TDC resulting in more work. Specific Conclusions can be summarized as:

- The addition of H_2O_2 gas reduces the specific fuel consumption at all percentage of electrolyte concentration and all values of oxy-hydrogen generator supplied current. Fuel saving ranging from 1.62 at 10 A to 6.47 % at 26 A at 5% electrolyte concentration while at 25 % of electrolyte concentration the fuel saving ranged from 6.47 at 10 A to 13.29 % at 26 A.

- The fuel saving percentage is higher for small load namely 11 kW for all concentrations level. This can be attributed to higher hydrogen energy contribution at low load and lower energy share at moderate loading conditions. The fuel saving percentage tends to increase at higher load (44 kW) owing to the increase of the hydrogen flame speed at excess air factor of (1.5:1.7)
- volumetric efficiency decreases by about 4.5 % when the supplied current is 26 A at 5 % electrolyte concentration and about 5.5 % when the supplied current is 26 A at 25 % electrolyte concentration.
- The exhaust temperature is shown to decrease with increasing the supplied current (amount of added oxy-hydrogen gas) at all power output The exhaust temperature was shown to decrease for the same supplied current with increase of electrolyte concentration. The maximum temperature decrease was about 80^{o}C at medium to high load, 26 A and 25 % electrolyte concentration.

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Appendix A Engine Technical Data

Make and Model	Mercedes 352 series -Natural aspirated Diesel engine
Compression ratio	17 : 1
No. of Strokes	4
No. of cylinder	6
Arranging	In-line
Cooling	Water
Bore	97 mm
Stroke	128 mm
Combustion chamber	Open type, Direct Injection
Cam shaft	Sided

Speed range	800-2800 rpm
Maximum power	120 HP at 2800 rpm
Maximum torque	28 kp.m at 1600 rpm
Static injection	23 CA BTDC
Firing order	1 5 3 6 2 4 1
Min. compression pressure	20 bar at 150-200 rpm
Injector opening pressure	200 bar

Appendix B Oxy-hydrogen Generator Technical Data

Design	leak proof plexi-glass reactor
Electrodes	stainless chromium-nickel steel plates 316L
Number of cells	18
Connections	Three (6 cells in series) in parallel
Electrode area	[13 cm X8 cm]
Electrode spacing	2 mm
Electrolyte Concentration	KOH (5-25%)
Maximum Current intensity	1500 A/m^2
Operating Voltage	12 Volt
Maximum Operating Temperature	80 ^{o}C

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