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Effect of using diesel - water emulsion as a fuel on diesel engine emissions: An experimental study

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Abstract
Diesel engines are considered one of the main sources of air pollution because of the gases emissions and particulate matter (PM), so, must be searched for a fuel helps to reduction from these harmful emissions. The aim of this research is to study the effect of using diesel-water emulsion as a fuel on diesel engine emissions. In this study, an experimental test was conducted on a single cylinder four-stroke diesel engine at constant speed (1500 rpm) and various loads (0% to 100% load) fueled with different ratios of diesel-water emulsions and compared it with the pure diesel fuel. Emulsion was prepared with proportions at 5%, 10%, 15% and 20% of the volume of water in diesel fuel; the Tween 20 and Oleic Acid were used as a surfactant to maintain the stability of emulsion fuel for long periods of time. The tests were conducted on the engine and NOX, HC, CO, and CO_2 emissions were measured by using an exhaust gas analyzer of type (AVL DIGAS 444), and smoke opacity by using a smoke meter device of type (AVL 437C). Experimental results showed that the using of diesel-water emulsion significantly reduces from the NOX and smoke emissions. From the results, it was found that the highest of reduction ratio in NOX and smoke emissions were at fuel of WD-20, where they decreased by 32.3% and 38.8% respectively, compared with pure diesel fuel.

Keywords: Diesel engine; Diesel-water emulsion; NO_X emissions; Smoke opacity; Combusition engine.

1. Introduction
Diesel engine is considered as one of the types of internal combustion engines, which depends in its work on the conversion of the potential chemical energy in fuel to the kinetic energy and uses diesel fuel in its running. The diesel engine is widely used in many applications such as transportation, industrial sector, agricultural sector and the power generation sector [1]. This is because it has a better economy in fuel consumption, higher efficiency and greater power compared to the gasoline engine [2]. But during the combustion process in a diesel engine it emit some harmful emissions like nitrogen oxides (NO_X), smoke, unburned hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2) [3]. These emissions are considered as one of the main sources of air pollution, which seriously effect on human health and environment [4]. NO_X and smoke are the most emissions of dangerous and most concern in the diesel

engine. So, must be searched for an alternative methods helps to improve performance and reduce emissions for diesel engine.

Using of diesel-water emulsion is one of the alternative methods and the most appropriate to reduction of NO_X emissions and smoke simultaneously, without any modifications to the engine [5]. When the water is added in diesel fuel and its entry into the cylinder, the water will evaporate due to high temperature, and this steam will helps to transfer part from the heat which reduces the flame temperature and thus reducing NO_X emissions and smoke [6, 7].

There are a number of previous studies had mixed the different types of fuel like biodiesel, gasoline and alcohol. [8] They carried out an experimental test to evaluate the performance of diesel engine that works with a mixture from Pongamia piñata methyl ester (PPME) at 50% and ethanol percentage is increased from 5% to 20%, thus reducing the diesel participation. The test results showed that a mixture of PPME at 50%, 15% ethanol and diesel fuel 35% reduces fuel consumption and increases thermal efficiency of the engine [9]. Experimental investigation was conducted on diesel engine at constant speed and various loads by using biodiesel, diesel and biodiesel – diesel – ethanol (diestrol) water micro emulsion as fuels. They found that the use of diestrol – water as a fuel gave a reduction in NO_X emissions and smoke compared with diesel fuel, but increases in HC, CO and CO_2 emissions compared with biodiesel [10]. They used three samples as fuels are water – butanol – diesel fuel for diesel engine operation, both of Polycyclic Aromatic Hydrocarbon (PAHs) and PM were measured. They found that when increasing the n-butanol proportion led to a reduction of PAHs and PM, but increased fuel consumption and CO emission.

On the other hand, there are many studies focused on the use of diesel-water emulsion as fuel in the diesel engine: [11**]**. Study the effect of water ratio in the diesel emulsion on the performance and emissions of diesel engine. It was found that 20-30% of the volume of water in diesel fuel is the optimum ratio to improve the performance and reduction of emissions [12]. Experimental test was carried out on a diesel engine at different speed (1000-3000 rpm) using a diesel water emulsion by a range of (5 to 30%) of water volume in diesel to evaluate the performance and emissions of the engine. The results showed that the use of diesel water emulsion as fuel improves thermal efficiency, better fuel consumption and reduces the NO_X emissions but has an increase in CO_2 emissions [13**]**. A study was conducted on the physical properties, spray behavior and combustion properties of water emulsion in diesel. Through this study, it was found that the emulsion has a little ignition delay and a decrease in soot concentration compared with those in diesel fuel [14]. An experimental investigation was performed on a single cylinder diesel engine fueled with diesel-water emulsion by 10% - 30% of the volume of water in diesel fuel. Show that when using the emulsion has the ability to improve performance and significantly reduce the NO_X and PM emissions. **[15]** They carried out the tests on a diesel engine type of agricultural tractor at various engine speed and load using water in diesel emulsion and pure diesel fuel. They found that there is a decreased in the engine torque when increasing of water volume in the emulsion this is because of the reduction of lower heating value of emulsion compared with pure diesel. They also found that the use of the emulsion gave a decrease in NO_X emissions, but increased in CO and CO_2 emissions [16]. The test was conducted to evaluate the performance and emissions of the generator of a light-duty diesel engine fueled by different ratios of diesel-water emulsion (0, 5, 10 and 15% of water content) and diesel fuel. Through the test, it was found that when using diesel-water emulsion the thermal efficiency increased by (1.2% - 19.9%) and nitric oxides (NO) emissions decreased by (18.3% - 45.4%) compared with diesel fuel.

The aim of this research is to investigation a new emulsion at proportions 5%, 10%, 15% and 20% of the volume of water in diesel fuel with the use the Tween 20 and Oleic Acid as a surfactant. The engine was run at constant speed (1500 rpm) and different loads (0, 12.5, 25, 50, 75 and 100%) by using diesel-water emulsion once and pure diesel fuel again, and the emissions results were compared between them.

2. Methology

2.1 Preparation of diesel – water emulsion

The emulsion is a mixing of two type from immiscible material, one of the two materials (represents the dispersed phase) where they spread regularly through the second material (which represents the continuous phase). The emulsifier can be usually in two forms: either oil in water or water in oil [12]. The stability requirements for emulsions is to remain stable for a specified time and under a wide range of the temperatures [17], because the emulsion when used will pass through the tubes before pumping into the combustion chamber and the unstable emulsion will begin the separation process before entering the combustion chamber [18].

In order to prepare the emulsifier used in this current study, a diesel fuel was used which has the cetane index of 48, the distilled water and the surfactant materials that has been used is (Tween 20 + Oleic Acid). First, the surfactant materials used should be mixed with each other at specific proportions (0.5% for each type) to obtain on HLB. Then blending the emulsifying materials mixture with diesel fuel at (79 – 94 %) by using mechanical mixer at 3000 rpm for 20-25 minutes, and then adding the distilled water by (0 – 20 %) to the mixture of diesel and emulsifying materials. It was added gradually with the mixing and high speed at laboratory temperature. The mechanical mixer used is shown in Figure 1.
In this study, four samples of emulsified fuels were prepared are W-D5, W-D10, W-D15 and W-D20 as shown in detail in Table 1. Before conducting the experimental investigation, the physical and chemical properties of pure diesel and the four samples of diesel-water emulsion fuel were determined. The density, viscosity and calorific value of all fuels used were determined by using devices of a hydrometer, viscometer (type - VR 3000 MYR Viscometers, models V0, V1 and V2) and calorific value analyser (type - P6310 - Bomb Calorimeter), respectively, as shown in Figure 1. The properties of the four samples of diesel-water emulsion were compared with the pure diesel fuel as shown in Table 2. It was observed that the addition of water slightly reduces the thermal value and increases the density and viscosity of the emulsion fuel compared to diesel.

Mechanical mixer Hydrometer Viscometer Clorific value analyser

Figure 1. The physical and chemical properties of fuel analyser devise.

Table 1. Percentages of the emulsified fuels samples.

Fuel Type	Diesel (%)	Water (%)	Surfactant (Tween 20) (%)	Surfactant (Oleic Acid) (%)
W-D5	94	5	0.5	0.5
W-D10	89	10	0.5	0.5
W-D15	84	15	0.5	0.5
W-D20	79	20	0.5	0.5

Table 2. Properties of diesel-water emulsion samples and diesel fuel.

Property	Diesel	W-D5	W-D10	W-D15	W-D20
Density at 20 °C (kg/m^3)	831	837	846	853	862
Kinematic Viscosity @ 40 °C (cst)	2.72	3.15	3.34	3.632	4.829
Calorific Value (MJ/kg)	42.9	41.5	40	39.2	38

2.2 experimental setup

Experiments were conducted on a single cylinder 4-stroke direct injection (DI) diesel engine, to study the effect of the using of diesel - water emulsion fuel on the diesel engine emissions. The specifications of engine used are shown in Table 3, and Figure 2 shows the schematic diagram of the test engine. The engine consists of a single cylinder DI diesel engine, water-cooled and a rope brake dynamometer, which works as a loading device. An exhaust gas analyzer device of type (AVL DIGAS 444) was used, to measure the exhaust emissions that represents of nitrogen oxides (NO_X), unburned hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO_2) as shown in Figure 3a, Also, the Smoke Meter device of type (AVL 437C) was used to measure the smoke opacity as shown in Figure 3b.

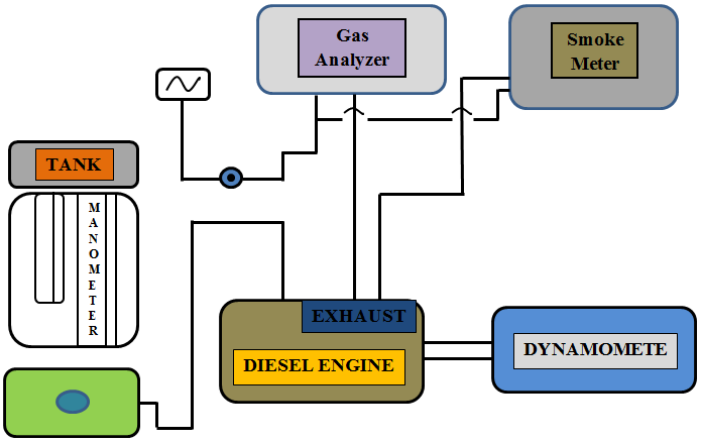

Figure 2. Schematic diagram of the Experimental Setup

(a) (b)

Figure 3. (a) AVL Gas Analyzer, (b) AVL Smoke Opacity Meter.

Table 3. Engine test spesfication

Bore	80 mm
Stroke	110 mm
Rated Power	3.7 KW (5 HP)
Engine Speed	1500 rpm
Compression Ratio	17:1
Dynamometer	rope brake dynamometer, water cooled

2.3 experimental procedure

Experiments were performed on the DI diesel engine by using a pure diesel fuel once and diesel - water emulsion fuel again, and the steps of experiments conduct can be explained in below:

1. Before starts the engine running, the input of exhaust gas analyzer (AVL DIGAS 444) as well as the smoke opacity meter (AVL 437C) have been installed with the exhaust port of the engine.
2. After that, the fuel tank is filled with diesel pure, and then operated the engine at a constant speed of 1500 rpm.
3. The engine was loaded by eddy current dynamometer through changing the loads where it was (0, 12.5%, 25%, 50%, 75% and 100% load), when the engine reaches to the stable state, each reading is recorded for every 10 ml of fuel consumption.
4. In each case of load the exhaust emissions (NOX, HC, CO and CO2) were measured by the exhaust gas analyzer (AVL DIGAS 444) as well as measuring the smoke opacity by a (AVL 437C) device.
5. The test was repeated for each case of load three times in order to obtain the optimum values for adoption in the test results.
6. After completing from the test of pure diesel the fuel tank was drained out from the remains diesel, and it is then filled with diesel-water emulsion fuel.

7. The tests were conducted again on the four samples of diesel-water emulsion fuel are (W-D5, W-D10, W-D15 and W-D20) which were prepared before the experiments start.
8. Repeated the same of previous steps that were used in diesel fuel for each sample from these four samples of emulsion fuel in terms of changing the loads from (0 to 100%) and also repeat each test for the load three times, and then recorded all data for the exhaust emissions and smoke opacity for the engine.

3. Result and discussion

Experimental test was performed on the diesel engine by using a pure diesel fuel and diesel-water emulsion fuel for four samples are W-D5, W-D10, W-D15 and W-D20. After the completing of all tests and get the final results, the engine emissions (NOX, smoke, HC, CO and CO2) were discussed for diesel-water emulsions and compared them with pure diesel fuel as shown in below:

Figure 4 shows the variation between NOX emissions of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load. The NOX emissions for all fuels used increases with the increase of load this is because when the load increases, the fuel injected mass will increase this leading to a higher flame temperature. Through the figure, it was observed that the NOX emissions for W-D5, W-D10, W-D15 and W-D20 were less compared to pure diesel fuel. This is because that when water in diesel is added, and its enters into the engine cylinder will evaporate to steam due to the high temperature inside the cylinder, this steam will helps to transfer part from the heat and thus reduce the flame temperature. Reduce the flame temperature which will lead to reduce from the formation of NOX emissions. Therefore, when increasing the water content in diesel significantly reduces from NOX emissions. It was found that the proportion of decrease in NO_X emissions for the W-D5, W-D10, W-D15 and W-D20 were 11.1%, 17.67%, 25.8% and 32.3% respectively compared with pure diesel fuel.

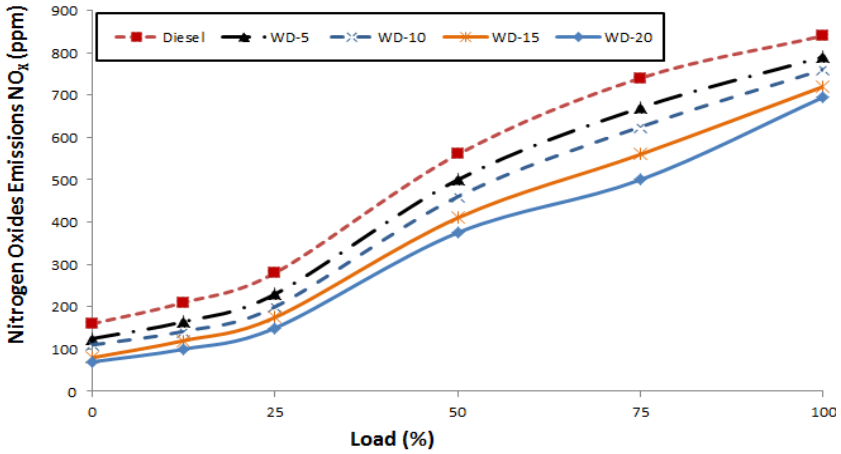

Figure 4. The NOX emissions of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load.

Figure 5 shows the smoke opacity for the fuel of diesel-water emulsions (W-D5, W-D10, W-D15, and W-D20) and pure diesel fuel versus load. The reason behind the formation of smoke opacity is the deficiency of air amount inside the engine cylinder as well as the oxygen content in the fuel, which leads to incomplete combustion and thus increases the opacity of smoke. From the figure, it was seen that the smoke opacity of W-D5, W-D10, W-D15 and W-D20 were less compared with the pure diesel fuel. The using of diesel-water emulsion significantly helps to reduce the smoke in the diesel engine, this is because the diesel-water emulsion has a large amount of oxygen, which helps to obtain a homogenous mixture inside the cylinder and this will lead to improve the combustion process and thus reducing the smoke opacity. Through the figure, it was found that the smoke opacity of W-D5, W-D10, W-D15 and W-D20 decreased by 11.6%, 22%, 30.4% and 38.8% respectively, compared with pure diesel fuel.

Figure 6 shows the HC emissions of the four samples of diesel-water emulsion (W-D5, W-D10, W-D15, W-D20) and pure diesel fuel versus load. The exhaust gases that coming out from the combustion chamber almost containing on 100 PPM of hydrocarbon. So, HC emissions are produced because fuel transmission to the exhaust without doing the work, this is a result to insufficient temperature that occurs near from cylinder wall. Through the figure, it was observed that the HC emissions in the case of fuel W-D5 was less compared with the pure diesel fuel, but in the case of W-D10, W-D15 and W-D20 the HC emissions were

higher than those in diesel fuel. This is because when the water content increases to more than 10% in diesel fuel it will significantly reduce the flame temperature, leading to increased HC emissions. From the figure, it was found that the HC emissions in the case of W-D5 was decreased by 8.3%, but in W-D10, W-D15 and W-D20 were increased by 2%, 9.3% and 12.6% respectively, compared with pure diesel fuel.

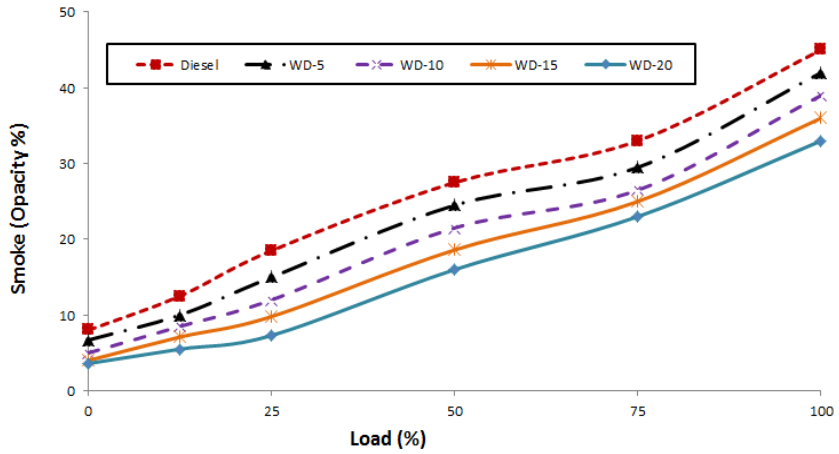

Figure 5. The smoke opacity of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load.

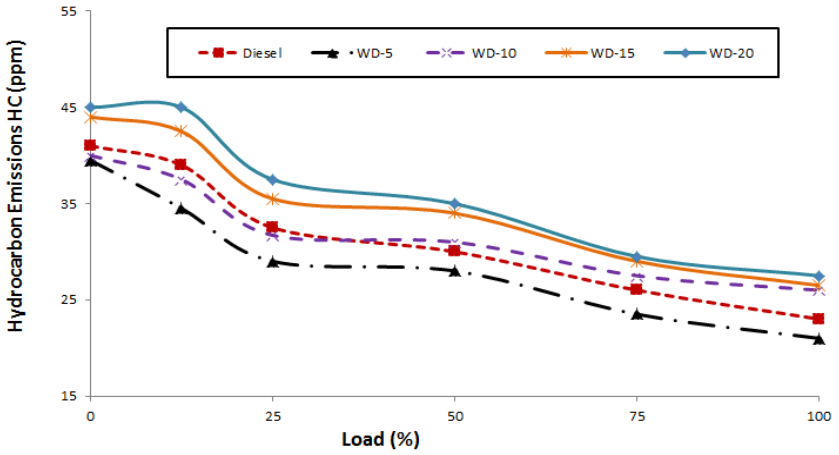

Figure 6. The HC emissions of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load.

Figure 7 shows the variation between the CO emissions for W-D5, W-D10, W-D15, W-D20 and pure diesel versus load. The main reason behind the increase in CO emissions is the incomplete combustion of fuel inside the engine cylinder. From the figure, it was observed that the CO emissions in the case of fuel W-D5 was less compared with diesel fuel, either in the case of W-D10 also was less at low loads and almost to be equal at high load compared with those in diesel fuel. But in the case of W-D15 and W-D20 the CO emissions were higher than those in diesel fuel. This is due to that the increase of water volume in the emulsion leads to a decrease the combustion temperature, resulting to incomplete combustion of carbon and oxygen under high temperatures inside engine cylinder and thus increases the CO emissions for emulsions. It was found that the CO emissions for W-D5 and W-D10 were decreased by 11% and 2.5% respectively, compared with diesel fuel but in W-D15 and W-D20 were increased by 9% and 14.4% respectively, compared with diesel fuel.

Figure 8 shows the CO_2 emissions for the four samples of diesel-water emulsions (W-D5, W-D10, W-D15 and W-D20) and pure diesel fuel versus load. The CO_2 emissions increases with engine load increased for all fuels used, this is because that the complete combustion process inside the engine cylinder leads to an increased CO_2 emissions. Therefore, through the figure it was found that the four samples for the emulsions had higher CO_2 emissions compared to pure diesel fuel. The reason behind for this increase is when addition of water to the emulsion will gives some improvements to the combustion process inside the engine cylinder. It was found that the CO_2 emissions of W-D5, W-D10, W-D15 and W-D20 increased by 4%, 8.7%, 12% and 14.3% compared with pure diesel fuel.

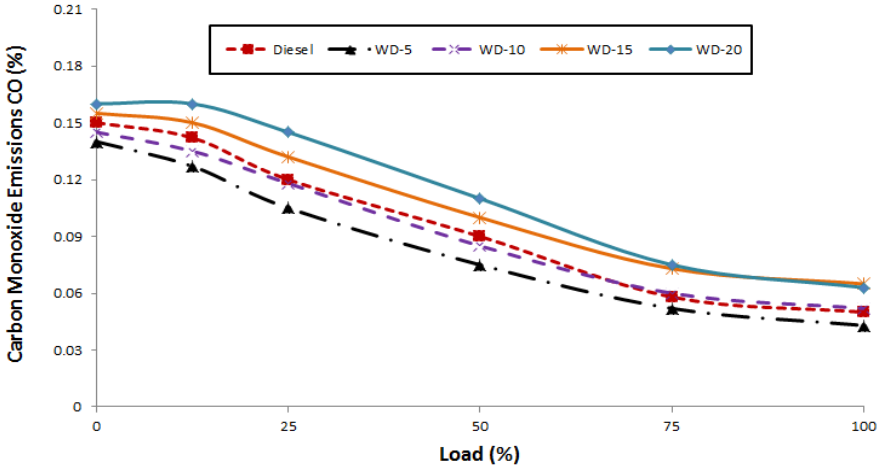

Figure 7. The CO emissions of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load.

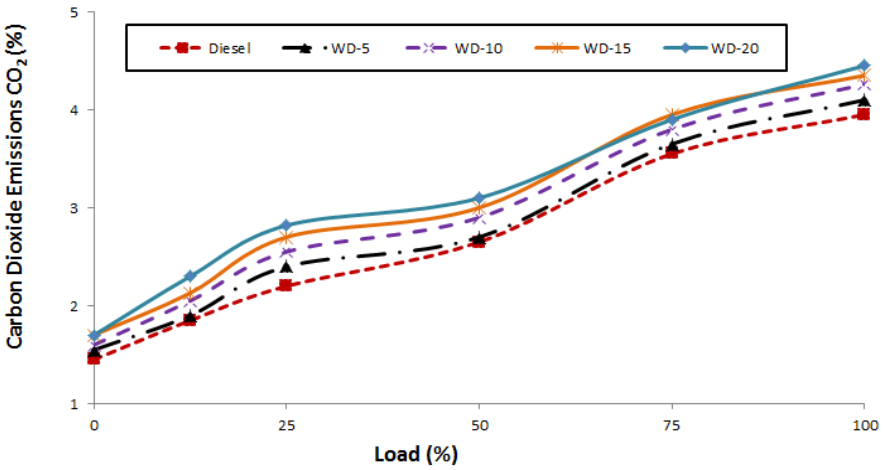

Figure 8. The CO_2 emissions of W-D5, W-D10, W-D15, W-D20 and pure diesel versus load.

4. Conclusions

An experimental study was conducted to determine the effect of water addition in diesel fuel on the emissions of single cylinder DI diesel engine. From the results; some conclusions can be extracted in the following points:

1. Reduction in NO_X emissions when using water in diesel as a fuel for the engine, NO_X emissions for W-D5, W-D10, W-D15 and W-D20 were found to be less by 11.1%, 17.67%, 25.8% and 32.3% respectively compared with pure diesel fuel.
2. It was found a decrease in the smoke opacity when adding water to the emulsion, smoke opacity of W-D5, W-D10, W-D15 and W-D20 were less by 11.6%, 22%, 30.4% and 38.8% respectively, compared with pure diesel fuel.
3. The HC emissions for W-D5 were found to be less than diesel fuel by 8.3%, but when the volume of water in the emulsifier increases at W-D10, W-D15 and W-D20 the HC emissions were higher than those in diesel fuel by 2%, 9.3% and 12.6% respectively.
4. The CO emissions in the lower proportions from water volume in the emulsion were less or almost to be equal with the diesel fuel, but when the volume of water increases (up to 10%) this led to an increase CO emissions compared with diesel fuel. This is due to incomplete combustion of carbon and oxygen under high temperatures inside the cylinder.
5. Finally, the using of diesel-water emulsion (0 - 20% of water volume in diesel) as a fuel in the diesel engine significantly helps to reducing the combustion temperature and thus reduces the NOX and smoke emissions, but there is a slightly increase in HC, CO and CO2 emissions. Therefore, the using of diesel-water emulsion is considered as an effective method to reducing NOX and smoke emissions in diesel engine without any modifications to the engine.

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