Methods of using water additive and its effect on performance and emissions of diesel engine

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ABSTRACT

Increasing greenhouse gases and harmful gases to human health has become more intense due to the increasing consumption of fossil fuel. The strict regulations on exhaust emissions from motor vehicles have encouraged researchers to improve combustion quality. Using water additive is one of the interesting ways that could reduce the emissions of diesel engine, especially nitrogen oxides emission. Water could be injected either directly into the cylinder or through the air inlet manifold, as well as it could be used in the form of emulsion with diesel fuel into the inside cylinder. Due to the water cooling property, each of these methods significantly reduces nitrogen oxides emissions. But using a water/diesel emulsion could also reduce other emissions as well as could improve the performance of the diesel engine. In this study, 3% water additive was used as additive into diesel and B5 fuels. The results showed that, the water/diesel emulsion fuel reduced the amount of unburned hydrocarbons and nitrogen oxides emissions, and also resulted in a higher brake thermal efficiency and lower brake specific fuel consumption than neat diesel.

Keywords: Water Additive; Diesel engine; Performance; Emissions, Micro-explosion phenomena.

1. INTRODUCTION

The limitation of fossil energy resource and increase of environmental pollutants are one of the main concerns of the human community. Increasing regulations relating to the production of pollutants released by vehicles, researchers in the field of fuel and motor technologies have led to find appropriate solution (Fig. 1). Due to the strict engine emission regulations, engine manufacturers have added different technologies for engine design to reduce engine emissions.

These changes consist of the use of a variable fuel injection system, variable valve timing (VVT), using exhaust catalysts, etc. On the other hands, diesel engines have been increasingly interested due to the higher thermal efficiency, higher torque, and lower emissions than spark ignition engines (Vigneswaran et al. 2018). Although these methods have produced high power, low fuel consumption as well as emissions, however they have not addressed the concerns about diminishing fossil fuels and greenhouse gases (GHG). In fact, air pollution is one of the major problems has become a major concern around the world. This problem is also very tangible in Iran. For example, in 2014, the amount of dangerous pollutants was in unhealthy conditions in Tehran for third of the year, more specifically, 85% of these pollutants belonged to the pollutants emitted from the car engines, according to the Tehran's air quality control statistics (Anonymous, 2014). One of the best solutions to solve this problem is using fuel additives. Different additives have been employed in the diesel engine for this purpose. Biodiesel is one of the most commonly used additives that many countries have employed it as a renewable and sustainable for diesel fuel.

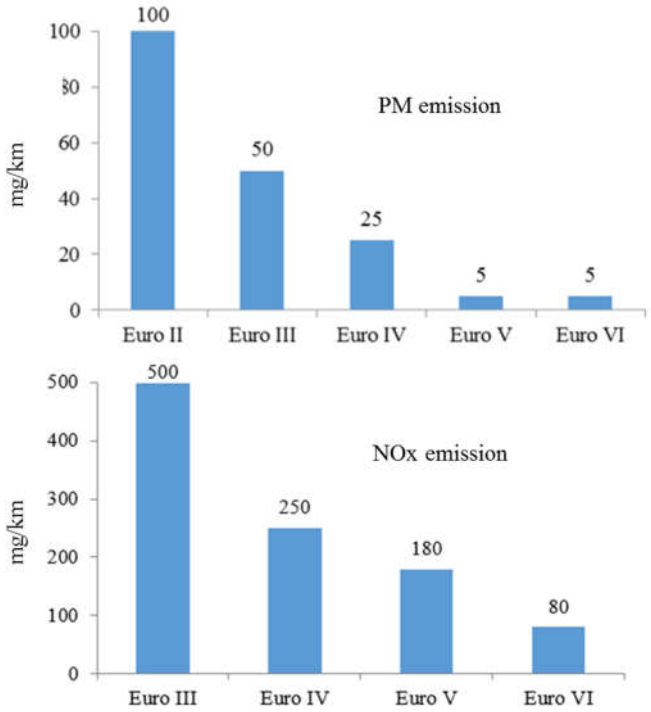

Figure 1. Maximum amount of emissions released by the diesel engine in European Standard Rules.

Investigation have proved several biodiesel benefits. For instance, biodiesel could reduce the amount of unburned hydrocarbons (HC), carbon monoxide (CO), and particle matters (PM), but increases the amount of nitrogen oxides (NOx)., There are several methods which could be used to overcome this issue however using fuel additive such as water is an interesting solution to reduce NOx emission. in addition, the results of some studies have shown that water additive inclusion into diesel fuel could also improve engine performance. Since high temperature inside cylinder during combustion is one of the main reason of increasing NOx emission, using water as additive could be an appropriate solution to reduce NOx emissions.

Survey of previous studies have showed that there are three techniques for adding water to a diesel engine as described below:

- Direct injection of water into the cylinder (DWI)

In this method, water directly injected into the cylinder chamber and sprayed water carefully controlled whenever needed (Fig. 2). This makes the DWI relatively be superior to other methods (Subramanian, 2011). However, this method has some drawbacks. For instance, in this method, the engine must be equipped with additional equipment and water spraying is performed using a separate nozzle, or the same fuel spray nozzle, and subsequently the amount and time of spraying water are controlled using an electronic system. This method increases of the price of the engine, and therefore did not achieve much success. However, in the year of 2000, a good research in this field was done by Bedford et al. (Bedford et al., 2000). This study compared the result of a computational work by numerical fluid dynamics (CFD) using the Kiva-3v code software with experimental results. The results indicated that fuel consumption, PM and NOx decreased at some loading, but NOx emission reduction was recorded in most loading states. Bedford et al. used an electronic system to control the amount and time of sprayed water (Sahin et al.,2014).

- Addition of water to the air inlet (WF)

due to the requiring advanced equipment in the DWI method, the research process propelled towards the addition of water into the air inlet called WF method. In WF, water sprayed out by a nozzle, carburetor, or by using a vaporization system into the air inlet manifold (Fig. 3). The application of this method, like the DWI method, requires to equip the engine with additional equipment. Nevertheless, the added cost is lower than DWI method and it seems to be the easier way to add water to the engine.

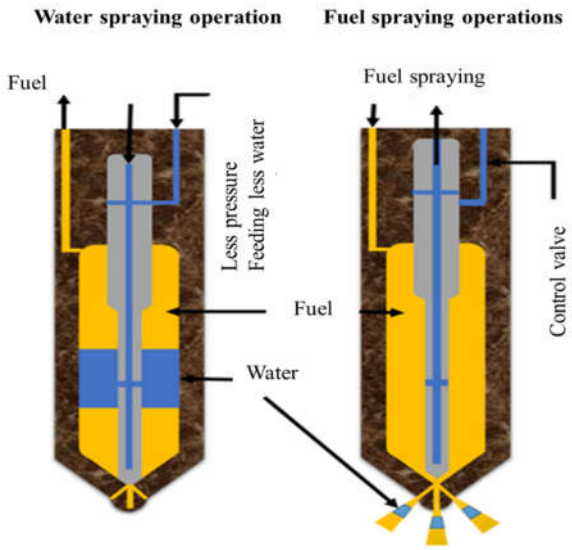

Figure 2. Direct injection of water into the combustion chamber.

Figure 3. Spraying water into the air inlet manifold.

Various strategies for spraying water into the cylinder could be found in previous studies: multi-point spraying near the air valve, single-point spraying upstream of the compressor, and downstream of the compressor. In all of these strategies, the ratio of water to fuel can be adjusted up to 50%. Some of the benefits of these methods include uniformity of the variation of the water content, increased efficiency due to the cooling effect, and the almost uniform distribution of water inside the cylinder. One of the disadvantages of this method is requiring to more water (65-60%) to reduce NOx emissions by 50%, and this is a very high amount to achieve a reasonable amount of NOx reduction (Tesfa et a., 2012; Tauzia et al., 2010). Many researchers have investigated WF techniques in their studies (Sahin et al., 2014; Tauzia et al., 2010. For instance, Tauzia et al. in 2010 investigated the effect of water spraying on combustion delays, released heat rates, and pollutants in a common-rail high speed injector. The engine was a 2-liter turbocharged diesel engine equipped with a low-pressure exhaust gas recirculation (EGR) system. In this study, the water spraying system was installed after the intercooler and just before the air inlet. They claimed that high rates of water spraying led to a delay in high peak heat, and low NOx emission, but increased the amount of CO and HC emissions (Tauzia et al., 2010).

- Water/diesel emulsion (WDE)

Among the investigated methods of water adding to diesel engine, water inclusion into diesel fuel as emulsion fuel showed could offer better efficiency overly. Because of the oil and water properties, these two materials cannot forma stable phase. To solve this problem and making stable emulsion surfactants provide a good solution for inclusion water into diesel/biodiesel blend. For example, span and tween are two most used

surfactants among between all materials which employed for fuel emulsification (Khalife et al., 2016). Each surfactant will be used for different purposes, depending on the emulsion is for dissolving water in oil or vice versa. Various emulsions which could be used in in this regard could be divided into the following methods:

- Oil in water emulsion
- Water in oil emulsion
- Emulsion of oil and water mixture in oil (oil-water in oil)

Emulsification of water in oil in the engine is more practical than other techniques. Fig. 4 shows the schematic of a two-phase and three-phase of water-oil emulsion (Lin et al., 2006). Due to the different water and oil properties, its mixture could not be easily formed in combination with surfactants until the material be mixed by using an ultrasonic bath or prob.

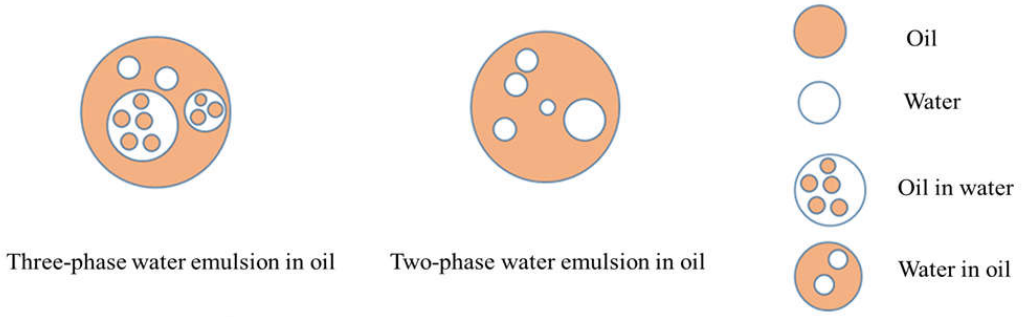

Figure 4. Different emulsions of water/oil.

However, the use of water in diesel fuel and as an emulsion has many advantages that make it superior to other methods. One of the effects of the WDE emulsion is that this compound could led to makes micro-explosion phenomena during combustion extra to the effect of its cooling property. The micro-explosion phenomenon provides faster evaporation of water particles encapsulated by biodiesel/diesel fuel particles, which causes a secondary explosion in sprayed droplets inside the cylinder chamber and consequently resulted in better air to fuel mixing (YNG ET A., 2013). A schematic illustration of the micro-explosion phenomenon that causes the disintegrating of fuel droplets, is shown in Fig. 5.

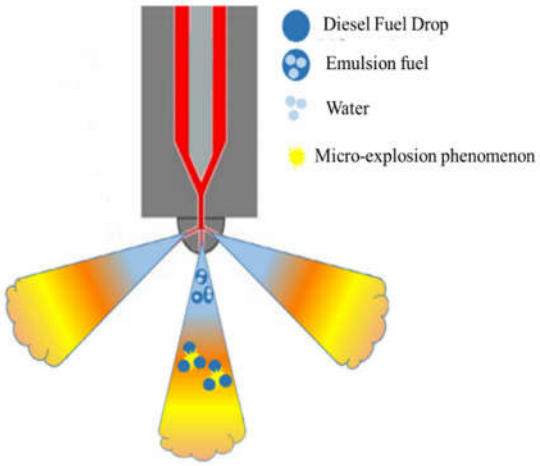

Figure 5. Schematic of the phenomenon of micro-explosion

In 2013, Koc and Abdullah conducted a study on water/diesel/biodiesel emulsion on a 4-cylinder diesel engine (Koc and Abdullah, 2013). The ratios of used water in the emulsion were 5, 10 and 15%. Their findings indicated that water/diesel/biodiesel emulsion led to lower NOx and soot emission compared to B5 and B20. Increasing the concentration of nano emulsion led to increasing brake specific fuel consumption (BSFC) and

CO emissions. The results of their research showed that by increasing the amount of water ration in the emulsion a more decrease in NOx and CO emissions was happened.

The purpose of this paper is to survey different water inclusion method into the diesel engine and study the effect of water impact of neat diesel and B5 combustion characteristics (performance and emissions) simultaneously and comparison the results with each other. The tests were carried out using a single cylinder, four stroke and direct injection diesel engine (YANMAR L48N) coupled with an eddy current dynamometer (10 kW).

2. MATERIALS AND METHODS

Biodiesel fuel was produced in the laboratory using waste cooking oil (WCO). The method used for the production of biodiesel was transesterification of methanol with potassium hydroxide. The used water additive was (3% wt), which was added to neat diesel fuels and B5. A single-cylinder, four-stroke, and direct injection diesel engine (YANMAR L48N) was employed to perform engine tests (Fig. 6). An SPTC gas analyzer was used to measure CO and HC using non-dispersive infrared gas analysis (NDIR). NOx concentration was evaluated through the exhaust manifold using the electrochemical method. The sensor of the analyzer was exposed to the exhaust gas and the observations were recorded. Engine test was performed at a constant speed (1000 rpm) and four different loads (i.e., 25, 50, 75, and 100%).

3. RESULTS AND DISCUSSION

Engine performance results are shown in Fig. 7. As shown in this figure, it is clear that biodiesel had a negative effect on engine performance and was led to reduce the brake thermal efficiency (BTE) and increased BSFC, which probably is due to the low caloric value of biodiesel fuel. The effect of adding water to neat diesel led to lower BSFC and higher BTE than neat diesel. The best performance was obtained at full load. The increase in engine performance for DW3 and neat diesel were 36 and 33%, respectively. The results showed that adding water to neat diesel fuel had better results than its addition into B5.

The results of the exhaust emissions from the engine in different loading conditions and related to the tested fuels are shown in Fig. 8. NOx emission graphs shows that the addition of water had a decreasing effect on both neat diesel and B5. The amount of NOx emissions at full load for DW3 and B5W3 was higher than neat diesel and B5, respectively. This could be due to the effect of micro-explosion on increasing the inside cylinder temperature at the maximum engine pressure and consequently increasing the amount of NOx emission (Al-Sabagh et al., 2012). The highest drop in NOx emission was at 75% load for B5W3 fuel. NOx emission amount for fuel B5W3, B5, and neat diesel were 96, 112, and 134 ppm, respectively.

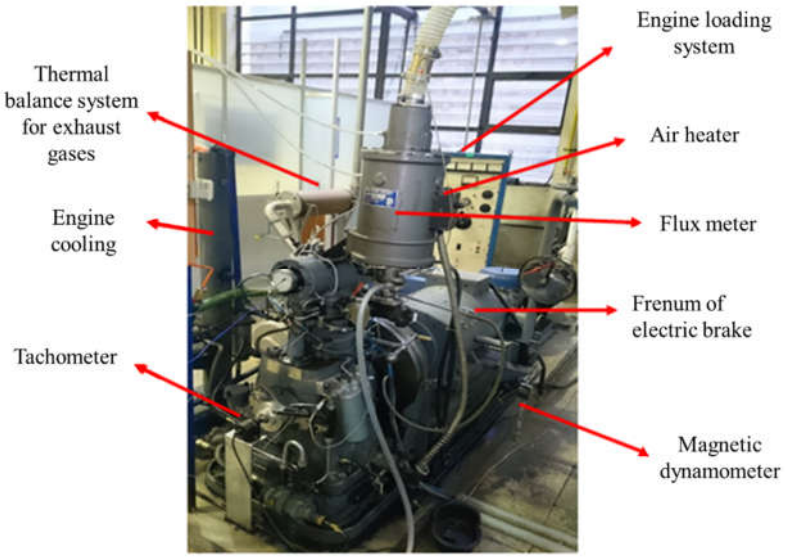

Figure 6. Ricardo E6 single cylinder motor (Gharehghani, 2015).

The results of the CO emission at 25 to 75% load showed close results for all fuel samples. But the results of CO emission at full load showed that addition of biodiesel into neat diesel fuel reduced CO emission. Decreasing effect of biodiesel on CO emission were also reported by previous researchers (Najafi, 2006; Lee et al., 2004). The result obtained that at full load, the water additive increased the amount of CO emission in cases of B5 and neat diesel fuels. The amount of CO emission increasing in the B5W3 emulsion was much higher than that of DW3.

The results of water additive effect on combustion of B5 and DW3 fuels are presented in Fig. 8 and the findings showed that water additive reduced the amount of HC emission at all loads excluding at full load for B5W3. The lowest amount of HC emission was obtained for DW3 emulsion fuel. In addition, the maximum reduction observed at 25% load, and in general, the reduction amount of HC emissions for DW3 compared to neat diesel was 30%, averagely. Improved combustion due to the better mixing of air and fuel resulting caused by micro-explosion phenomenon may be probably one of the main reasons for reducing HC emission (Khalife et al., 2017).

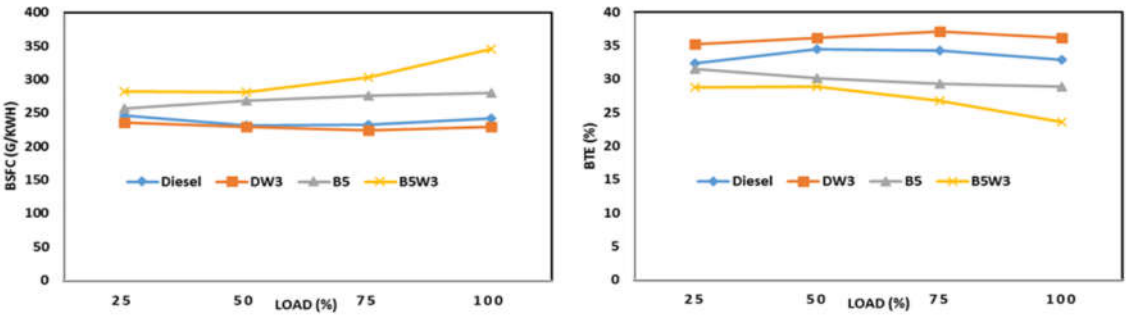

Figure 7. BSFC and BTE results at different loads.

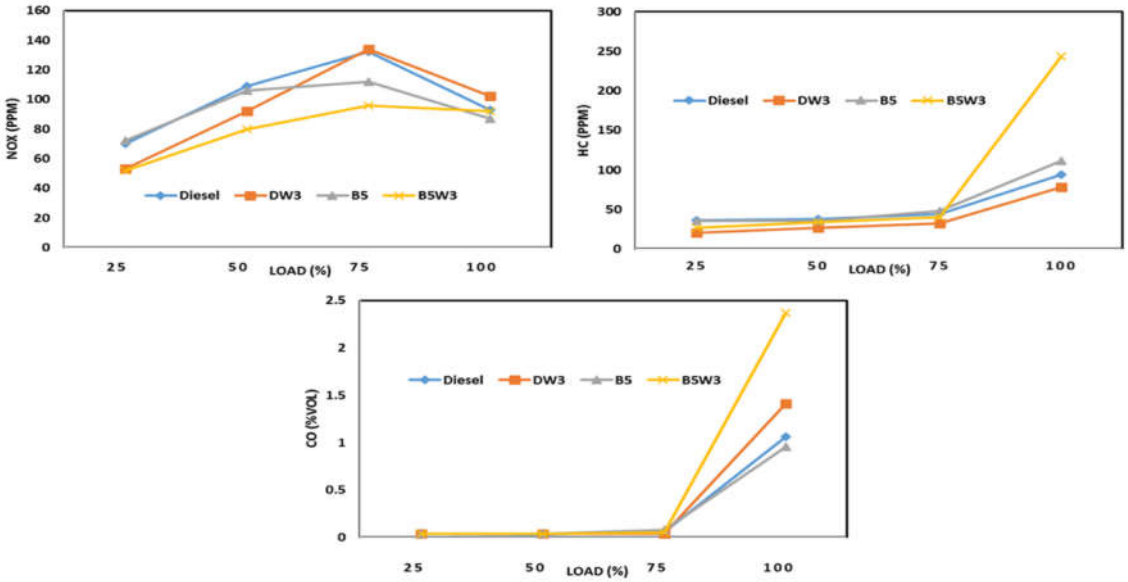

Figure 8. The results of engine exhaust emissions at different loads.

4. CONCLUSION

An experimental study was performed on a single cylinder diesel engine to study using water (3 wt%) as an additive fuel to neat diesel and B5 fuels. The result obtained showed that the inclusion of water into neat diesel resulted in improvement of BSFC and BTE values, in spite of the fact that the calorific value of the water-containing fuels were decreased. These improvements could be well attributed to the occurrence of the micro-explosion phenomenon in response to the presence of water. But, addition of water into B5 resulted in increase of BSFC and drop BTE values due to calorific value reduction. Also, the results showed that the combustion of neat diesel and B5 in the presence of water led to decreased emission of NO_x (in most conditions).

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