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Investigation of Water-Diesel Emulsion Characteristics using Optical Technique

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ABSTRACT

The idea of using water-in-Diesel (W/D) emulsion in recent studies as fuel for diesel engines is to reduce the emissions. The introduction of water into a diesel engine using W/D emulsion has a number of potential benefits and can be used as an alternative fuel. One of important factors to use this fuel was the distribution of water droplets in emulsion and emulsifier stability. In the present work, the effect of emulsifier dosage (water in diesel ratio) and heating of W/D emulsion on the stability period with using optical technique was investigated. Five samples of W/D emulsion at different emulsifier dosages (5%, 10%, 15%, 20%, and 25%) water content were studied, whereas the heating of emulsions was carried out for 40°C, 60°C, and 80°C. The results obtained from the current work manifested that an increase in water dosage to W/D emulsion had bad effects on the stability period, also, the increase in heating temperature for W/D emulsion revealed a negative effect on the emulsion stability.

Keywords: Water-diesel emulsion fuel; Optical technique; Stability of mixtures; Surfactant.

NOMENCLATURE

A_b	droplet area	d_b	droplet diameter

1. INTRODUCTION

In recent studies, the idea of using the emulsions: water in diesel or diesel in water, as fuel for diesel engines is to increase the oxygen charge in combustion mixture and reduce the emissions. Several researchers Chen and Tao (2005), Kannan and Udayakumar (2009), concluded that water-in-diesel (W/D) emulsion combinations are to reduce the emissions of NOx, CO_2 and unburned hydrocarbon (HC). Also, a research has shown that it can effectively reduce the maximum flame temperature and increase the combustion efficiency thus reduces both unburned hydrocarbon and emissions, Park *et al.* (2000), Andrea *et al.* (2003), Tauzia *et al.* (2010) and Subramanian (2011). So there are many advantages to use W/D emulsion as a fuel for diesel engines such as more complete combustion, leading to better fuel economy and cleaner burning fuels with fewer emissions. To the present date, new researches on W/D emulsion are active and even its comparative advantage to its base fuels is not widely known. Also, the unusual physical behavior of the emulsion concerning mixing and evaporation within the combustion chamber and lack of understanding of the phenomenon of combustion and the composition of soot inside the combustion chamber was one of the most important reasons to study the emulsions properties.

Several research methodologies have been used to study W/D emulsion as a fuel for diesel engine both inside and outside the engine combustion chamber. Abu Zaid (2004), Alahmer *et al.* 2010, Selim *et al.* 2001, Tanaka *et al.* (2005) and (2007) have used horizontal stainless steel and aluminum surfaces to study the evaporation of W/D emulsion by varying the surface temperature from 200 to 550°C at atmospheric pressure. While Tsue *et al.* (1996) have been used the hot surface was isolated from the atmosphere with a high pressure cylindrical chamber, this surface was made of duralumin. So the application of both suspension single droplet and hot surface as a means to examine both the microexplosion phenomena for diesel emulsion is very important to predict the air/fuel mixing process. The results might not be accurate as compares with the major assumptions. However, the empirical investigation of the effect of these phenomena in the composition of combustion and emissions within the combustion chamber remains the most difficult task.

The stabilization of the diesel emulsions are influenced significantly by the emulsification period, emulsification method, water dosage in emulsion, viscosity of diesel fuel, concentration of surfactants, and stirring speed. Chen and Tao (2005), Ghojel and Tran 2010, Armas *et al.* (2005), and Watanabe *et al.* (2009) studied the mainly affecting factors on the stabilization limits for W/D emulsion using mechanical technique, these are emulsifier dosage, stirring speed, and emulsifying temperature. They reported that the decrease in water dosage into emulsion, and the mixing period had a positive influence on stability, also an increase in stirring speed. Further, the application of ultrasonic wave vibrator to improve range of mixing period for W/D emulsion showed better engine performance with less CO emissions, which were explained by Armas *et al.* (2005). While, many studies explained testing other parameters, such as the selections of suitable values for surfactants, the choice of a suitable agitator frequency, and agitation time have also been identified as equally important parameters in the formation of stable emulsified fuels, Kadota and Yamasaki (2002), Armas *et al.* (2005). Surfactant value is the most important factor that affects the stability of an emulsion.

On the other hand, a good fuel of CI engine should hold characteristic agreement for example: short ignition, high Cetane number in order to avoid knocking, so water-in-diesel emulsion should possess most of the positive effects of diesel fuel. As this type of engine is well established, a complete alteration of fuel characteristics that requires engine retrofitting would not be feasible economically, Ghannam and Selim (2009), Ganesan (1994). Also, the mechanical and physical properties of water-in-diesel emulsions were studied: density by Ghannam and Selim (2009), Nadeem *et al.* (2011), Siegmund (1980), viscosity by Rosen (2004) and Park *et al.* (2000), bulk modulus of elasticity by Rosen (2004), and compressibility Kannan and Udayakumar (2009). In the past few years, many researchers have been interested in testing engine performance: torque, power, brake specific fuel consumption, and brake thermal efficiency by varying the volume percentage of water from 0 to 40% water/diesel ratio, Ghojel *et al.* (2006), Samec *et al.* (2000).

The literature review appeared that many works have studied the stability of water in diesel emulsion, the influence of the water concentration, mixing speed, surfactant concentration, viscosity, density and time. However, the study of many affecting factors on emulsifier has not been effectively identified; the distribution of water droplets in the emulsion (droplet size) with increasing water dosage, and the heating rate of the emulsifier and what can this parameter effect on stabilization period for W/D emulsion. Also, the effect of heating for W/D emulsion on water droplets size and emulsion stability has not been reported. Hence, in this study, the digital microscopic image processing was used to analyze the distribution of water droplets in W/D emulsion, and the effects of W/D emulsion heating on the stabilization was investigated. For that, the analysis for microscopic images of water droplets was carried out by developing a MATLAB code.

2. EXPERIMENTAL SETUP

2.1 Experiments of Water Content in Diesel (W/D)

Figure 1(a) shows a photo for the optical microscope type Meiji Techno ML2100 during tests. The W/D emulsion images were captured and recorded with 400X magnification. The image acquisition system includes optical microscope filter tray ML2100, photomicrography with 35mm digital SLR camera, camera attachment w/finder eyepieces, and integrated illuminator. The microscopic images were recorded with maximum resolution 1280*800 pixels. The water droplets in diesel emulsion prepared for the current study was observed for different periods through 90 days since it was emulsified to note its stability, as shown in Fig. 1(b). The distribution of water droplets in W/D emulsion for five samples 5%, 10%, 15%, 20%, and 25% were tested, it was noted that the larger the water content in the emulsion, the brighter and milkier the produced emulsion. Also, because the water droplets in diesel emulsion are transparent, a backlighting photography or shadowgraphys used to capture the shadow images for water droplets in diesel. The captured microscopic images are showed that the size and shape of the water droplets are always changing with volumetric percentage of water content; Fig.1(c) shows samples of microscopic images captured with the magnification percentage 400X.

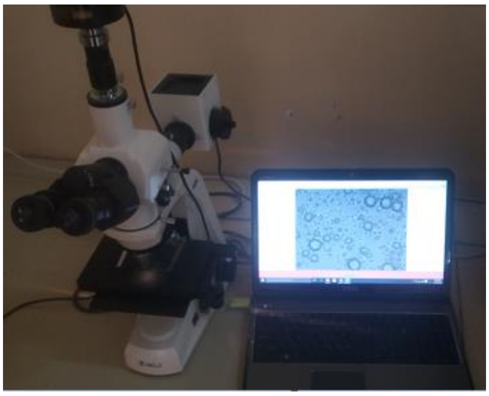
2.2 Experiments of Heating W/D Emulsion

The percentage of water in the emulsion, emulsifying temperature and operational pressure are the main parameters that affect the stability of an emulsion. The stability of W/D emulsion was investigated under the influence of emulsion heating to determine the separation time for emulsion components. The W/D emulsion prepared for the current study was observed for more than 90 days under heating for temperature range 28^{o}C to 80^{o}C, to know if it was emulsified (found to be stable for that period) or not. The 500 ml of three emulsions with water dosages 5%, 10%, and 15% were determined at temperatures ranging from 28 to 80^{o}C. A 127°C electrically heated, cleanroom cabinet oven was used for heating samples at the required temperature, into the steady state these samples were tested of periodic.

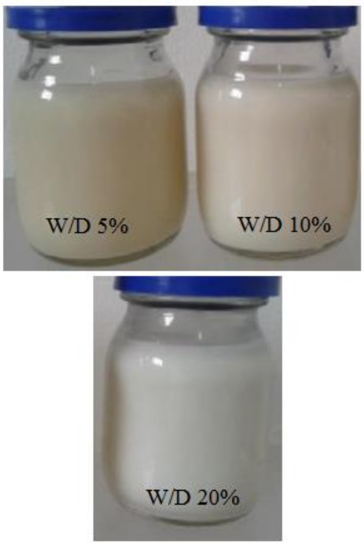
2.3 Digital Image Processing

Image processing algorithm was developed to extract information from the recorded microscopic images. The program is divided into three stages: droplet identification; and verification of droplet parameters, Fig. 2 displays a schematic of microscopic image processing used in the present work. In the first stage, image subtraction was used to reduce background noise. Therefore, a calibration image was acquired without a droplet; it was subtracted from each image to provide an image of the droplet with reduced background noise. In the second stage, each image was converted to a binary image using a threshold of around 0.7-0.85. The output image replaces all pixels in the input image with luminance greater than a threshold with the value 1 (white) and replaces all other pixels with the value 0 (black), where it was possible to suppress light structures connected to the image. In the third stage, some morphological functions were used to improve the quality of the image and the droplet shape. Finally, microscopic images with the droplet were prepared for the next step quantitative analysis such as measuring the diameter of the droplet. The droplet area (A_b) was measured by counting the number of pixels in the droplet and scaling them to physical dimensions. The diameter of the droplet (d_b) can be calculated as an equivalent diameter assuming a round droplet shape:

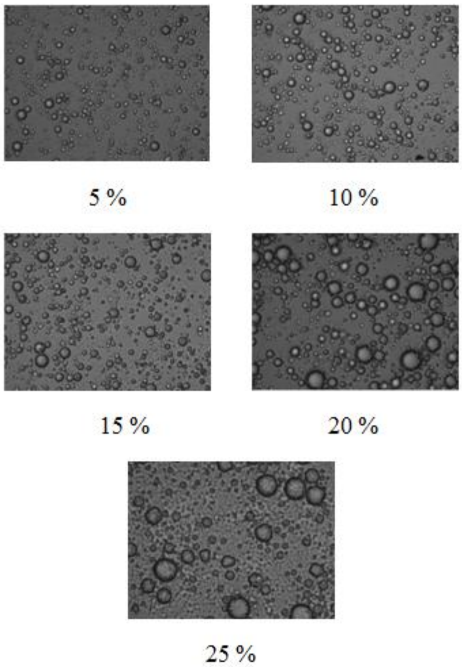
$$d_b = 2\sqrt{\frac{A_b}{\pi}} \quad (1)$$



(a) Photo for the optical microscope type Meiji Techno ML2100



(b) W/D Emulsion samples with 5%, 10%, 15%, 20%, and 25% water



(c) Samples of microscopic images captured with the magnification percentage 400X

Fig. 1. Experimental procedures and optical system.

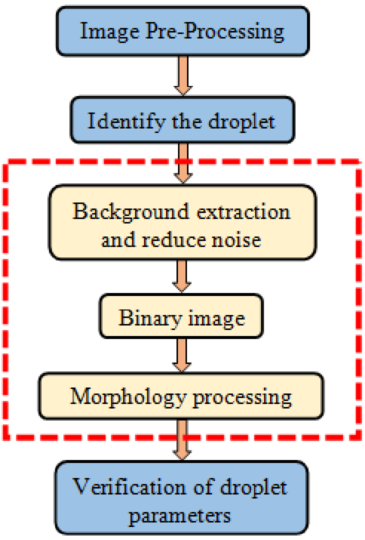


Fig. 2. Flowchart of digital microscopic image processing algorithm.

3. RESULTS AND DISCUSSION

3.1 The Effect of Water Dosage on Droplet Size Distribution

To ascertain whether the increasing of water dosage in emulsion had an effect on the number and size water droplets, the dispersed phase water droplets size distributions at different dosages from water in diesel emulsion at volumetric percentages 5%, 10%, 15%, 20%, and 25% were investigated. It can be seen in Fig. 3 that the number and size of the water

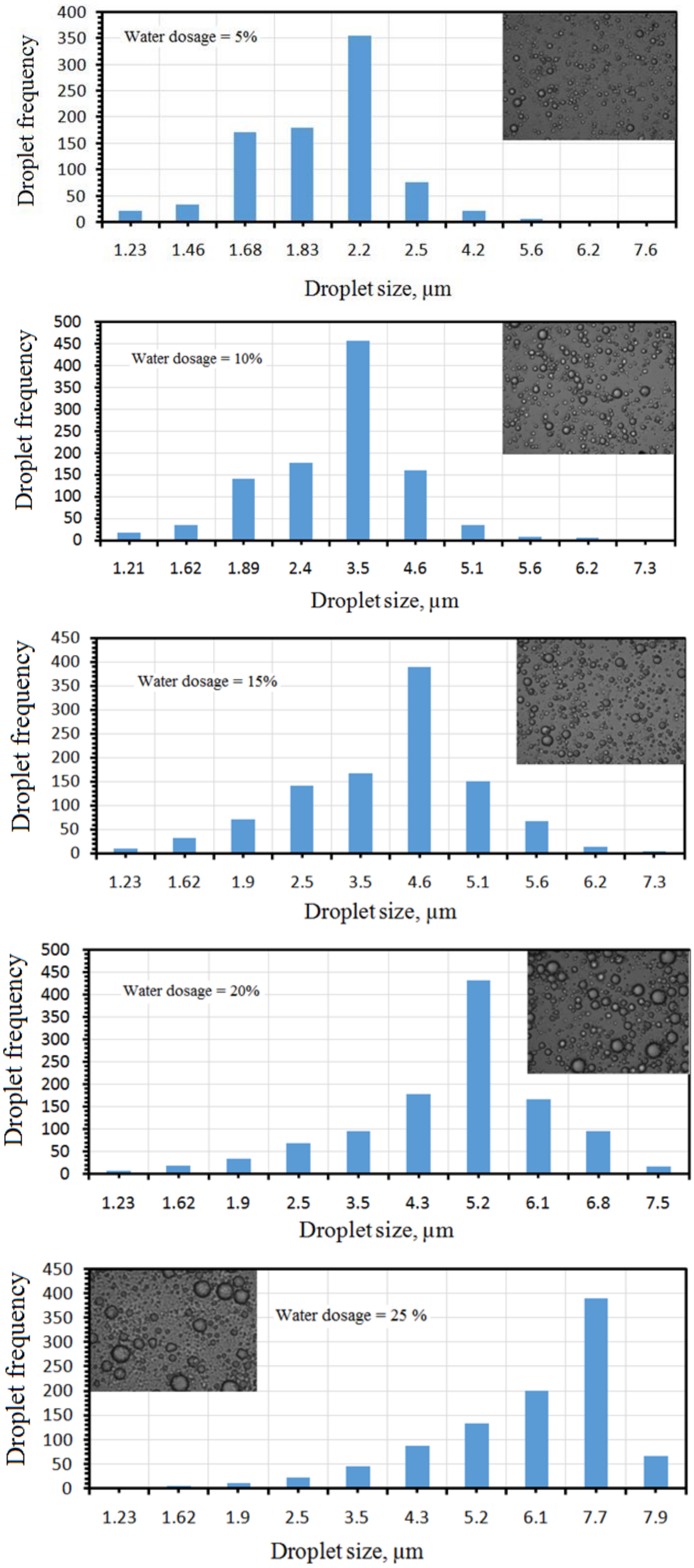


Fig. 3. Appear the histogram for the emulsions of 5%, 10%, 15%, 20%, and 25% water content.

droplets were affected significantly by increasing of water dosage, so the water droplet size was increasing with the increase in water volumetric percentage. This result is in agreement with microscopic result of emulsion for Khan *et al.* (2014). The mean diameter of water dosages: 5%, 10%, 15%, 20% and 25% were 2.2, 3.5, 4.6, 5.2 and 7.7 µm, respectively. Indeed, these tests were repeated within different periods of emulsification time (90 days). Microscopic experimental tests showed an increase in the diameter of water droplets in the emulsifier as well as the accelerated degradation with the increase water dosage for emulsion when W/D emulsion with water was 25%, as shown in Fig. 4. It can be seen that the separation limit increasing with the increase of water dosage in W/D emulsion. In another words the stability time for W/D emulsion is shortened with increase water dosage in emulsion. Therefore, it is clear from the above results that the properties of emulsion were changed by increasing the water dosage; density and viscosity affected the surface tension and thus reduced the stabilization period of emulsifier. These results are also agreement with the experimental tests for Ghannam and Selim (2009).

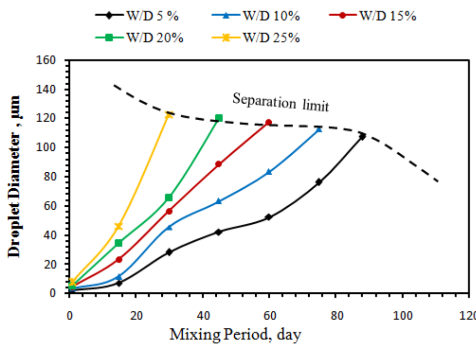


Fig .4. Represent separation limits for W/D emulsion with different water dosage.

3.2 The Effect of Emulsion Heating on Droplet Size Distribution

Concerning the W/D emulsion stability in different temperature, the influence of heating on emulsion stability with a different temperature 28°C, 40°C, 60°C, and 80°C was studied, and a microscopic images analysis was then used to compute the water separation limit for each sample 5%, 10%, and 15%, respectively. Figure 5 represents the separation limits for W/D emulsion with different temperatures from 28°C to 80°C at water dosage 5%, 10%, and 15%. From this figure, it is shown that changing surfactant due to the increase heat rate was the most important factor that affects the stability of an emulsion. In Fig. 5(a) at 5% water dosage and heat rate 28-80°C, the droplet diameter increased from 98 to 115 µm before the separation limit, while the mixing period decreased from 93 to 47 days. In Fig. 5(b) at 10% water dosage and heat rate 28-80°C, the droplet diameter increased from 110 to 123 µm before the separation limit, while the mixing period decreased from 76 to 34 days. In Fig. 5(c) at 15% water dosage and heat rate 28-80°C, the droplet diameter increased from 122 to 131 µm before the separation limit, while the mixing period decreased from 58 to 19 days. Finally, the experiments showed the increasing heating rate for the W/D emulsion resulted to reduce the stability period. Also, this is due to the water and diesel have different thermal properties: boiling temperature and evaporation rate. So the water molecules expansion during the heating stage faster than the diesel, creating acceleration towards the phase of separation.

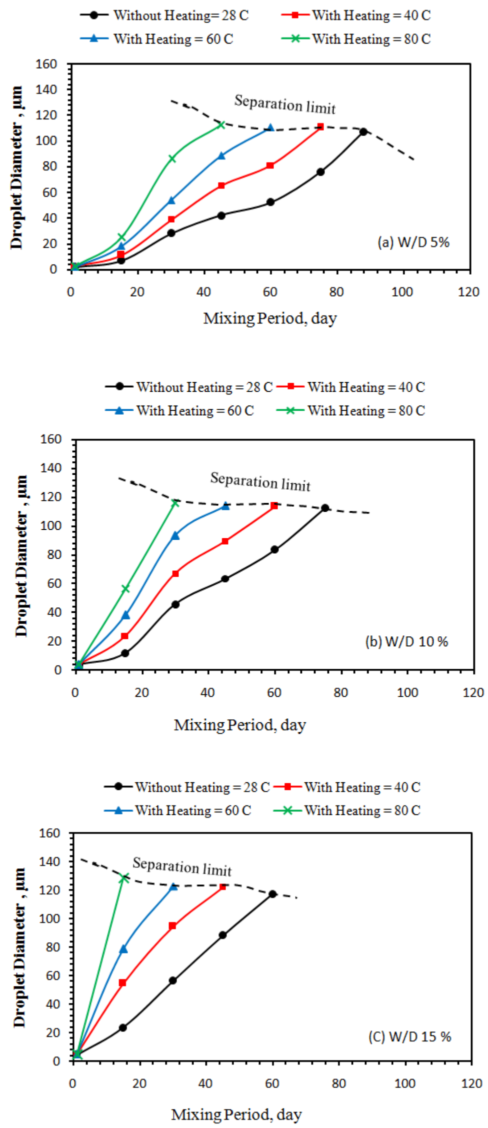


Fig. 5. Represent separation limits for W/D emulsion with different temperature 28°C to 80°C.

5. Conclusion

The most important factor in the preparation of emulsions is the selection of suitable water dosage or blend of surfactants which can satisfactorily emulsify the chosen ingredients at a specific temperature. In the present work, the effect of emulsifier dosage (water in diesel ratio) and heating of W/D emulsion on the stability period with using optical technique was studied. Five samples of W/D emulsion at a different emulsifier dosage 5%, 10%, 15%, 20%, and 25% water content were tested, while the heating for emulsion carried out at 40ºC, 60ºC, and 80ºC. The W/D emulsion prepared for the current study was observed for more than 90 days. It was noted that, the larger the amount of water content in the emulsion, the brighter milky emulsion produced. The experiments indicated that increasing the water dosage in W/D emulsion influenced negatively on the emulsion stabilization period; where it appeared that the possibility of getting stable emulsion with water dosage 25% made the stabilization period reduced to 1/4 approximately than it used to water dosage 5%. Further, it was appeared that the increase in heating rate for W/D emulsion reduced of the stabilization period for W/D emulsion.

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