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Determining Characteristics and Engine Emission of Steam Generated Water-in-Diesel Emulsion Fuel

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Abstract – *Water-in-diesel emulsion fuel (W/D) is an effective method for reducing emission of nitrogen oxides (NOx) from a diesel engine. However, the current approach of producing W/D has its disadvantages in terms of cost and complexity. Therefore, a new approach to produce W/D is developed where water is introduced in vapour state, instead of as liquid, into the fuel. This new method may simplify the emulsion production process as it requires less mechanical parts than any previous non-surfactant emulsion forming methods. The objective of this study is to determine the physical characteristics of steam generated W/D and its engine emission. The characteristics to be determined include the size distribution of water droplets as well as water content. Engine emission will be measured from a 5 kW single cylinder, direct injected, air cooled diesel engine.*

Keywords: Steam, water in diesel emulsion, non-surfactant, engine emission, physical characteristics

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1.0 INTRODUCTION

The need to conserve fuel and reduce undesirable emission has resulted in the use of water-in-oil emulsion in conventional liquid fuel combustors. It has been experimentally proven that the use of emulsion fuel has significant advantages for combustion. Aside from being a promising alternative fuel that can reduce emission of nitrogen oxides (NOx) and at the same time improve combustion efficiency of diesel engine, the use of emulsion fuel does not require any engine modification (Ithnin et al., 2014). A well-known method for producing W/D is by using surfactant, or a surface active chemical additive that lowers interfacial tension between the emulsion phases. The presence of surfactant keeps the two immiscible liquid from coagulating together and improves stability of W/D emulsion produced by mechanical agitation. This prolongs the emulsion stability for storage (Ithnin et al., 2014).

However, one major drawback of W/D is its shelf life and the additional costs on chemicals and preparation process (Ithnin, 2015). Researches aimed at overcoming such a drawback have been carried out which result in non-surfactant methods of emulsion formation. A US-based company, Nonox Ltd., has successfully implemented an ultrasonic based system for such a purpose, while in 2015, the Vehicle System Engineering lab in MJIIT-UTM Malaysia devised a system called Real Time Non-surfactant Emulsion Fuel Supply system (RTES) (Ithnin, 2015). The latter combines the use of high shear mixer and ultrasonic transducer to produce W/D in real time. This system has also succeeded in feeding a stationary (generator) engine.

The same VSE lab recently developed a new method to produce W/D by utilising steam. Through this method, water is introduced to diesel in its vapour state. Steam bubbles would undergo a phase change (condensation) and loss of sensible heat in the sub-cooled diesel stream to form fine water droplets. This steam-induced formation method has several advantages including less mechanical components, purer water phase and cooler engine temperature. A more refined water phase is obtained because the water is of distillate quality. Hence, impurities will remain in the feedstock water tank resulting in less risk of residual deposits in the combustion chamber.

The objective of this paper is to identify characteristics of the water-in-diesel emulsion fuel (W/D) namely, water droplet size distribution and water percentages and the resulting engine emission.

2.0 METHODOLOGY

The methodology section will include fuel preparation, engine performance and emission test, water droplet size and distribution as well as water percentage measurement.

2.1 Fuel Preparation

D2 was used as the base fuel. The W/D is prepared by introducing steam into D2 inside a mixing device. The steam will condense as it comes in contact with the cooler diesel and remains as tiny droplets suspended in the diesel. Eventually, condensate will accumulate at the bottom of the mixing device and be discharged from the mixer. Some of the steam will not condense and will leave the mixture as vapour. Figure 1 shows the mixing device diagram.

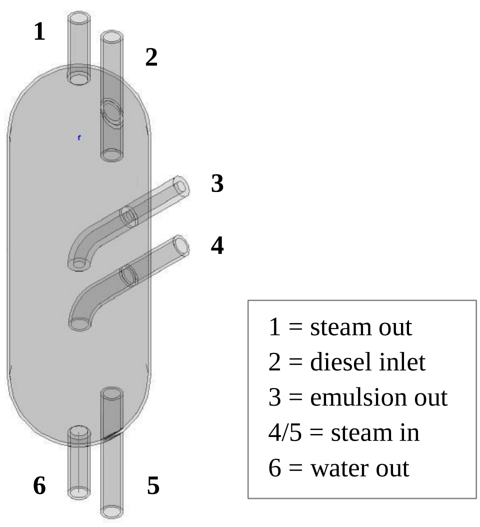

Figure 1: Diagram of mixing device

2.2 Engine Performance and Emission Test

Engine tests were performed to evaluate emission using neat D2 and W/D as fuel. Engine emission of the W/D emulsion fuel was then compared to that of the neat D2. The engine was coupled to a dyno for loading purposes. The load applied to the diesel engine by the dyno was adjusted from 1KW to 5KW while engine speed was kept constant.

The single cylinder, four-stroke, air-cooled diesel engine used in the project comes from an electric generator. It used a toroidal crown combustion system and had helical intake port. Figure 2 illustrates the emission test set up's schematic diagram. The detailed specifications of the engine are given in the Table 1.

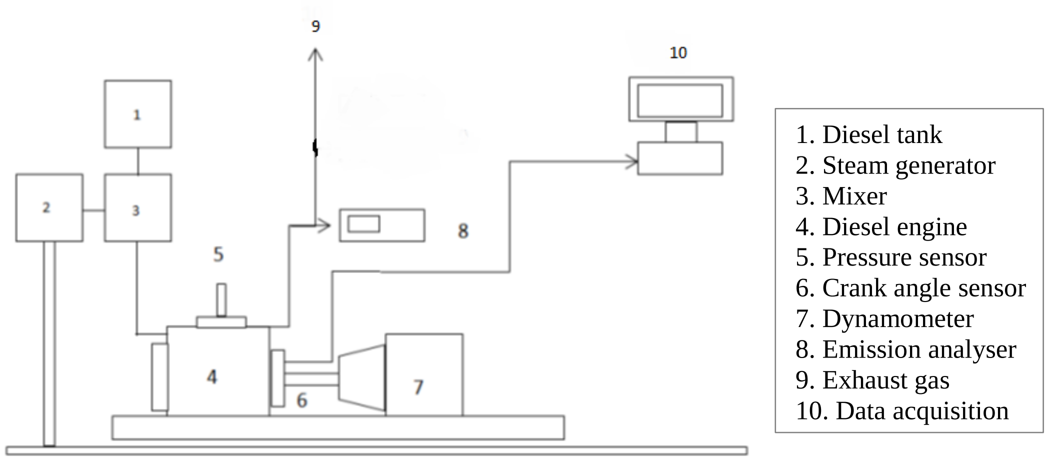

Figure 2: Schematic diagram of the emission test set up

Table 1: Engine specifications

Parameter	Specification
Engine type	4-stroke, single cylinder, air-cooled, direct injection diesel engine
Rated engine speed (RPM)	3750
Displacement volume (L)	0.406
Bore x Stroke (mm)	86 x 70
Cooling system	Forced air cooling
Maximum power (kW)	5
Fuel injection pressure (Mpa)	19.6
Fuel injection timing (bTDC)	13
Compression ratio	19.3

The emission analyser used was E-Instruments model E4500 which could read NOx, CO and CO2 emissions. The measurement was set for every 10-second interval for 5 minutes, and the average was calculated for analysis.

2.3 Water Droplet Size and Distribution

Samples from the mixing device were put under a KEYENCE VHX-200E super resolution digital microscope equipped with wide-ranged zoom lens VH- Z100R. Its lens is capable of analysing micro size objects with a magnification range from 100 to 1000 times. The microscope is connected to a PC for display and can capture real-time images and video.

To support microscope observation, a laser-diffraction particle size analyser (Shimadzu SALD 2300) was used to analyse the droplet size distribution. The SALD can examine across the broad particle concentration range of 0.1 ppm to 20%, and its measurement range covers particle sizes from 17 nm to 2,500 µm.

Blank background measurement for the sample was needed, and diesel was used as the dispersing medium in the SALD batch cell. While stirring, the emulsion sample was injected into the cell, after which the measurement could start. One of the key constants of the laser diffraction measurement method is the refractive index of water as a dispersant which is set at value of 1.35.

2.4 Water Percentage Measurement

One major disadvantage of producing steam generated W/D is that the water content cannot be easily controlled; the condensation rate of steam to water and the condensation rate constantly changes with the temperature of the diesel. To determine water percentages in samples, distillation was performed at a cut temperature of 140°C.

3.0 RESULTS AND DISCUSSION

3.1 Emission Test

As shown in Figure 3, steam generated W/D successfully lowers emission of NOx by up to 50% at 2KW load. Such reduction of NOx is caused by the lower peak flame temperature during combustion due to the presence of water in W/D. The lower combustion temperature restricts production of NOx. This claim is supported by the increase in CO and UHC measurement as shown in Figures 4 and 5, respectively. CO and UHC production increases when the combustion temperature is lower. When the temperature of combustion decreases to a temperature below 1400K, oxidation of CO to carbon dioxide (CO_2) is hindered thus the increase in CO emission level (Syu et al., 2014).

UHC is caused by fuel "avoiding" the flame zones. For example, in piston engines, some of the fuel-air mixture "hides" from the flame in the crevices provided by the piston ring grooves. Furthermore, some regions of the combustion chamber may have very weak flame, that is, they either have very fuel-lean or very fuel-rich conditions, and consequently have low combustion temperature. Therefore, when utilising W/D emulsion fuel, the flame temperature inside the cylinder decreases while increasing the amount of UHC production.

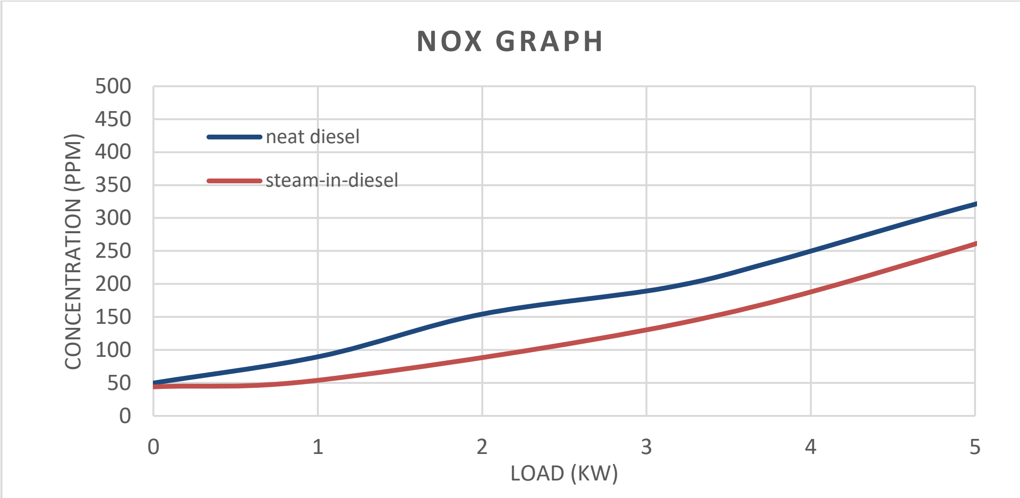

Figure 3: Graph of nitrogen oxides emission against load

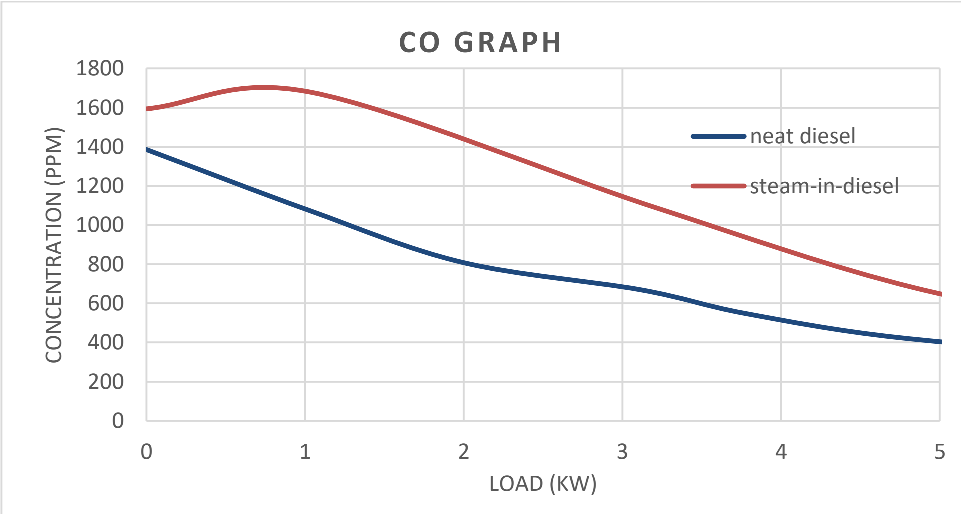

Figure 4: Graph of carbon monoxide (CO) emission against load

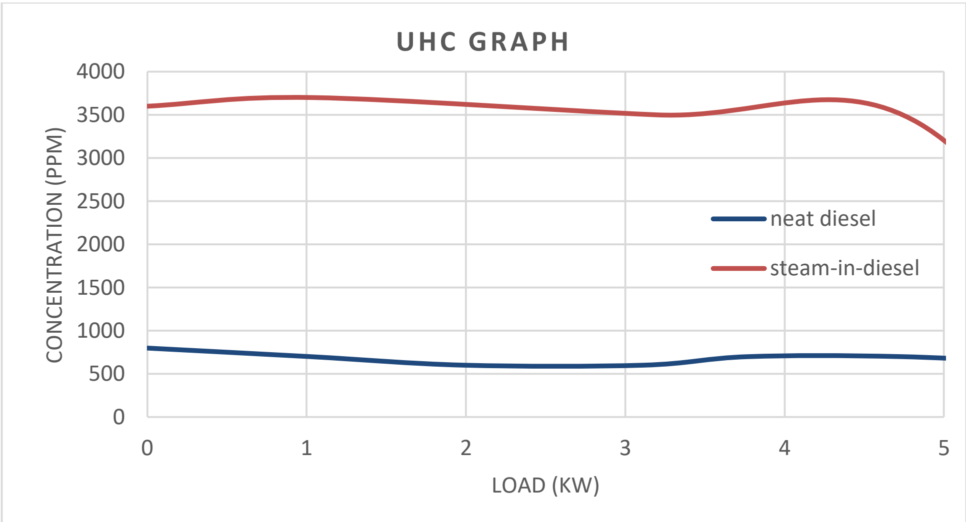

Figure 5: Graph of unburnt hydrocarbon (UHC) emission against load applied

3.2 Water Droplet Size Distribution

Droplet size distribution is measured using Shimadzu SALD 2300 Laser-Diffraction Particle Size Analyser, and in Figure 6, three plots of the resulting size distribution are produced. Batches 1, 2 and 3 are measured with the interval of 15-minutes between each graph. However, series 1 is measured 90 minutes after the emulsion is produced.

It is evident that a shift towards bigger droplet occurred, which can be explained as coagulation of the droplets as a function of time. It is also apparent that the suspended droplets retains a size in the sub-micron range after almost 2 hours after the emulsion is formed even without the presence of a surfactant.

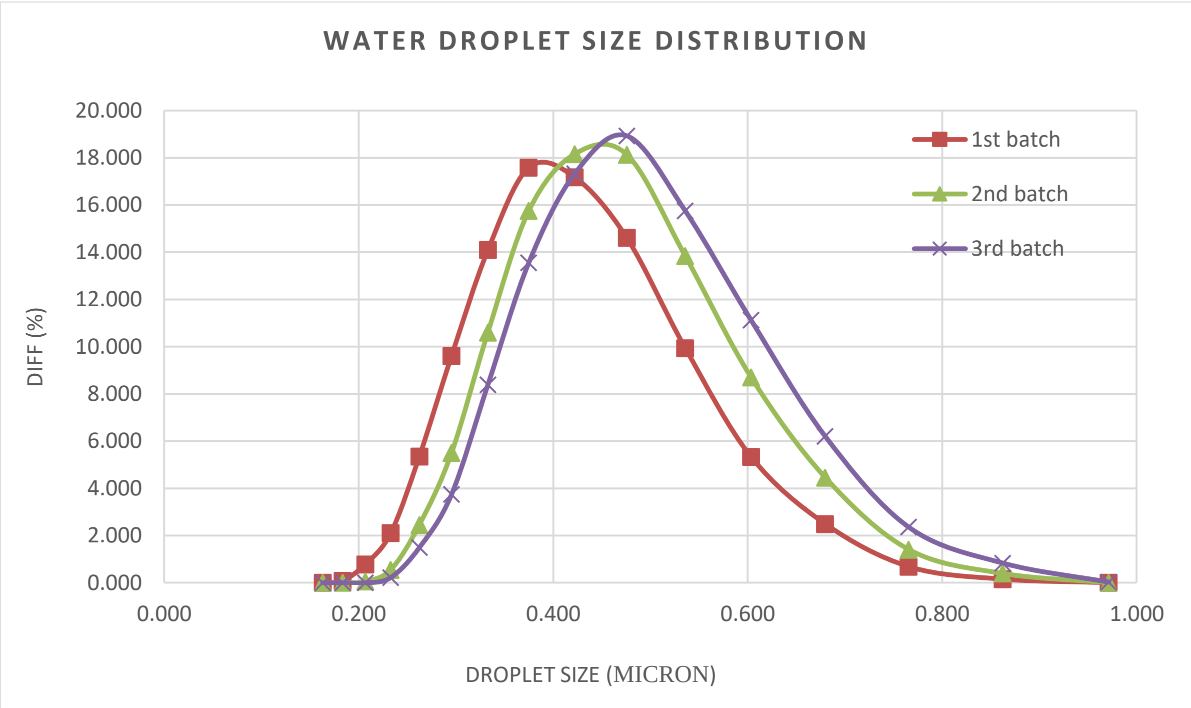

Figure 6: Water droplet size distribution of steam generated W/D

The result obtained from the Particle Size Analyser could be compared to a microscopic photograph shown in Figure 7 wherein the dark circles represent water droplets suspended in diesel. It could be visually observed that the population of sub-microns droplets are significant.

The result of this test shows the water particle produced through this method is small (in the sub-micro region) and retains that size for a long time. This may lead to a weak micro-explosion. Research shows that the optimum water droplet size for micro explosion is between 2.1µm – 4.5µm with bigger sizes rendering higher micro-explosion intensity. If the size of water particle is too small, the strength of micro-explosion is weak and leads to a weak expansion and puffing (Marrone et al., 2007).

However with certain water percentages, the droplet population will increase significantly when smaller droplets are present. Even though the micro-explosion that resulted from the small water droplet is weak, the amount of micro-explosion that occurred in total is huge. This may compensate the effects of the smaller droplet size.

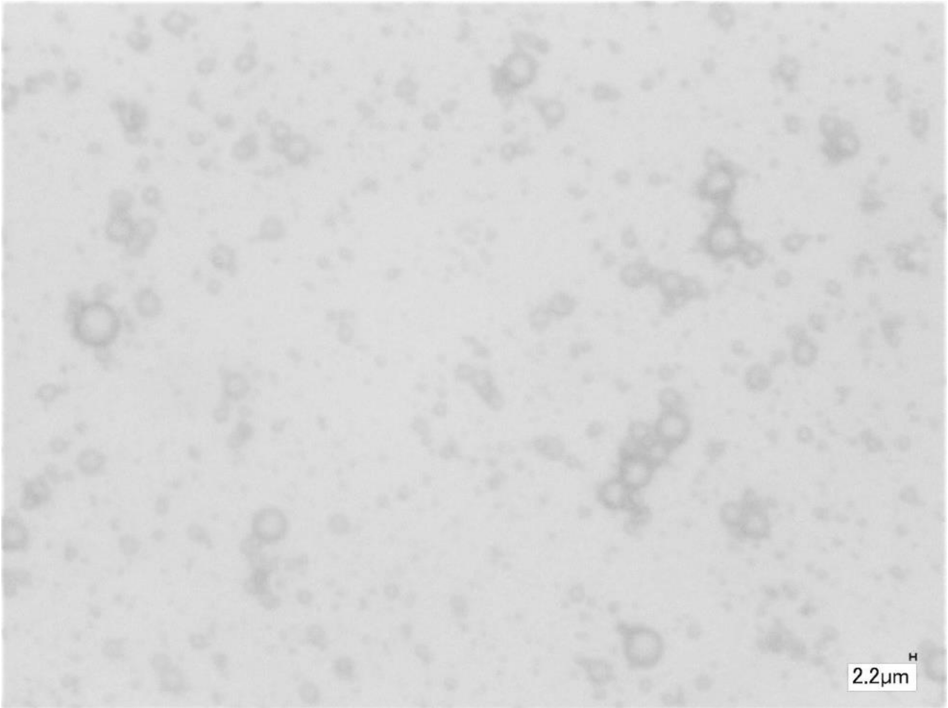

Figure 7 Microscopic images of water droplets suspended in diesel

3.3 Water Percentage

Water percentage of steam generated W/D was determined by distillation. The sample was heated to 140°C to allow water to evaporate. In this study, water percentage contained in the emulsion was found within the range of 3.2% to 6.1% of weight percentage. However, it was found that some volatile matters also evaporated. To determine the actual water content, correction should be taken into account.

4.0 CONCLUSION

Based on results of this study, it is technically feasible to produce W/D by introduction of steam. Result of emission test shows that W/D successfully reduced NOx emission. Even though the water droplet size of this fuel is small (within the sub-micron range), the large population of droplets compensate this. The water content of emulsion produced through this method is also low with a maximum of 6.1%.

Previous study has shown that the optimum water content is 8% and water content any lower than that may lead to weak micro-explosion as a result of less stored energy of nucleation. Nevertheless, in this study, the steam generated W/D still manages to reduce NOx emission.

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