



# Emulsifier-free Water-in-Diesel emulsion fuel: Its stability behaviour, engine performance and exhaust emission

Ahmad Muhsin Ithnin<sup>a,\*</sup>, Wira Jazair Yahya<sup>a</sup>, Mohamad Azrin Ahmad<sup>a</sup>, Nur Atiqah Ramlan<sup>a</sup>, Hassanuddin Abdul Kadir<sup>a</sup>, Nor Azwadi Che Sidik<sup>a</sup>, Tsuyoshi Koga<sup>b</sup>

<sup>a</sup> Advanced Vehicle System, Malaysia-Japan International Institute of Technology, Kuala Lumpur, Malaysia

<sup>b</sup> Department of Mechanical Engineering, Faculty of Engineering, Yamaguchi University, 2-16-1 Tokiwadai, Ube shi, Yamaguchi Prefecture 755-8611, Japan

## ARTICLE INFO

### Keywords:

Surfactant  
Water-in-Diesel emulsion fuel  
Stability  
Diesel engine  
Exhaust gas emission

## ABSTRACT

Water-in-Diesel emulsion fuel (W/D) is an alternative fuel which progressively intrigues the world attention due to its great impact to the environment as well as energy consumption. However, the high dependency on surfactant for the production of W/D makes it non-effective in terms of cost, and this restricts the commercialization of said fuel. This paper presents the first time ever that W/D without surfactant is being used in a conventional compression ignition engine. Diesel fuel and water, being stored in different units, are quantitatively transferred and instantaneously emulsified by a mixing system combination of high shear mixer and ultrasonic mixer before the produced emulsion fuel is transferred into the engine. The non-surfactant emulsion fuel so called unstable emulsion fuel, labelled as UW/D, is tested in a single cylinder, direct injection diesel engine. The engine is tested under four different load conditions (1 kW (25%), 2 kW (50%), 3 kW (74%), 4 kW (100%)) and with a constant speed of 3000 rpm. As for comparison, a surfactant added emulsion called as the stable emulsion (SW/D), and neat diesel fuel (D2) are also tested. 5% of water is used for both unstable emulsion and stable emulsion. The surfactant used for making the SW/D is SPAN 80 with 0.2% of volume fraction. The engine testing result showed that emulsion fuel without surfactant UW/D does give significant improvement to the engine with a 3.59% increase in brake thermal efficiency (BTE) and 3.89% reduction in brake specific fuel consumption (BSFC) as compared to diesel fuel. In addition, Nitrogen Oxides (NOx) and Particulate Matter (PM) contents in the exhaust emission reduced significantly compared to neat diesel fuel with the average reduction of 31.66% and 16.33% respectively. Overall, the concept of producing and supplying the emulsion fuel in real-time into the engine without having surfactant was proved to be working and functioning through this research while maintaining its benefits; greener exhaust emission and fuel saving.

## 1. Introduction

Water-in-Diesel emulsion fuel (W/D) is a promising alternative fuel that able to simultaneously reduce the formation of Nitrogen oxides (NOx) and Particulate Matter (PM) in a large extent and at the same time improving the combustion efficiency [1]. To date, many kinds of emulsion fuel have been tested in diesel engine and evaluated through the engine performance, combustion characteristic and exhaust emission. Attia and Kulchitskiy [2] investigated the effect of emulsion fuel structure to the diesel engine using membrane emulsification. Two different pore sizes of the membrane were tested; 0.2  $\mu\text{m}$  and 0.45  $\mu\text{m}$ , and the results reported that emulsions with large size of water droplets resulted in greater reduction in NOx emissions up to 25%. The emulsions with finer droplets reduced the engine smoke with values greater than 80% and, while increasing the engine efficiency by up to 20%.

Ithnin et al. [3] tested W/D emulsion made from low grade diesel and found that NOx and PM reduced 41% and 45% respectively as compared to diesel fuel, with the emulsion having 20% water content. Other researchers reported that the PM emission is reduced to 81% and 89% by using the W/D emulsion fuel and micro-emulsion fuel respectively [4]. Arun Kumar [5] used non-ionic surfactant with carbon black-water-diesel emulsion and found that the engine's NO emission was reduced by about 16–42% compared to diesel. Yilmaz et al. [6] prepared diesel emulsion using auxiliary emulsifier mono ethylene glycol and utilized the fuel in a turbocharged diesel engine. They remarked a 5.42% and 11.01% reduction in NOx formation when using 5% and 10% water fraction in the emulsion respectively. Hassanuddin et al. [7] investigated the durability of a diesel engine that is running on emulsion fuels with 10% and 20% water content (E10, E20). The engine was running for 200 h and the result reported that emulsion fuels produced

\* Corresponding author.

E-mail addresses: [ahmadmuhsin@utm.my](mailto:ahmadmuhsin@utm.my) (A.M. Ithnin), [wira@utm.my](mailto:wira@utm.my) (W.J. Yahya), [azwadi@utm.my](mailto:azwadi@utm.my) (N.A.C. Sidik), [koga@yamaguchi-u.ac.jp](mailto:koga@yamaguchi-u.ac.jp) (T. Koga).

less carbon deposit with 65% and 52% reduction for E10 and E20 respectively. Other than that, Dolanimi et al. [8] tested the first oil-in-water emulsion in diesel engine with three different base fuel (diesel, biodiesel and jet fuel) mixed with 30% of water and stabilized by a carboxymethylated wood lignin surfactant. They reported that biodiesel and diesel emulsion give higher mechanical efficiency at 1.26 bar and 3.26 bar brake mean effective pressure (BMEP), lower brake specific fuel consumption (BSFC) and higher brake thermal efficiency (BTE).

Other than engine testing, micro-explosion phenomena is one of the prominent research areas in emulsion fuel study that intrigues researchers worldwide, as it is non-existent in other normal diesel combustion. It is a secondary atomization of the primary spray as a result of the rapid evaporation process of water that is initially contained in the oil drop, making the combustion more efficient [9]. The micro-explosion was first discovered by Ivanov and Nevedov [10] in 1965. They reported that the suspended droplets of residual water-in-oil (W/O) emulsion underwent a spontaneous explosion during the combustion and suggested that this phenomenon be called micro-explosion. Different kinds of approaches have been explored by researchers and experts in understanding the occurrence, behaviour, and fundamentals of the micro-explosion process. Some studies use single droplet method to investigate the occurrence of the micro-explosion process [11–14] where the droplet of emulsion is put on a hot plate in which the temperature can be measured and controlled, and then the vaporization process of emulsion and the occurrence of the micro-explosion is captured by a high-speed camera and presented as a shadowgraph. Mura et al. [15] tested the strength of micro-explosion of two different size of dispersed water droplet in the emulsion; 4.7  $\mu\text{m}$  and 17.4  $\mu\text{m}$ , made from a mixture of sunflower oil, water (25–35%) and Span 83 as the surfactant and placed the aforementioned droplets on the hot surface. From their observation, the 17.4  $\mu\text{m}$  showed a less intense explosion compared to 4.7  $\mu\text{m}$ . In other respect, Sheng et al. [16] observed the micro-explosion through flame characteristic, where they reported that the flame angle of W/D emulsion fuel is much wider and the flame is much larger than that of neat diesel fuel indicating the effect of micro-explosion during the combustion of the said fuel.

Despite its great impact to the environment and energy usage, W/D emulsion fuel has a major weakness which is its stability issue that creates a huge barrier in the effort to commercialize this alternative fuel. The immiscible liquids that were previously being tied together forming one solution will separate after exceeding its stability period. In order to stabilize the mixture of oil and water, surfactant is utilized. The surfactant functions by reducing the surface tension of the water through adsorption at the liquid–gas interface, while also reducing the interfacial tension between oil and water via adsorbing process at the liquid–liquid inter phase [17]. The surfactants that are most used by researchers and experts are Sorbitanmonooleate, which is called Span 80; Polyoxyethylenonylphenyl ether, so called Span 80 and Tween 80; Octylphenoxy poly ethoxy ethanol or called Triton X-100; and Dai-ichi Kogyo Seiyaku (Solgen and Noigen TDS-30) [18,19]. The destabilization process of W/D emulsion fuel will occur after it goes through several phenomena: flocculation, followed by coalescence and the final stage is sedimentation or creaming. The flocculation process is where the droplets in the internal phase attract each other. As for the coalescence process, the combination of those droplets shall make for bigger droplet size. The sedimentation/creaming is the final stage for the destabilization process where the result of the different densities of two phases can be observed [20]. If the emulsion reaches to sedimentation stage when the engine is running, the probability of engine failure is high. Plus, it may damage the parts inside the engine. There are four types of stability; stable, mesostable, unstable, and entrained water. Usually, stable emulsion can maintain its stability for a few months [21], but it will depend on various factors, such as the type and percentage of surfactant, the temperature, viscosity, specific gravity and water content [22]. Ghannam and Selim [23] tested the stability behaviour of W/D under different water fraction and mixing condition

and reported that emulsions of 10% and 20% W/D were stabilized for 4 weeks and 10 days, respectively, under the conditions of 0.2% surfactant, 15,000 rpm of mixer speed, and 2 min of mixing time. Mesostable emulsion is where it possessed both stable and unstable emulsion. It is probably due to having less sufficient stabilizing materials than destabilizing materials [24]. As for unstable emulsion, it will decompose to oil and water rapidly after the mixing process stop. It happened if no surfactant is added into the mixture. Most of the researches conducted regarding emulsion fuel are heading towards finding the best surfactant that can maintain its stability for a very long time. In fact, some researchers have already succeeded in forming a thermodynamically stable emulsion. However, it is not cost effective since it requires a high amount of surfactant and other chemical additives, plus they need tedious processes to be completed.

W/D can possibly be made and fuelled the engine without the presences of surfactant by continuously mix diesel fuel with water through an in-line mixing system before the produced fuel is supplied into the engine. A preliminary studies on making and testing the non-surfactant emulsion fuel through the aforementioned concept have been initiated by Ithnin et al. [25–28]. The authors has conducted an initial test on destabilization period of the non-surfactant W/D with different water percentage (5% and 10%) through microscopic view and reported that the fuel destabilized and sediment within 25 s [27]. The said fuel has been tested to the single cylinder diesel engine and evaluated its performance [25] and emission [28], and the result showed promising improvement for both performance and emission especially the NO<sub>x</sub> and PM as compared to neat diesel fuel. However, through the concept, the unstable emulsion fuel (UW/D) will destabilize and change its physical properties rapidly over short period of time inside the fuel feed system, making it difficult to identify correctly what form of fuel is burned inside the combustion chamber and the range of the water droplet size during the combustion. Other than that, the UW/D will be physically slightly different as compared to the surfactant added W/D especially the droplet size of the W/D. It is crucial to compare the effect of both emulsions to the engine performance and exhaust emission. Therefore this paper aims to investigate and characterize the destabilization process of UW/D through the changes of the water droplet size over period of time and evaluate the effect of the said fuel in the diesel engine through engine performance and exhaust emission and compare with surfactant added W/D. The in-line mixing system so-called ‘Real-Time Emulsion Fuel Supply System’ (RTES) has been developed based on the aforementioned concept and it is attached close to the diesel fuel feed system of the engine. In the present experimental work, 5% of water is used to form the UW/D. As for engine testing, the stable emulsion (SW/D) and diesel D2 are used for comparison with said fuel. A single cylinder, direct injection diesel engine is tested under four different load conditions (1 kW (25%), 2 kW (50%), 3 kW (74%), 4 kW (100%)) and with a constant engine speed of 3000 rpm. In the engine performance analysis, the brake thermal efficiency and specific fuel consumption are discussed in detail. With respect to the emission characteristics, NO<sub>x</sub>, PM, CO and CO<sub>2</sub> are analysed before being further discussed.

## 2. Experimental setup and procedure

### 2.1. Fuel preparation

The UW/D is made by using the in-line mixing system called RTEs. Fig. 1 shows the overall configuration of RTEs system where the fuel from tank flows into the mixing system through the fuel channel. The water is introduced into the system through the injector which is attached to the water channel. The two immiscible liquids will first homogenized by the high shear force made by the high shear mixer in which consisting of high speed rotor and stator. The newly made emulsion will then experience vigorous ultrasonic wave made by the ultrasonic transducer before the emulsion fuel flows into the engine

Download English Version:

<https://daneshyari.com/en/article/6632353>

Download Persian Version:

<https://daneshyari.com/article/6632353>

[Daneshyari.com](https://daneshyari.com)