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Performance of Diesel Engine Equipped with Real-Time Non-Surfactant Emulsion Fuel Supply System (RTES)

W. J. Yahya, A. M. Ithnin, H. A. Kadir, N. A. Mazlan, S. A. Norazni*

Vehicle System Engineering, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia
**wira@utm.my*

Abstract – *Water-in-Diesel emulsion fuel (W/D) has been tested by many researchers around the world and reported that its potential as an alternative fuel which can give 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 the fuel. In order to remove dependency of surfactant a device called as Real-Time Non-Surfactant Emulsion Fuel Supply System or RTES that can supply an emulsion fuel without addition of surfactant has been developed. The non-surfactant emulsion fuel so called unstable emulsion fuel or UW/D made by RTES is tested in a single cylinder, direct injection diesel engine and being compared with a neat diesel fuel (D2). The engine is tested under four different load conditions and with a constant speed of 3000 rpm. The engine testing result showed that unstable emulsion fuel (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.*

Keywords: Surfactant, Water-in-Diesel Emulsion Fuel, Diesel Engine, Engine Performance

1.0 INTRODUCTION

Water-in-Diesel emulsion fuel (W/D) has been studied by many researchers as an alternative fuel since 1950`. Most of them reported that W/D is 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 of the engine[1]. A.M.Ithnin et al. [2]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 than that, Dolanimi et. al. [3] 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).

Despite its great impact to the environment and energy usage, W/D emulsion fuel has a major weakness which is its stability issue. 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

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at the liquid-gas interface, while also reducing the interfacial tension between oil and water via adsorbing process at the liquid-liquid inter phase [5]. The surfactants that are most used by researchers and experts are Sorbitanmonooleate, which is called Span 80; Polyoxyethylenenonylphenyl 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) [6,7]. Most of these surfactants are expensive and this is the main hindrance of emulsion fuel to get into the market.

In order to remove dependency on surfactant a concept that can produce emulsion fuel without surfactant has been proposed. The said concept is illustrated in Fig. 1. Through this concept, the dependency of surfactant to make emulsion can be eliminated. To date, from the enormous amount of studies regarding emulsion, none of the researchers tried to investigate the possibilities of making and testing said fuel into an engine. From that motivation, this paper aims to investigate the effects of using the unstable emulsion in a diesel engine. An in-line emulsification system so called 'Real-Time Non-Surfactant 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. As shown in Fig. 1, water and diesel fuel will be quantitatively transferred into the in-line mixing system and instantaneously transferred into the engine.

In the present experimental work, 5 % of water is used for unstable emulsion fuel (UW/D). Diesel fuel (D2) is 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.

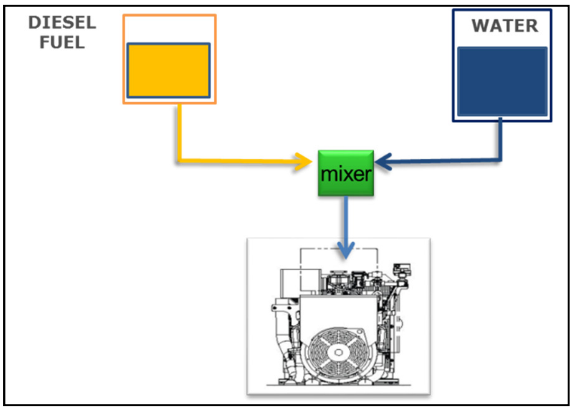

Figure1: In-line mixing system concept

2.0 DETAILS EXPERIMENTAL

2.1. Testing fuels

Testing fuel is unstable emulsion fuel (UW/D) made by RTES and for comparison neat diesel fuel (D2) has been used. Fig. 2 shows the overall configuration of RTES system where both diesel fuel

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and water are transferred into the in-line mixing system of RTES which consists of two strong mixing devices; the high shear mixer and ultrasonic horn. Both the rotor speed of the high shear mixer and ultrasonic horn are set by a controller. Water fraction is controlled by the solenoid pulse controller which is shown in the same figure. The RTES is attached close to engine's fuel feed system, as shown in Fig. 3, for instantaneous and continuous delivery of the UW/D emulsion. The water fraction that used to make UW/D is 5 %. Water percentage more than 5% will cause unstable engine combustion. As for diesel fuel, Malaysia Grade 2 diesel (D2) is utilized. The details specification of said fuel is shown in Table 1.

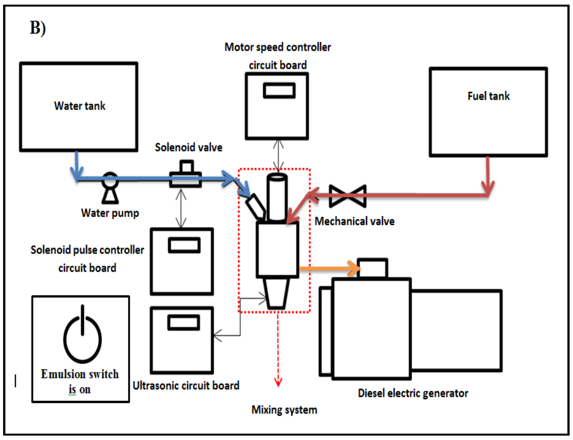

Figure 2: Overall configuration of RTES system

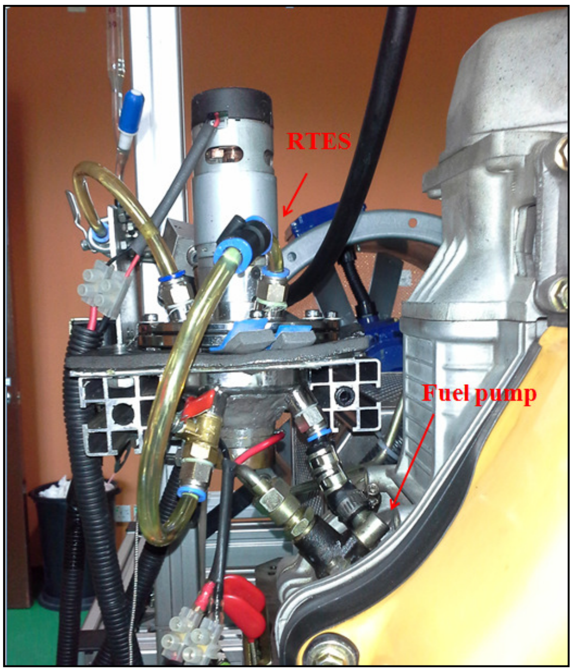

Figure 3: Location of RTES during the engine test

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Table 1: D2 fuel characteristic

Properties	Unit	D2
Calorific Value	MJ/kg	45.280
Cloud Point	°C	18
Density @ 15 °C	kg/L	0.8538
Total Sulphur	mass %	0.28
Viscosity @ 40 °C	cSt	4.642
Distillation temperature, 90% recovery	°C	367.9
Flash Point	°C	93.0
Pour Point	°C	12
Cetane Number	-	54.6
Carbon	wt %	84.1
Hydrogen	wt %	12.8
Sulphur	wt %	0.2
Nitrogen	wt %	< 0.1
Oxygen	wt %	3.9

2.2 Engine Testing Setup

The schematic diagram of the engine testing setup is shown in Fig. 4. The type of engine used in the experiment is a 0.406 L single cylinder, four stroke, air-cooled, direct injection diesel engine. The combustion system of the engine is a toroidal crown and the intake port type is helical. Other basic specifications of the engine are shown in Table 2.

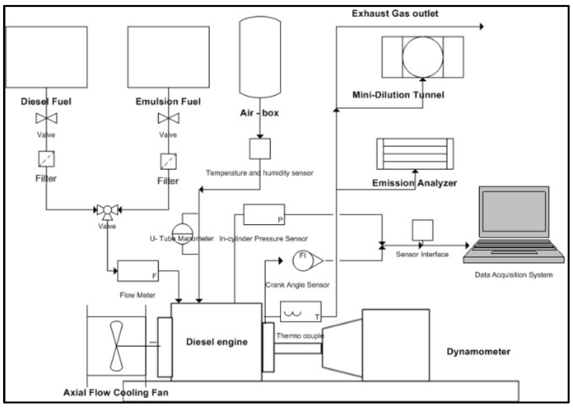

Figure 4: Engine testing setup

The aforementioned engine is coupled with an eddy current dynamometer for loading purposes. The eddy current used in the experiment is a 10kW KLAM RETARDER T10 dynamometer (dyno) which is able to sustain torque up to 25 Nm at 3700 rpm. The fuel flow into the engine is measured using the OMEGA FLR1007 flow meter sensor. Said flow meter sensor uses the Pelton-type

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turbine wheel to measure the flow rate of the liquid. It is able to measure flow rate ranging from 13 to 100 mL/min, plus with the promise of 1% flow rate accuracy and up to 0.2 % repeatability. The sensor is attached to the diesel fuel line, at the location just before the fuel enters the engine fuel pump, to measure the fuel consumption of the engine.

Table 2: Engine specification

Parameter	Specification
Engine type	Single cylinder, 4 stroke, direct injection diesel engine
Cooling system	Force air cooling by flywheel
Displacement volume (L)	0.406
Compression ratio	19.3
Bore X stroke (mm)	86 X 70
Maximum power (kW)	4.2
Rated revolution (RPM)	3100
Fuel injection pressure (Mpa)	19.6
Fuel injection timing (bTDC)	13

3.0 RESULTS AND DISCUSSION

3.1 Brake specific fuel consumption

The brake specific fuel consumption (BSFC) of the engine running with the RTES fueled by D2 and UW/D under varying engine load conditions (1-4kW) with constant speed of 3000 rpm is illustrated in Fig.5. Both fuels show the same trend in the graph: the BSFC is significantly reduced when the load is increased indicating that the engine burns the fuel efficiently at high engine load. UW/D consumed lower as compared to the D2 at average reduction of 3.89%. The reduction of BSFC in using UW/D is due to the effect of micro-explosion phenomena inside the combustion chamber that helps to increase the combustion efficiency. Tsuhara et al. [8] concluded that the reduction in BSFC may be caused by the following: (1) micro-explosion phenomena, (2) improved air-entraining in the spray due to the increased spray momentum, (3) bigger premixed combustion due to ignition delay, (4) increase in excess of air ratio due to the presence of water in the fuel, (5) reduction in combustion temperature due to the reduction of cooling loss, (6) suppression of thermal dissociation as a result of the reduction of combustion temperature, and (7) more product of combustion gas due to presence of water in the emulsion.

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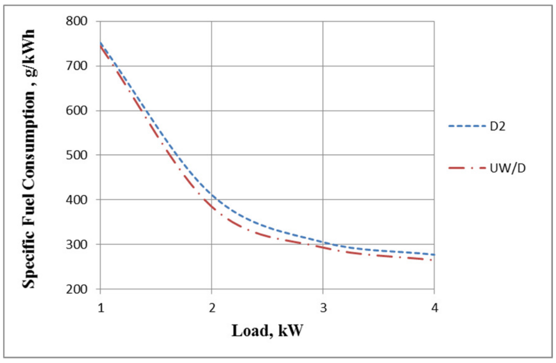

Figure 5: Brake specific fuel consumption versus engine load

3.2 Brake thermal efficiency

Fig. 6 shows the brake thermal efficiency (BTE) of each test fuel under varying engine load (1-4kW). As in the figure, both fuels show the same trend where the BTE is significantly increased as the load is increased. This is another proof that shows the engine combust efficiently at higher load condition. UW/D are found to have higher BTE as compared to D2 with an average of 3.59 %. The UW/D increased engine's thermal efficiency due to the micro-explosion phenomena. This is where rapid evaporation process of water that is initially contained in an oil drop tears up the droplet into very fine particles, which helps the mixing process of air and fuel thus escalating the combustion efficiency. Another factor is due to the longer ignition delay when using the emulsion fuel. The effect of increasing the ignition delay is that more diesel fuel can be physically prepared (evaporation and mixing process) for chemical reaction leading to an increase in the heat release rate and higher fuel burning in the pre-mixed burning. Consequently, more diesel fuel will be consumed and burned. This phenomena will lead to enhanced combustion, and, at the same time, improve the combustion efficiency [4,5]. This indicates that the concept of RTES which tries to eliminate the dependency of surfactant in the emulsion can be utilized with the improvement of BTE over the neat diesel.

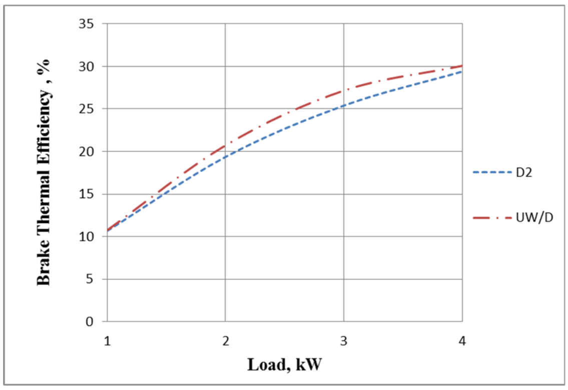

Figure 6: Brake thermal efficiency versus engine load

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4.0 CONCLUSIONS

Overall, the concept of making and supplying the emulsion fuel in real- time into the engine without using surfactant was proven to be working and functioning through this research, eliminating the stability issue and high dependency of surfactant in making the emulsion. In addition, the concept successfully maintained the emulsion fuel benefits towards the energy usage where improvement of the combustion efficiency is achieved with 3.89% reduction of BSFC and increment of 3.59% for BTE.

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