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Performance and emissions of light-duty diesel vehicle fuelled with non-surfactant low grade diesel emulsion compared with a high grade diesel in Malaysia

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ABSTRACT

The use of water-in-diesel (W/D) emulsion as a diesel substitute has imposed significant interest due to its benefits to engine performance and exhaust emissions. However, the development on emulsification technology especially without using surfactant is still not widely known. Therefore, in this study, a study into the application of non-surfactant W/D emulsion has been done with the objective to analyze the potential of non-surfactant W/D emulsion made from low grade diesel as a substitute for higher grade diesel. This study was conducted using light-duty diesel vehicle, a 1 ton truck tested in a chassis dynamometer. A variety of test fuels was used, comprises of Diesel Euro 5 (DE5), Diesel Euro 2 (DE2) and emulsion made from Diesel Euro 2 (EDE2). EDE2 was produced real time just before it is injected into the diesel engine, with water percentage of 6.5% and no additional surfactant. The testing was executed on a chassis dynamometer in accordance to the West Virginia (WVU) 5 Peak-Cycle standard. Among the data collected are fuel consumption, exhaust temperature, gas emissions (NO_x, CO and CO_2) and smoke number. The results show that the EDE2 improved the engine fuel consumption by 7.39% compared to DE5. As for exhaust emissions, EDE2 produced slightly higher NO_x and CO compared to DE5. However, CO_2 and smoke of EDE2 were found to be lower. For that reason, with some adjustments, non-surfactant W/D emulsion fuel made from low grade diesel has a potential to be applied in road transport with some adjustment in order to replace the high grade diesel.

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1. Introduction

In Malaysia, transportation sector including private cars, motorcycles, light and heavy-duty vehicles, is the most important contributor of atmospheric pollutants. With focus on light and heavy-duty vehicles, diesel engines play an important part and are the main cause of dangerous exhaust emissions like nitrogen oxides (NO_x) and particulate matter (PM). By the end of 2014, the Ministry of Transport of Malaysia reported that there were 1,224,561 diesel goods vehicles and buses registered, compared to 1,069,433 in 2011, an increase of almost 14.5% within only three years [1]. Table 1 portrayed the total number of buses and goods vehicles in Malaysia in 2011 and 2014 respectively. These types of vehicle are one of the major contributors of the severe traffic congestion in almost all parts of the highway network and corridors especially in central business areas. At the same time, the air quality in these areas worsens due to the exhaust emissions.

The implementation of higher emission standard (Euro 5 emission standard) was planned to be enforced by 2020 in Malaysia [2]. In the interest to overcome the negative impact of diesel engines on air quality, Malaysia's Department of Environment enforced a regulation designed to reduce emission from diesel engines, namely The Environment Quality (Control of Emission from Diesel Engine) Regulations 1996 [3]. The regulation concentrates on prevention by controlling vehicular emissions at the manufacturing or assembly stage. Moreover, the emissions standards in this regulation are based on the European Economic Commission on Standards. Based on this regulation, a diesel engine with a gross vehicle weight of less than 3.5 tons should comply with the standard emission of the gases pollutant.

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Table 1
Total number of buses and goods vehicles in Malaysia on 2011 and 2014 [1].

Vehicles	2011	2014
Bus	71,784	65,044
Goods vehicle	997,649	1,159,517
Total	1,069,433	1,224,561

With the intention of improving air quality by reducing diesel engine's harmful emissions, one of the approaches is the improvement of the fuel quality. For example, ultra-low sulfur diesel (ULSD) was introduced and gained enormous interest of scholars worldwide. The US Environmental Protection Agency (EPA) defined ULSD as a diesel with a maximum sulfur content of 15 ppm. As already known, the existence of sulfur in diesel fuel enhanced the formation of harmful components such as NO_x, and PM. This is due to the content of diesel which is composed of paraffin and aromatic with small amounts of organic sulfur and nitrogen compounds. During combustion, the sulfur compounds burn and form harmful sulfur oxides (SO_x) and sulfate particulates, while the nitrogen compounds are oxidized to form NO_x. In addition, US EPA reported that about 2% of the sulfur from diesel fuel also contributes to the production of PM [4]. Therefore, the efforts to reduce sulfur and other chemical compound levels in diesel fuel have high potential to reduce harmful emissions. Nonetheless, there is a disadvantage of the application of ULSD. For instance, the refining process of removing sulfur in ULSD results in a minor decrease in the energy content, which would indirectly result in reduced peak power and fuel economy. In Malaysia, the price of ULSD (known as diesel Euro 5) is around RM 0.10 higher than the low grade diesel (diesel Euro 2M) per litre at May 2016. Moreover, in order to use this type of fuel, the vehicle's engine must comply with Euro 5 grade diesel fuel, which are mostly vehicles manufactured as early as 2007. The engine, along with the exhaust system, must be designed to meet the newer emission standard. In other words, if the engine is originally designed to meet the older emission standard, the diesel Euro 5 might not be compatible. Therefore, the engines need to be modified in order to adopt the new standard, and this will bear additional costs. Also, ULSD contains reduced levels of lubricity which is caused by the refining process. This leads to the premature failure of wear-prone fuel system components, such as fuel pumps and injectors [5].

In contrast, currently, most Malaysian diesel consumers still use low grade diesel, also known as diesel Euro 2M, since this country still implements its own emission standard labeled as Euro 4M. Nevertheless, since last two years, diesel Euro 5 has been introduced to the market by some of the oil and gas companies. As mentioned previously, the main feature of diesel Euro 5 is that it is a codename of ULSD, a cleaner fuel as it contains lower sulfur compared to diesel Euro 2M [4]. Other than ULSD, some other emission control strategies emerge which originated from combustion optimization approach and, usage of exhaust after-treatment technologies [6]. Combustion optimization can be achieved by controlling the fuel injection, in terms of raising injection pressures, retarding the injection timing, introducing multiple injection events per combustion cycle, and also by adjusting spray patterns. The exhaust after-treatment technologies, on the other hand, were specifically developed for new diesel engines. Some of the examples of after-treatment technologies are diesel particulate filter (DPF), exhaust gas recirculation (EGR), selective catalyst recirculation (SCR), lean NO_x trap (LNT), diesel oxidation catalyst (DOC), etc. However, these methods also present weaknesses, such as decrease in engine performance, increase in other types of emission, as well as increased costs [7–9].

There are alternative ways which does not require any engine modification, but still can improve engine performance and at the same time preserve the environment. Water-in-diesel (W/D) emulsion fuel is one of the potential alternative fuels, that becomes popular among researchers, since it can provide a solution to the world's needs to reduce NO_x and PM emissions, while at the same time improving combustion efficiency [10–13]. It is attributed to its most popular aspect of the micro-explosion phenomenon [14]. Then again, the main issue of W/D emulsion fuel is its stability, which is why surfactant is used. It can boost its stability to up to 3 months [15], depending on the temperature, the amount of surfactant, its viscosity, specific gravity and water content [16]. If W/D emulsion fuel is destabilized during storage or engine operation, this may cause engine failure.

In large scale commercialization, the utilization of W/D emulsion fuel with the addition of surfactant is not cost effective since the cost of surfactant and the emulsion preparation is quite expensive. Therefore, a novel method of supplying non-surfactant W/D emulsion is suggested by previous study [17]. The concept, namely Real Time Non-Surfactant Emulsion Fuel Supply System (RTES), focuses mainly on producing W/D emulsion, by continuously mixing diesel with water in an in-line mixing system and promptly supplies it to the engine. With this concept, the dependency on surfactant to create emulsion with long stability is eliminated.

Up to this time, there is no other research which performs on-road engine testing, using non-surfactant W/D emulsion. Most research conducts experiments using emulsion with the presence of surfactant in order to stabilize the mixture of diesel and water in the running engine. For example, Hall et al. [18] ran the diesel/water emulsion fuel on a heavy-duty bus engine installed on a test bench and a chassis dynamometer. This test focused on the emission measurement which is influence of the emulsion on the particle size distribution, the effects of after-treatment and lubrication on the emissions' particle size and the influence of sampling methods. Also, most of other studies performed tests on the effect of W/D emulsion usage in a steady state condition [19–24]. However, in U.S., the concept of W/D emulsion has been applied on trucks. The application of W/D emulsion with a water percentage of 25% was demonstrated. It was proven that this system can save fuel costs up to 20% and simultaneously reduce the NO_x and PM emissions up to 55% and 80% respectively. Still, the use or absence of surfactant in this device was not clearly stated.

Therefore, in this study, the concept of RTES is applied to on-road transport, and the aim is to evaluate the efficiency of using RTES under a real driving cycle, and to predict the potential of W/D emulsion from low grade diesel (Euro 2) as a substitute of ULSD (Euro 5). In this context, the work was performed to estimate the effects of using two types of diesel fuel and emulsion from low grade diesel, and to look into the fuel consumption and gases emissions. The study was executed using a 1 ton truck on a chassis dynamometer.

This study should contribute to a better characterization of the fuel consumption and exhaust emission of vehicle using W/D emulsions from low grade diesel produced by RTES. It is relevant to note in the extent performed literature research, that there is no previous experimental data available which compares transient emissions higher grade diesel and W/D emulsion made from low grade diesel fuel. Hence, the present study is valuable to fill the research gap. Furthermore, this paper could assist local policy maker in Malaysia in important decisions about the emissions and fuel consumption of diesel vehicles operating with non-surfactant W/D emulsion.

2. Test procedure

2.1. Test vehicle

A 1 ton Isuzu NHR truck was used for this study as test vehicle. This vehicle has a four stroke and four cylinders engine and is

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