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Performance and Emissions of Diesel Engine Fuelled with Water-in-Diesel Emulsion

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Abstract – *Power generation using combustion engine cause severe air pollution. Research for a high efficient engine with less harmful emission is highly demanded. Water-in-Diesel (W/D) emulsion has a potential to reduce fuel consumption and harmful exhaust emission, especially nitrogen oxides (NO_X) and particulate matter (PM). Experimental study was conducted by operating single cylinder MR MARK MC-D6500E diesel generator at different loading conditions while using two types of W/D emulsion containing different water contents (10 and 20 vol.%) with 1 (one) vol.% of surfactant (span 80) as additive to stabilize the fuel. The effect of water on fuel consumption, exhaust temperature and emission has been studied and the results have been compared to conventional diesel fuel. The result showed NOx and PM were reduced up to 51% and 14% respectively by using W/D emulsion. Fuel consumption also was up to 10% improved by using W/D emulsion.*

Keywords: Diesel engine, emulsion fuel, particulate matter, nitrogen oxides

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1.0 INTRODUCTION

The world is currently facing environmental problems such as exhaustion of petroleum, global warming, climate change and air pollution. It is inevitable to start reducing fuel consumption and emission gas. Compression ignition engine, which is diesel engine, has the highest efficiency compared to other internal combustion engines. However, diesel engine generates a lot more undesirable emissions such as nitrogen oxides (NO_X) and particulate matter (PM) during combustion. The emissions have a bad impact not only on our health but also our ecosystem. It is proven to trigger fatal illnesses such as lung cancer, asthma, and cardiovascular issues.

The reduction of both NO_X and PM are normally cannot be achieved due to the contradictory mechanism of their formation in the combustion chamber of a diesel engine (Hasannuddin et al., 2014). The reduction of NO_X is achieved by a low combustion flame temperature. On the other hand, PM can be reduced by inhibiting their formation through better mixing of the fuel and improving their oxidation by increasing the combustion temperature. Thus, the balance between NO_X and PM must be considered in trying to reduce those emissions simultaneously. Diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs) is currently used to mitigate PM as an after treatment system. DOCs have potential to reduce the PM by up to 25% and they are widely used due to relatively cheaper than its rivals or alternatives, as well as being robust. DPFs on the other hand, can reduce PM by up to 90%. However, they can only be used under higher engine exhaust temperatures with low sulphur oil. Additionally, their costs are three times more expensive than DOCs.

The introduction of water into diesel engine is a method that can reduce the formation of NO_X and PM emissions simultaneously (Ahmad et al., 2014). There are three common methods to introduce water into the diesel engine: spraying water into the intake manifold which is called the intake manifold fumigation; water injection into the combustion chamber which is called direct water injection method; and Water-in-Diesel (W/D) emulsion. All of the methods can reduce both NO_X and PM simultaneously. However, intake manifold fumigation and direct water injection tends to be in direct contact with the fuel feed system and cylinder piston group when the water is introduced into the combustion chamber, thus leading to oil contamination and increasing wear.

In addition, both methods require essential modification to the engine in order to integrate the water addition device onto it. Thus, it requires high additional cost. W/D emulsion is the promising alternative fuel that can reduce NO_X and PM emission simultaneously while at the same time improves combustion efficiency. This is due to micro explosion phenomena which is a special occurrence that intrigues researchers worldwide as it is nonexistent in the normal diesel combustion process in a diesel engine. Micro explosion is the secondary atomization after the initial spray because of the rapid evaporation process of water that is initially contained in an oil drop, tearing up the droplet into very fine particles, more surface area of the fine droplets can be exposed to the air leading to an improvement in the fuel and air mixing process.

As a result, the combustion efficiency will increase. In addition to reduce the harmful emissions, emulsion can be utilized without any modification. W/D emulsion is a mixture of two immiscible liquid that consists of water and diesel fuel. W/D emulsion is formed with the help of mechanical agitation together with the chemical additives so called surfactant to keep the immiscible liquids being tied together forming one solution. The objective of this research is to evaluate the W/D emulsion at two different water concentrations using single cylinder diesel engine generator and determine the engine performance and exhaust emission.

2.0 METHODOLOGY

A four stroke single cylinder engine was employed in the experiment. The combustion system of the engine is toroidal crown and intake port type is helical. The other specifications of the engine are shown in Table 1. The schematic of engine testing setup is shown in Figure 1, which consists of emission analyser, voltage regulator, and mini-dilution tunnel. Mini-Dilution tunnel was employed for sampling particular emissions. Exhaust gas was diluted by clean air that was heated up to 50℃ at dilution rate of 10. Dilution ratio was controlled by the amount of CO_2 between inside exhaust gas and inside dilution channel. CO_2 was measured with nondispersive infrared analyser NDIR (HORIBA VIA-510). This diluted gas was absorbed with uniform velocity by diaphragm pump, and particulate was trapped with Teflon filter (MILLIPORE FHLP04700, diameter 47mm, orifice 0.47μm). The testing method is based on the SAE standard for engine testing as the guideline.

Table 1: Engine specifications

Engine Type	MR MARK MC-D6500E 4-stroke, single cylinder, air-cooled, direct injection diesel engine
Continuous Power [kW]	5.0
Max. Power [kW]	5.5
Bore x Stroke [mm]	86 x72
Displacement [L]	0.418
Rated Revolution [RPM]	3000

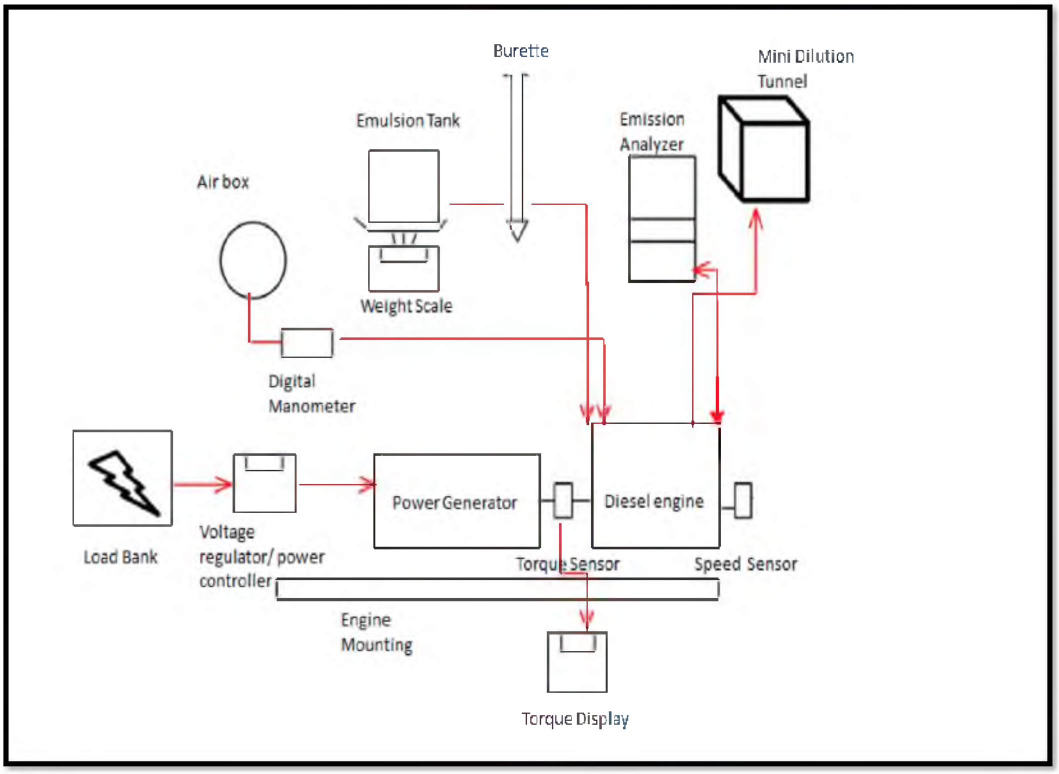

Figure 1: The schematic of engine testing setup

The engine generator is loaded by spotlight lamp from 1kW up to 5kW respectively which is controlled by a voltage regulator. Exhaust gases emission which is carbon monoxide (CO) and nitrogen oxides (NO_X) are measured by TESTO 350 emission analyser. The analyser is equipped inside the exhaust tail pipe of the engine. Table 2 shows the specification of the formation of emulsion fuel. Span 80 is used as emulsifier to stabilize emulsion fuel. Span 80 is the most effective surfactant while the optimum mixing condition to produce W/D emulsion fuels is approximately 5 minutes with the mixing speed of 2500rpm.

Table 2: Fuel specification

Fuel	Diesel [%]	Water [%]	Surfactant (span 80) [%]	Mixing Time [min]	Mixing Speed [rpm]
Diesel	100	0	0	0	0
E 10	89	10	1	5	2500
E 20	79	20	1	5	2500

3.0 RESULTS AND DISCUSSION

This study has attempted to use W/D emulsion with higher percentage of water content such as 30% and 40%. However, W/D emulsion with water content higher than 20% gives unstable running condition of diesel engine due to misfiring. Therefore, only W/D emulsion with 10% and 20% water content have been used in this experiment. Figure 2 shows the amount of PM with load using different fuel. From the graph, PM is approximately reduced from 6.5% up to 14% by using W/D emulsion. Additionally, as the percentage of water in W/D emulsion increases, the amount of emitted PM decreases. The formation of PM is reduced when using W/D emulsion due to the increase of OH radical with the addition of water. Others considered the occurrence of micro-explosions for water droplets of this small size and attributed the soot reduction to heat extraction by the droplets, decreasing the rate of pyrolysis reactions, and to the enhanced oxidation of soot by the additional OH radicals.

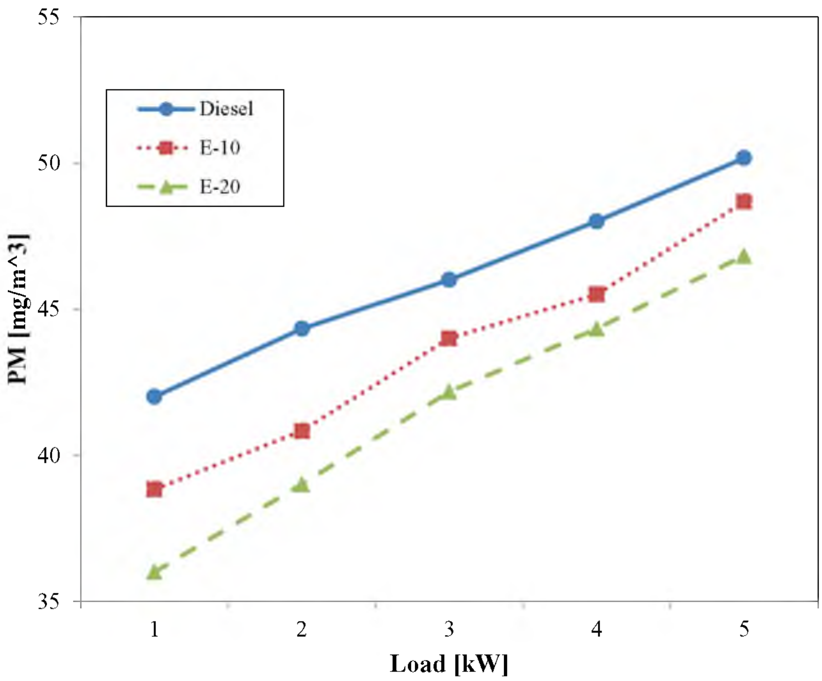

Figure 2: PM measurement for different fuel at varying load conditions

Figure 3 shows the exhaust temperature using different fuel at different load conditions. The results show the exhaust temperature to be decreasing when the percentage of water in the emulsion increases. The decrease in exhaust gas is caused by heat sink phenomenon. The phenomenon is caused by dispersed water droplets due to rapid evaporation of water. When heat sink occurs, it results in the water inner phase partially absorbing the calorific heat value of the emulsions, thereby decreasing the burning gas temperature (Hasannuddin et al., 2016).

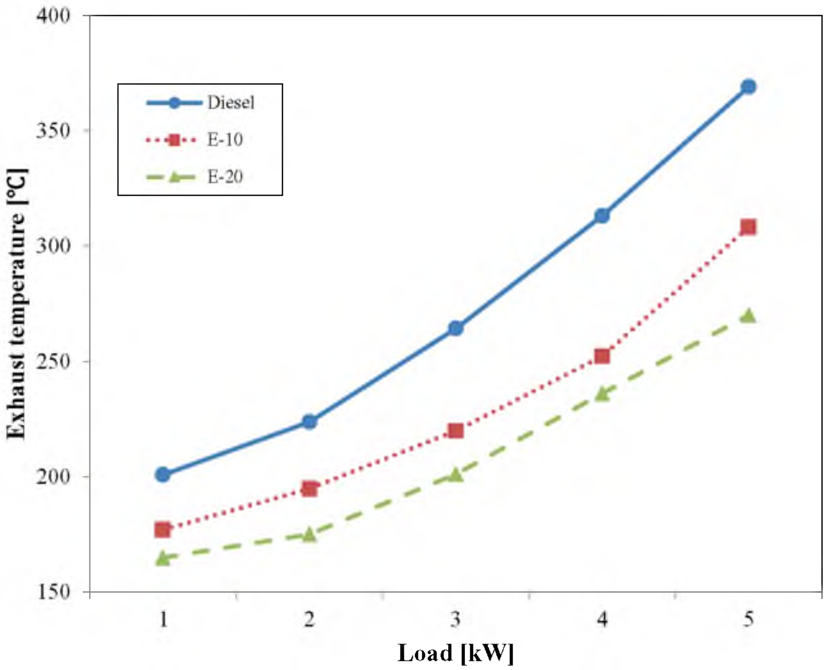

Figure 3: Exhaust temperature for different fuel at varying load conditions

Figure 4 shows the amount of emitted CO using different fuel. The formation of CO emission is increased when using W/D emulsion. This is due to the lower combustion temperature and the high amount of OH radical from the water that promotes oxidation of carbon to CO. The gap for the amount of CO between E-10 and E-20 shrinks at high load. This may be due to oxidation of carbon to CO that declined with the increasing exhaust temperature at high load (Ithnin et al., 2015).

Figure 5 shows the amount of emitted NO_X using different fuel. From the graph, the NO_X for emulsion fuels are reduced from 10% up to 51% in comparison with conventional diesel fuel. NO_X using E-20 shows more reduction than E-10 at all load conditions. This is because vaporized water reduces the flame temperature as shown Figure 3. The lower combustion temperature for emulsion inhibit the reduction of NO_X. Others conclude the reduction of NO_X occurs in order to change the chemical composition of the reactants, resulting in higher OH radical concentration controlling the NO formation rate.

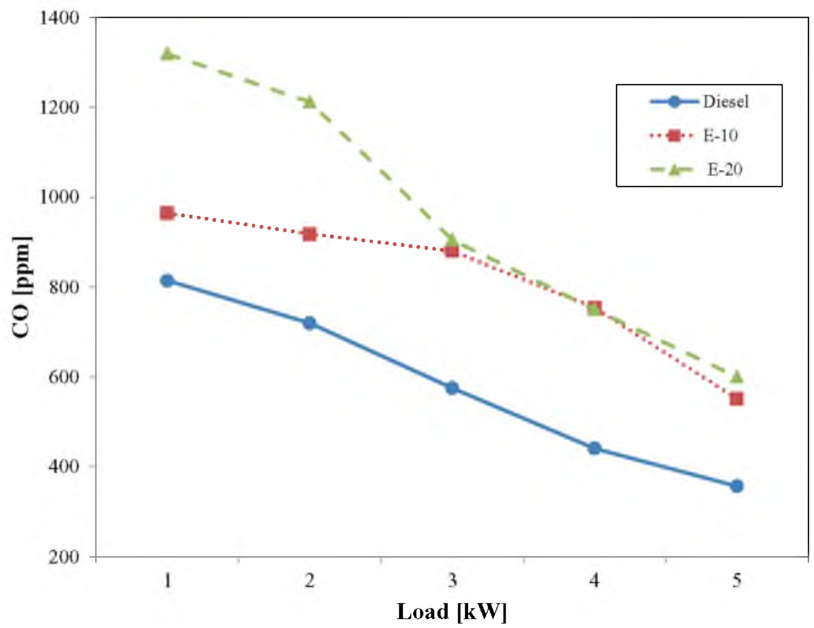

Figure 4: The amount of CO for different fuel at varying load conditions

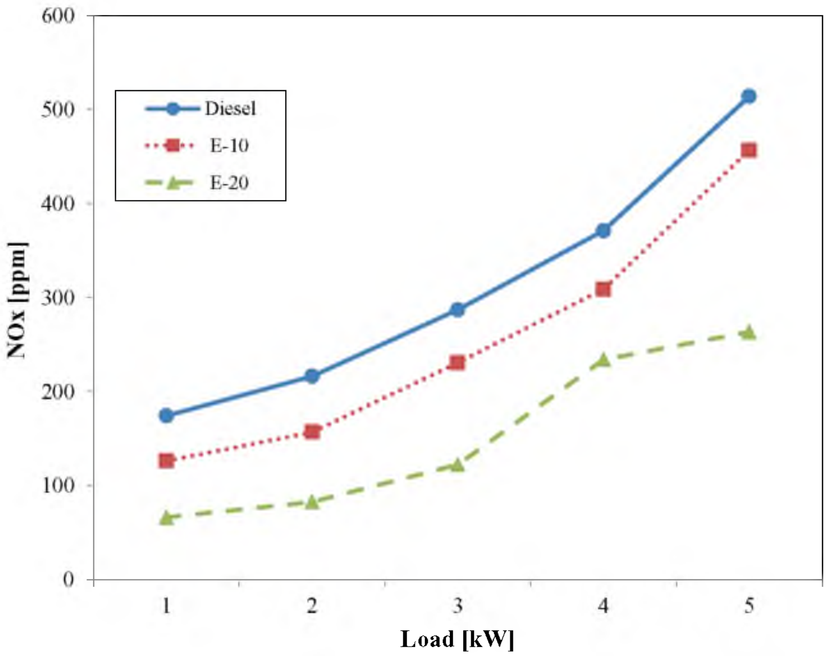

Figure 5: The amount of NOx measurement for different fuel at varying load conditions

Figure 6 shows fuel consumption with load and the consuming mass was calculated including water. Fuel consumption of emulsion fuels is higher than conventional diesel at all load condition. This is because the calorific value of emulsion is lower than conventional diesel. Fuel consumption for emulsion fuel increased due to the scarcity of heat value. Figure 7 shows the comparison of fuel consumption using different fuels and the consuming mass was considered without water. The graph shows that fuel consumption for diesel fuel is slightly higher than the consumption for emulsion fuels. The reduction in fuel consumption may be caused by the following seven factors: micro-explosion phenomena, improved airentraining in the spray due to the increased spray momentum, bigger premixed combustion due to ignition delay, increase in excess of air ratio due to the presence of water in the fuel, reduction in combustion temperature due to the reduction of cooling loss, suppression of thermal dissociation as a result from the reduction of combustion temperature, and more product of combustion gas due to presence of water in the emulsion (Nur Atiqah et al., 2016).

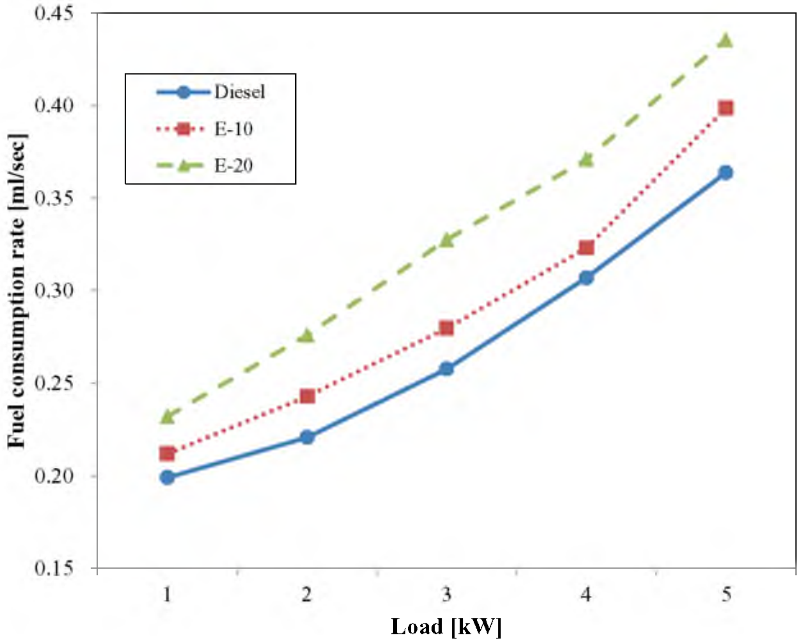

Figure 6: Fuel consumption for different fuel at varying load conditions by considering the diesel and water as total fuel

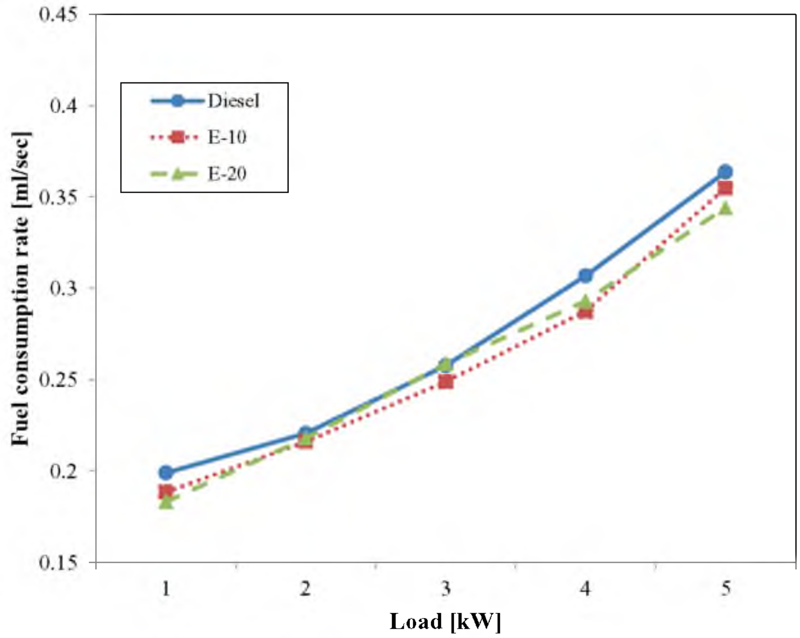

Figure 7: Fuel consumption for different fuel at varying load conditions by considering the diesel as total

4.0 CONCLUSIONS

Higher water content up to 20 vol.% in W/D emulsion give greater reduction of NOx and PM. Additionally, fuel consumption is also slightly decreased when W/D emulsion is used. On the other hand, higher water content in W/D fuel leads to increase CO. There is less research to investigate the effect of engine performance and emission using W/D fuel in long term operation and this will be an interesting topic to be explored in the future.

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