EFFICACY OF WATER-IN-DIESEL EMULSION TO REDUCE EXHAUST GAS POLLUTANTS OF DIESEL ENGINE

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ABSTRACT

The influence of engine loads of a single cylinder diesel engine on engine performance and exhaust emissions when using water-in-diesel fuels were experimentally studied in this work. The work aims to determine the parameter that influence pollutants reduction capability of emulsified fuel at different engine loads and to ascertain the type of fuel blend for optimum engine performance. Physical characterization analyses were performed on 16 stable WiDE samples to evaluate the viscosity, the density and the water droplet size of each sample with various water content, hydrophilic-lipophilic balance values and surfactant percentages. The analyses revealed that only a few samples satisfy the CWA15145 requirements. Hence, this paper only discusses the results of engine performances and emission measurements when using 4 types of emulsified fuels, i.e. percentage of water content of 9, 12, 15 and 18 with HLB value of 6.31 and surfactant percentage of 10% volume of water. Engine torque, fuel consumption and exhaust emissions were recorded and analysed from the engine operating at a speed of 2600 rpm, with variation of engine load between 0 to 100 percent. The results showed that in general, no significant change in brake power was observed but there was a prominent reduction in nitrogen oxides (NOx). The average nitrogen oxides emission was observed to be reduced by 40 percent for WiDE-12 compared to the B5 diesel fuel. The average brake power for WiDE-12 has slightly improved by 5 percent compared to the B5 diesel.

Keywords: water-in-diesel emulsion, exhaust emissions, diesel engine, engine performance.

INTRODUCTION

Emission regulations continue to become more stringent, exacerbating the need to find a solution for the emission of gaseous pollutant and particulate matter from diesel engines. Despite the fact that diesel engines offer higher efficiency and fuel economy, they emit pollutants, i.e. particulate matter (PM), nitrogen oxides (NOx), sulphur oxides (SOx), carbon monoxides (CO) and carbon dioxides (CO_2). Several techniques have been used to improve engine performance as well as reducing the NOx and soot emission which requires retrofitting of the existing engine.

Introducing water in the fuel is a fuel-based solution and can be done through several means including injecting water into the combustion chamber using an isolated injector, spraying water into the intake air and water with diesel emulsion [1]. Introduction of water into an engine has been proven to reduce emission through cooling effect of the in-cylinder peak temperature [2, 3]. However, introduction of water into the fuel blend decreases the engine power output, which is generally inversely proportional to the water concentration of the emulsion, due to the lowering of the fuel's heating value compared to neat diesel fuel [4]. In addition to the tendency of the water and fuel to be separated, the presence of water leads to engine parts corrosion when there is direct contact of water with the part surfaces.

On the other hand, water can also be used to break the big particle of the diesel into a smaller size which leads to a complete combustion of the fuel in the engine, a phenomena known as microexplosion [5]. Also the presence of water during the intensive combustion period seems to diminish the rate of formation of soot particles, which could be attributed to the microexplosion phenomenon [6, 7]. Consequently, the exhaust emission of the combusted fuel will be reduced according to the percentage amount of water in the diesel. Hence, Water-in-Diesel Emulsion (WiDE) fuel is viewed as an alternative fuel to improve engine efficiency and reduce exhaust emissions, particularly nitrogen oxides (NOx) and particulate matter (PM) [8, 9]. Not only does this alternative fuel reduces exhaust emissions but it also saves fuel [10].

Studies on the use of emulsified fuel in diesel engines are active in the recent years [11, 12] however, the extent of the efficacy of emulsified fuel on the engine performance is not precisely known. This is due to the inadequate understanding on how WiDE behaves under combustible condition as well as the complexity of engine operating parameters. This paper investigates the optimisation of engine performance and determines a suitable type of water-in-diesel emulsion in order to reduce the exhaust emission.

MATERIALS AND METHODS

The study involves preparation of 4 litres of Water-in diesel emulsion (WiDE) fuel blends for each types of WiDE at various water contents. The emulsion was stabilized by mixing commercial B5 diesel fuel with non-ionic surfactants, i.e. sorbitan monooleate (Span 80) and polyoxyethylene sorbitan trioleate (Tween 85) to obtain a HLB value of 6.31. The WiDE was then used to operate a single cylinder, direct injection diesel engine on an engine test bed.

Fuel preparation

The WiDEs consisting B5 diesel and distilled water were blended in an electrical blender at a speed of about 1400 rpm for 15 minutes. The emulsions were stabilized by adding 10% by volume of surfactant mixture consisting of Span 80 (Surfactant A) and Tween 85 (Surfactant B). Five fuel blends were tested: diesel, diesel + surfactant + 9%, 12%, 15% and 18% distilled water by volume. The WiDE fuel specifications are shown in Table-1.

Table-1. Water-in-diesel emulsion (WiDE) fuel specifications.

% of water	For 4 liters of fuel			
	Diesel (l)	Water (l)	Surfactant (ml)	
			A	B
9	3.604	0.360	25.2	10.8
12	3.472	0.480	33.6	14.4
15	3.340	0.600	42.0	18.0
18	3.208	0.720	50.4	21.6

Engine testing setup

A single cylinder, direct injection Yanmar L100V diesel engine was used for the engine testing. The engine specifications are shown in Table-2. Eddy current dynamometer was used to measure engine torque, engine speed and load.

Table-2. Engine specifications.

Engine Model	L100V	
Type	Vertical cylinder, 4-cycle, air cooled diesel engine	
Bore x Stroke	86 x 75 mm	
Displacement	0.435 liters	
Continuous Rate Output	Engine Speed	3600 rpm
	Output	6.2 kW
Maximum Rated Output	Engine Speed	3600 rpm
	Output	6.8 kW

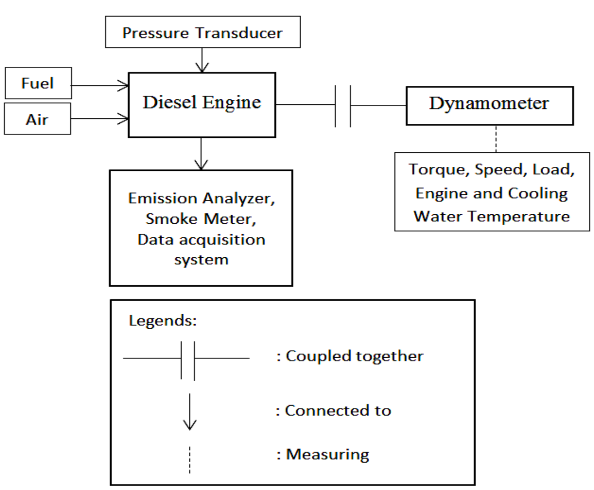

Figure-1. Test setup schematic diagram.

The engine test bed is equipment with instrumentation for air flow, fuel mass, in-cylinder pressure transducer and crank angle encoder. Brake power, air flow rate, fuel mass flow rate and thermal efficiency were automatically displayed on the PC, based on the data recorded by the data acquisition system. The exhaust emissions and smoke densities were measured using emissions analyser and smoke meter respectively. The test setup schematic diagram for engine performance testing is shown in Figure-1.

The tests were performed at a constant speed of 2600 rpm which correspond to the maximum torque of the engine and 10 dynamometer loads ranging from 0% to 100% for all type of fuel blends as shown in the experimental test matrix in Table-3.

Table-3. Experimental test matrix.

Speed (rpm)	Fuel Type	Engine Load (%)	Exhaust Emissions	Engine Performance
2600	Diesel WiDE-9 WiDE-12 WiDE-15 WiDE-18	0-100	➢ Smoke density ➢ Carbon Dioxide ➢ Carbon Monoxide ➢ Hydrocarbon ➢ Oxygen ➢ Nitrogen Oxides	➢ Brake Power, Torque, ➢ Brake Specific Fuel Consumption

The engine was operated using diesel fuel at the beginning during the warming up of the engine. At the end of each test, diesel fuel was used again to run the engine in order to flush out the emulsified fuel from the fuel line and injection system.

RESULTS AND DISCUSSION

WiDE properties

The properties of the fuels for density, kinematic viscosity and calorific value for B5 diesel and WiDEs are presented in Table-4.

Table-4. Fuel properties of B5 diesel and WiDE.

Fuel	Density@15°C (kg/m³)	Kinematic Viscosity (mm²/s)	Calorific Value (J/g)
B5 diesel	842.89	3.41	42600
WiDE-9	868.48	6.96	39888
WiDE-12	873.55	7.38	39282
WiDE-15	878.04	8.06	35843
WiDE-18	883.95	9.17	32569

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It can be observed from Table-4 that the density and kinematic viscosity of emulsified fuels when compared to B5 diesel increased with increase in water concentration due to the presence of higher density water in the blend and increased in the number of the disperse phase [13]. The calorific value of WiDE fuels however, deceased as the percentage of water content increased. This could be due to that water has no calorific value and increased in water content reduced the overall fuels calorific values.

Engine performance

Engine brake power

Engine brake power for all types of fuels was plotted against engine load as shown in Figure-2. The trend shows that engine brake power increases as the load increases for all fuels. In general, no significant change in brake power for all types of WiDE as compared to B5 diesel since the trends show a ±5% difference in brake power. However, the brake power improves slightly by approximately 5% for both WiDE-12 and WiDE-18 for the load between 60% and 100%. This indicates that WiDE fuels with higher water contents tend to improve engine power output. Similar results were also observed by Mukayat, H. *et al*. [14]

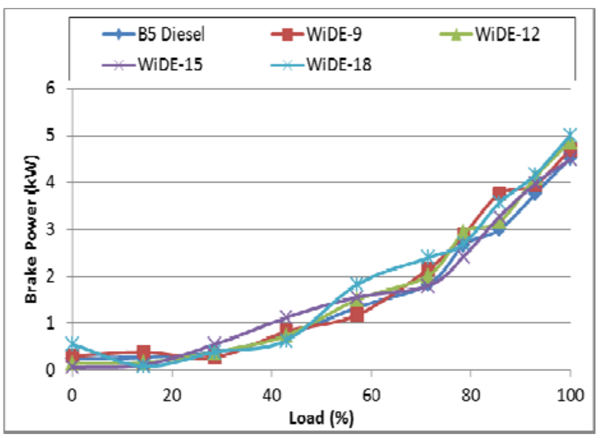

Figure-2. Engine brake power at varying load.

Brake specific fuel consumption

The effect of WiDE on the engine brake specific fuel consumption is shown in Figure-3. It can be observe that between the load of 0% and 40%, brake specific fuel consumption varies and at increasing trends for all WiDE fuels due to engine speed irregularity at low loads. However, as the load increases, brake specific fuel consumptions for all fuels were observed to be similar and remain constant.

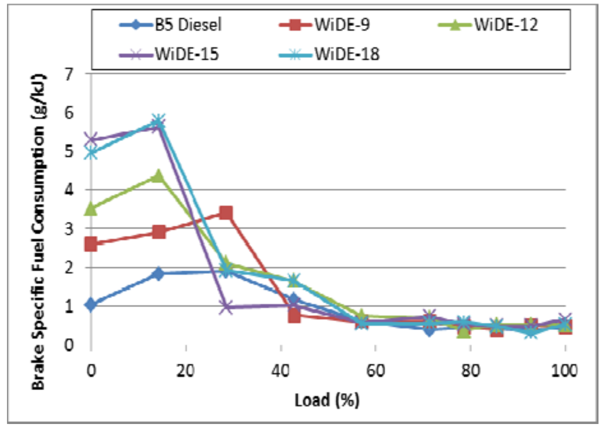

Figure-3. Brake specific fuel consumption vs load.

Engine exhaust emissions

Smoke opacity

Figure-4 shows the effect of WiDE on the smoke opacity emission as compared to B5 diesel. Based on the smoke observation, black smoke was observed at higher loads during the operation using B5 diesel fuel. However, during the operation of WiDE fuels, there was no black smoke emitted but rather white smoke was observed. The smoke meter showed higher values even with white smoke. So, it can be assumed that the smoke meter measures smoke opacity irrespective of the colour.

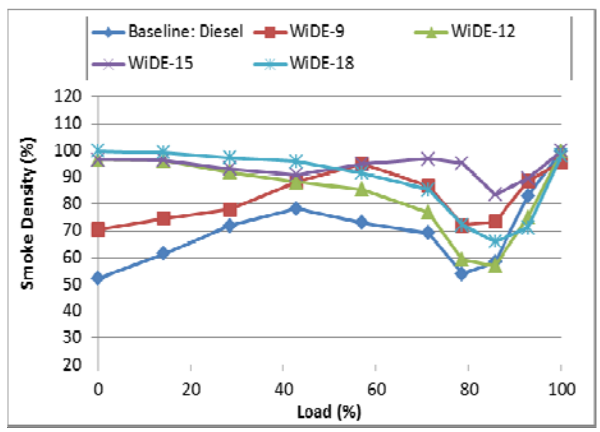

Figure-4. Smoke opacity vs load.

Nitrogen oxides emission

Nitrogen oxides (NOx) emission is shown in Figure-5 as the load increases. The trend for all types of fuel show that the emission of NOx increases with the increment in loads. An average reduction of NOx for all WiDE is approximately 30% compared to B5 diesel. However, the reduction of NOx for WiDE-12 is very prominent of about 40% reduction compared to B5 diesel and it was the highest reduction observed among other type of WiDE fuels

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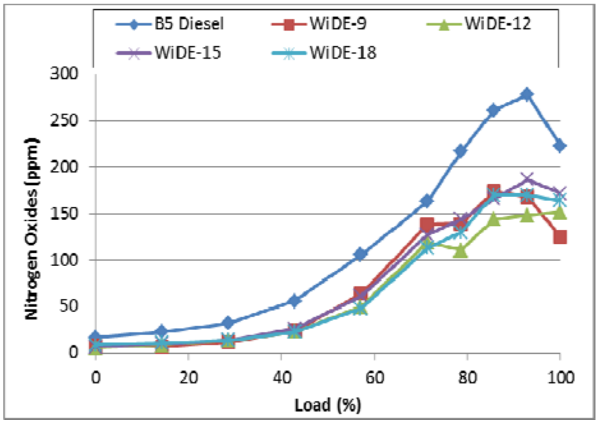

Figure-5. Nitrogen oxides vs load.

Hydrocarbon emission

The effect of WiDE on the hydrocarbon emission as the load increases is shown in Figure-6. The trend for hydrocarbon emission shows a deceasing trend as the load increases for all types of WiDE. WiDE fuels however, exhibit higher values of HC emission as compared to B5 diesel. This may be due to the water is quenched on the wall in the cylinder block. The hydrocarbon emission for WiDE-9 was observed to be the lowest among other WiDE fuels. It is noted that the trend for WiDE-12 is almost the same as compared to WiDE-9 for the load between 80% and 100%.

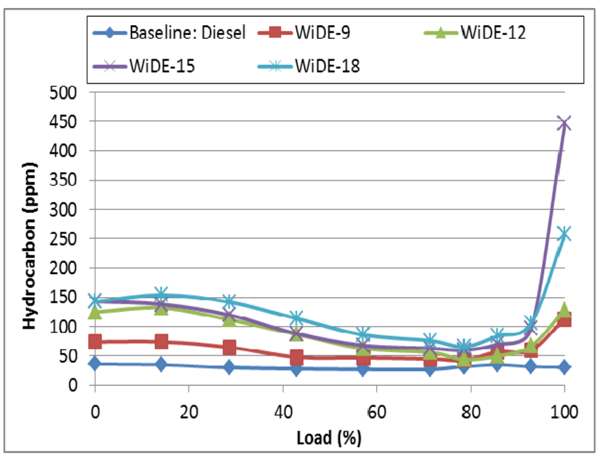

Figure-6. Hydrocarbon vs load.

Carbon monoxide emission

Figure-7 shows the effect of WiDE on carbon monoxide emission at different load. The trend of carbon monoxide released is observed to have no significant change as compared to B5 diesel. However, the carbon monoxide emission for WiDE-12 is observed to be approximately the same with B5: Diesel for the loads between 80% and 100%.

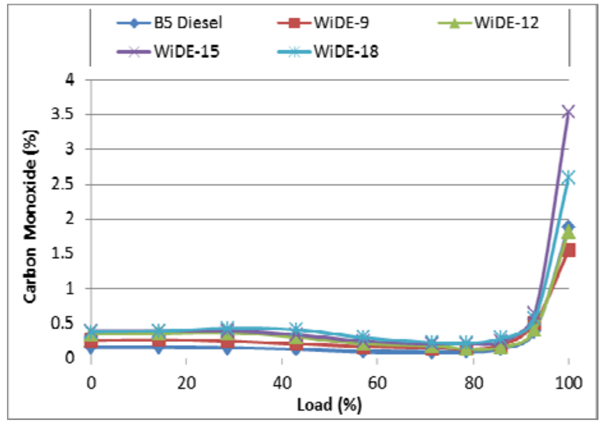

Figure-7. Carbon monoxide vs load.

Carbon dioxide emission

Figure-8 shows the effect of WiDE on the emission of carbon dioxides on the variation of loads. All types of fuel show that the emission of carbon dioxide increases as the load increases. It is observed that the amount of carbon dioxide released for WiDE-15 and WiDE-18 increases for the loads of between 0% and 80% as compared to B5 diesel. This shows that as the amount of water increases in the emulsified fuels, the combustion of fuel improves.

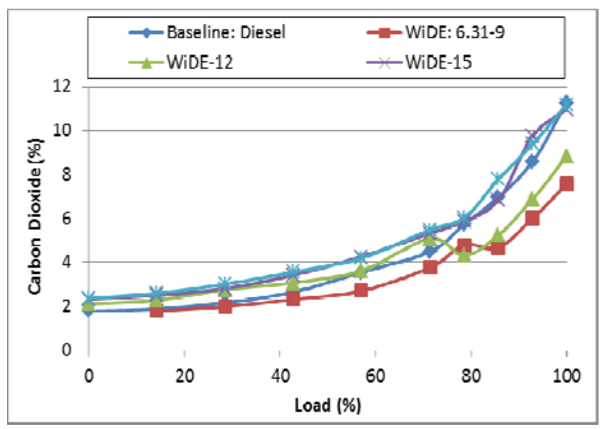

Figure-8. Carbon dioxide vs load.

Oxygen emission

Figure-9 exhibits the effect of WiDE fuels on the oxygen concentration in the exhaust gas as the load increases. It can be seen that the trend is reducing as the load increases for all types of fuel. The trend of oxygen emission for WiDE-15 and WiDE-18 is approximately the same as compared to B5 diesel.

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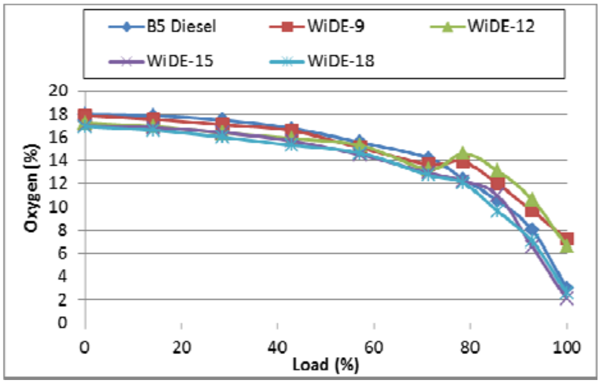

Figure-9. Oxygen vs load.

CONCLUSIONS

Four WiDE fuel samples were experimentally investigated to study the effects of water contents on pollutants reduction capability at different engine loads. In this study, it is shown that incorporation of water in diesel improves engine performance especially brake power by 5% for the load between 50% and 100% and reduces emissions especially nitrogen oxides by 40% for WiDE-12 between the load of 80% and 100%. The smoke opacity for all WiDE samples were observed to be increasing when compared to B5 diesel, although white smoke, as oppose to black smoke, was observed in the exhaust gas. For optimum engine performance, WiDE-12 exhibited improvement in brake power by approximately 5% for the load between 50% and 100%, has no significant change in brake specific fuel consumption as the load increases above 40% and reduces nitrogen oxides emission by approximately 40% for the load between 80% and 100%. It is recommended for future research to conduct a study on the optimization of engine performance by adjusting engine operating parameters, blending the WiDE using neat diesel and varying the engine speeds and loads. It is believed that the variations of types of fuel blend and adjusting engine operating parameters can further improve the engine performance as well as reducing the emission, particularly particulate matter (PM) and Nitrogen Oxides (NOx).

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