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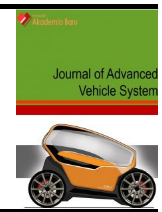

Exhaust Emission Analysis of Single Cylinder Diesel Engine Fuelled with Water-in Diesel Emulsion Fuel

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ABSTRACT

Water-in-diesel emulsion fuel (W/D) is one of the alternative fuel that capable to reduce the exhaust emission of diesel engine significantly especially the nitrogen oxides (NOx)and particulate matter (PM) The present paper investigates the effect of using W/D made from Malaysian low grade diesel (D2) on the diesel exhaust emission.. Four different water percentages (5, 10, 15 and 20%) with constant 2% of surfactant were tested and labelled as E5, E10, E15 and E20, respectively. NOx and PM are found to be reduced for all types of W/D. E20 is reported to be the best in reducing NOx and PM with an average reduction of 41% and 35%, respectively, in every load condition. Overall, it is observed that the formation of W/D from low-grade diesel is an appropriate alternative fuel method that can bring about greener exhaust emissions and fuel savings without deteriorating engine performance.

1. Introduction

Water-in-Diesel emulsion fuel (W/D) is an alternative fuel which progressively intrigues the world's attention due to its great impact to the environment as well as energy consumption. 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]. There is a special occurrence in W/D ignition called the micro-explosion phenomena that attract 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 [2].

Numerous studies have been conducted concerning the W/D emulsion fuel involving the performance and emissions of an engine running on the said fuel, in return, explaining the combustion characteristics and micro-explosion process. According to Abu-Zaid [3] brake thermal

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efficiency is increased by 3.5% from that of the neat diesel fuel. Basha *et al.*, [4] found that the measurement increased to 26.9% compared to diesel, which is 25.2%. Other study also agrees with these positive findings of using W/D [5]. A. Attia and A. Kulchitskiy [6] 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 µm and 0.45µm, 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 and unburned hydrocarbons (HC) with values greater than 80% and 35% respectively, while increasing the engine efficiency by up to 20%. 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 [7].

Nevertheless, from enormous studies of W/D being conducted, the fuel quality in W/D emulsion fuel studies has received less attention, especially in utilizing low-quality diesel as the emulsified fuel. Low-quality diesel fuel may cause more severe damage to the environment compared to higher Euro standard fuel.The present paper aims to investigate the effect of using W/D made from Malaysian low-quality diesel (D2) on the diesel exhaust emission.

2. Experimental Setup

The W/D is made by mixing the D2 diesel with different water percentages (5, 10, 15 to 20% by volume count), together with a constant 2% of span 80 and is emulsified by a high shear mixer (constant speed of 5000 rpm for 5 minutes). The W/D is labelled as E5, E10, E15 and E20, respectively. The details of the diesel D2 specification are shown in Table 1.

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. 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.

As for the emission measurement, there are two devices /machines used which is an emission analyser for the measurement of NOx, while a mini dilution tunnel is utilised for the measurement of PM. The emission analyser used in the project is Testo 350. The probe of the emission analyser is placed inside the exhaust tail pipe of the engine in order to sample the exhaust emission. The sampling pump is diluting the exhaust gases going into the emission sensor for reading and calculating process on each type of exhaust gas. The measurement is recorded for every 5 second interval during the 2 minute duration of engine running and the average data are calculated for consideration and discussion. As for the measurement of the PM, a custom mini dilution tunnel is used, with the tunnel inner diameter and length of 70mm and 680mm respectively. The PM reading is taken using the mini-dilution tunnel where 10% of exhaust gasses are diluted by clean air inside the tunnel with a controlled temperature of 50ºC. The diluted gas is then absorbed by the uniform velocity of the diaphragm pump in which the particulate is then trapped on a Teflon filter (MILLIPORE FHLP04700, diameter 47mm, orifice 0.45 µm). The particulate concentration is determined by measuring the filter weight before and after sampling. The engine tests are performed for different engine load conditions consisting of 1kW (25%), 2 kW (50%), 3 kW (74%) and 4 kW (100%), with a constant engine speed of 3000 rpm. The engine is initially run for 10-12 minutes and the corresponding exhaust temperature and speed are monitored. Once these parameters became steady, data are recorded.

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

3. Result and Discussion

Figure 1 shows the formation of NOx for D2 and W/D (E5, E10, E15, and E20) under varied load (25, 50, 75, and 100%) and constant speed (3000 rpm). As shown in the graph, there is a remarkable reduction of NOx in all types of W/D compared to D2. In addition, the percentage of NOx reduction is almost directly proportional to the percentage of water content in W/D by which NOx is reduced when the percentage of water in the aforementioned fuel increases. The same finding is also recorded by other studies [8]. E20 is reported to be the best in reducing the NOx emissions with an average reduction of 41% in every load condition. Many researchers agree that the reduction of NOx while utilizing emulsion fuel is because of the lower peak temperature of the flame during the combustion [9]. The reduction of the temperature is due to the high latent heat from the evaporation of water in the emulsion that absorbs the heat during the combustion [10]. According to W. Jazair *et al.*, [11], the reduction of NOx is due to the phase transition of water to steam, which is an endothermic reaction that occurs in the combustion chamber, leading to the reduction of the in-cylinder temperature. In addition, Farfaletti *et al.*, [9] explained that the combustion temperature is reduced due to the heat sink effect. The water content in the inner phase absorbs the calorific heat value of the emulsion. Consequently, this reduces the burning gas temperature inside the combustion and thus restricts the generation of NOx.

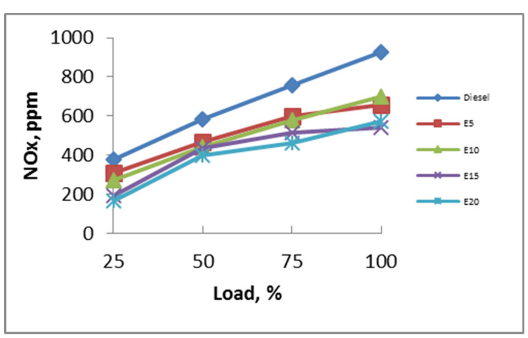

Fig.1. Formation of NOx under different engine load

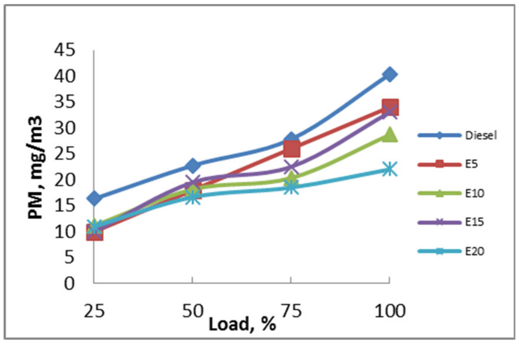

Fig. 2. Formation of PM under different engine load

Figure 2 exhibits the formation of PM for D2 and W/D (E5, E10, E15, and E20) under varied loads (25, 50, 75, and 100%) and constant speed (3000 rpm). It clearly shows that the formation of PM in all types of W/D is reduced when compared to D2 in all load conditions. The maximum reduction of PM is detected at high load where E20 reduced the PM up to 45% in comparison to D2. Furthermore, the aforementioned fuel is reported to be the best in reducing the PM with an average reduction of 35% in every load condition. The reduction of PM when using W/D is perhaps due to the better mixing and enhanced atomization caused by the micro-explosion phenomena [12]. Moreover, the addition of water in the emulsion augments the concentration of (hydroxyl) OH radicals, which leads to the oxidation of soot precursors [13]. Ochoterena *et al*., [7], concluded that the causes of the reduction of PM emissions are lower flame temperature, rapid evaporation of water, decreasing of pyrolysis reaction and the enhanced oxidation of soot precursor due to the addition of OH radicals.

4. Conclusion

The detailed analysis of exhaust emission characteristics have been conducted using four different water percentages of W/D (5,10, 15 and 20%) formed from low-quality diesel (D2). Based on the experimental investigations, NOx and PM are found to be reduced for all types of W/D compared to D2. E20 is reported to be the best in reducing NOx and PM with an average reduction of 41% and 35%, respectively, in every load condition. Overall, it is observed that the formation of W/D from low-grade diesel is a promising alternative fuel that can bring about greener exhaust emissions

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