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Engine performance and exhaust emission analysis of a single cylinder diesel engine fuelled with water-diesel emulsion fuel blended with manganese metal additives

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Abstract. Water-in-diesel emulsion fuel (W/D) is one of the alternative fuels that capable to reduce the exhaust emission of diesel engine significantly especially the nitrogen oxides (NOx) and particulate matter (PM). However, the usage of W/D emulsion fuels contributed to higher CO emissions. Supplementing metal additive into the fuel is the alternate way to reduce the CO emissions and improve performance. The present paper investigates the effect of using W/D blended with organic based manganese metal additives on the diesel engine performance and exhaust emission. The test were carried out by preparing and analysing the results observed from five different tested fuel which were D2, emulsion fuel (E10: 89% D2, 10% - water, 1% - surfactant), E10Mn100, E10Mn150, E10Mn200. Organic based Manganese (100ppm, 150ppm, 200ppm) used as the additive in the three samples of the experiments. E10Mn200 achieved the maximum reduction of BSFC up to 13.66% and has the highest exhaust gas temperature. Whereas, E10Mn150 achieved the highest reduction of CO by 14.67%, and slightly increased of NO_x emissions as compared to other emulsion fuels. Organic based manganese which act as catalyst promotes improvement of the emulsion fuel performance and reduced the harmful emissions discharged.

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]. Water-in-Diesel emulsion fuel is one of example of oil phased emulsion which can be used as an alternative fuel. Surfactant was added to improve the composition and provide a stable emulsion fuel [3].

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 [4] brake thermal efficiency is increased by 3.5% from that of the neat diesel fuel. Basha et al. [5] found that the measurement increased to 26.9% compared to diesel, which is 25.2%. A.K Hasannudin et al [6] conducted the durability study of W/D, fuelled the engine for 200 hour and study its effect to the lubricant oil. They reported that the water content in the fuel did not cause any excessive amount of metals or degraded the additive. However, these alternative fuels emitted higher emission of CO[7], [8]. This issue can be solved through the addition of metal additive to the W/D. Very few researchers worked, on the use of nano-additives to emulsion fuel for the enhancement of the performance and emission characteristics but many on biodiesel. Sajith et al. [9] carried out an extensive investigation on a diesel engine fuelled with and without cerium oxide additives, to study the performance and emission characteristics. They found that the viscosity and volatility hold direct relations with the dosing level of 20-80 ppm. The emission levels of HC and NOx are appreciably reduced with the inclusion of CeO2. El-Seesy et al [10] added the Multi-Walled Carbon nanotubes into the Jojoba methyl ester- diesel blended fuel (JB20D) and evaluate its combustion characteristic. The authors found that the combustion characteristics were improved compared to JB20D fuel where the peak cylinder pressure, the maximum rate of pressure rise and the peak heat release rate were increased by 7%, 4%, and 4%, respectively. In order to reduce the NOx and PM emission from the CI engines, emulsification techniques are adopted. Basha and Anand [11] investigated the performance and emissions of a diesel engine fuelled with biodiesel emulsion fuel incorporation of alumina nanoparticles in the mass fractions of 25, 50 and 100 ppm, with a higher concentration of water. They observed the improvement of NOx, and smoke emission.

From this motivation, the present paper investigates the effect of using W/D blended with organic based manganese metal additives on the diesel engine performance and exhaust emission. Three different volume of Manganese (100ppm, 150ppm, 200ppm) were blended into the W/D (E10: 89% D2, 10% - water, 1% - surfactant) and labelled as E10Mn100, E10Mn150, E10Mn200 respectively. The results are used for a comparison with neat diesel D2 and conventional emulsion fuel, E10. A single cylinder, direct injection diesel engine is tested under 5 different load conditions (0 to 5 KW) and with a constant engine speed of 3500 rpm. In the engine performance the specific fuel consumption is discussed in detail. In respect of the emission characteristics, NOx, HC, and CO are analysed before being further discussed.

2. Methodology

2.1 Fuel Preparation

In this study, W/D is made by mixing 10% of tap water, 1 % of surfactant and 89 % of diesel and labelled as E10. All the immiscible liquids were emulsified through the mechanical homogenizer at 2500rpm for 10 minutes. The surfactant used to form the emulsion is the Polyoxyethylenenonylphenyl ether, or so called span 80 with a HLB (Hydrophilic–Lipophilic Balance) of 4.3. The Malaysian Grade 2 diesel, D2 was selected as the base fuel; the detail specification is tabulated in Table 1. As for the metal additives blended W/D, three different volume of organic-based Manganese oxide were added to the E10; 100 ppm, 150ppm, and 200ppm and labelled as E10Mn100, E10Mn150, and E10Mn200 respectively. The blending process of the metal additives with the E10 where conducted by using ultrasonic mixer for 10 minutes.

2.2 *Engine Performance and Emission Test*

The schematic diagram of the engine testing setup is shown in Figure. 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 toroidal crown and the intake port type is helical. The other basic specifications of the engine are shown in Table 2. 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. 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. As for the measurement of emissions, E – instrument E4500 emission analyser is used to measure the NOx, CO and HC contents in the exhaust gas emitted by the engine. The measurement is recorded for every 5 second interval during the 2 min duration of engine running and the average data are calculated for consideration and discussion. The engine tests are performed for different engine load conditions, 0 to 5kW, with a constant engine speed of 3500 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	45.28
Cloud point	^{o}C	18
Density @ 15 ^{o}C	kg/L	0.854
Total sulphur	mass%	0.28
Viscosity @ 40 ^{o}C	cSt	4.64
Distillation temperature, 90% recovery	^{o}C	368
Flash point	^{o}C	93
Pour point	^{o}C	12
Cetane number	-	54.6
Carbon	wt%	84
Hydrogen	wt%	12.8
Sulphur	wt%	0.2
Nitrogen	wt%	<0.1
Oxygen	wt%	3.9

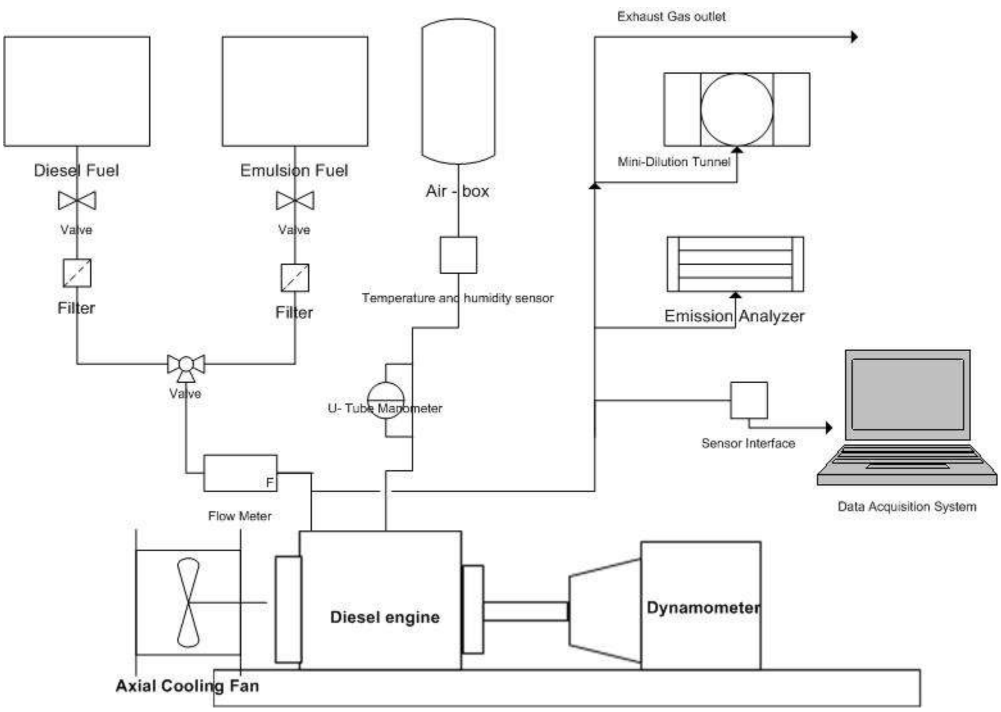

Figure 1. Schematic diagram of the engine emission test set up.

Table 2. Test engine specifications.

Parameter	Specification
Engine Type	4-Stroke, single cylinder, DI, air cooled,
Bore/ Stroke (mm)	86/70
Rated revolution (rpm)	3100
Compression ratio	19.3
Displacement (L)	0.406
Fuel injection pressure (Mpa)	19.6

3 Results and discussion

The brake specific fuel consumption (BSFC) of the engine fuelled with D2, E10, E10Mn100, E10Mn150, and E10Mn200 under varying engine load conditions (0-5kW) with constant speed of 3500 rpm is illustrated Figure 2. All three types of fuel 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. Maximum reduction of BSFC was obtained from the fuel E10Mn200. At 5kW load, E10Mn200 achieved maximum decreased of BSFC by 13.66% in comparison with E10. While, for E10Mn150 and E10Mn100 they reduced to 2.96%, and 0.49% of the brake specific fuel consumption. It was observed that the BSFC reduced when the load increased. The more quantity of additive being added increased reduction of BSFC. This proved that, supplementing additive which was organic-based manganese promotes better combustion of the injected fuel due to the additive that acts as an oxidation catalyser. Other than that, through introducing the organic-based manganese additive, the fuel properties were improved positively in which affect the atomization and penetration of the fuel, hence improving the fuel mixture.

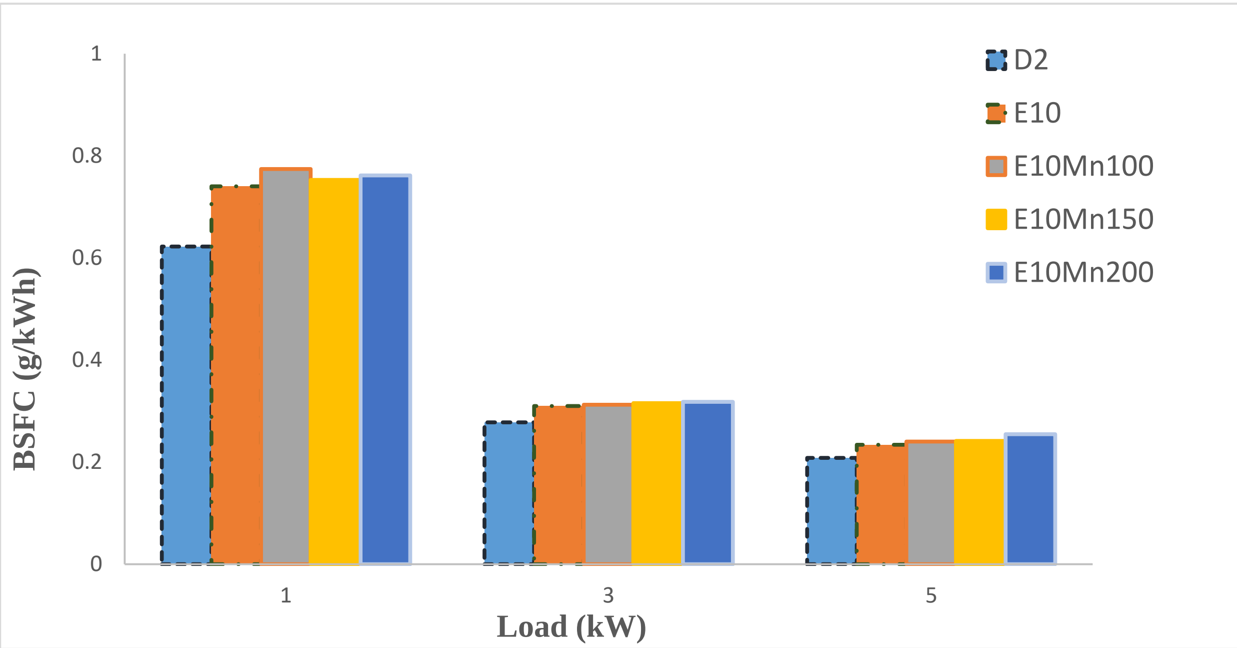

Figure 2. BSFC of tested fuel.

Figure 3 presents the CO emissions of tested fuel. As shown in the graph, overall trend in every fuels show that the formation of CO is drastically reduced as the load is increased, in which again this proves that the engine combust efficiently as higher load is applied. All the manganese blended emulsion fuels show significant reduction of CO compared to the neat E10. However, the said fuels still significantly higher than D2. The maximum reduction of CO was obtained from E10Mn150 as compared to other metal additive emulsions. At full load, E10Mn150 reduced up to 14.76% of CO emissions in comparison of E10. E10Mn100 reduced to 11.5% of CO emissions while E10Mn200 increased to 19.04% of CO emissions discharged at the full load. It was observed that the improvement of the CO emission start to decrease after 3 kW.

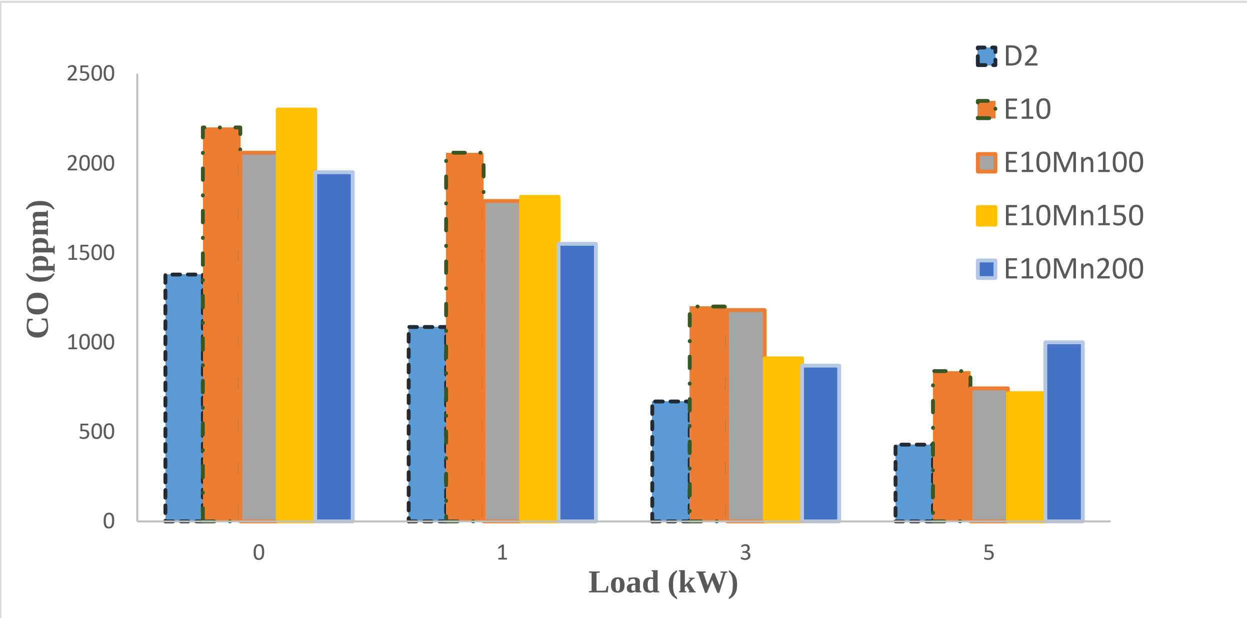

Figure 3. CO emission graph of tested fuel.

Figure 4 shows the plot of the formation of NO_x for D2, E10, E10Mn100, E10Mn150, and E10Mn200 under varying engine load conditions (0-5kW) with constant speed of 3500 rpm. As shown in the graph, overall trend for all the fuels plotted higher NO_x as the load is increased. Apart from that, all the manganese blended emulsion fuels show higher NO_x as compared with neat E10, however still significantly lower than D2. It was observed that adding of the manganese additive up to 150 ppm into the emulsion fuel indirectly increased the NO_x emissions. At maximum load, E10Mn150 emits the highest NO_x as compared to all emulsions 227ppm. However, the NO_x emission still much lower compared to D2 which is 302ppm. This is due to the to the water content in the emulsion that lowered the peak temperature of the flame during the combustion.

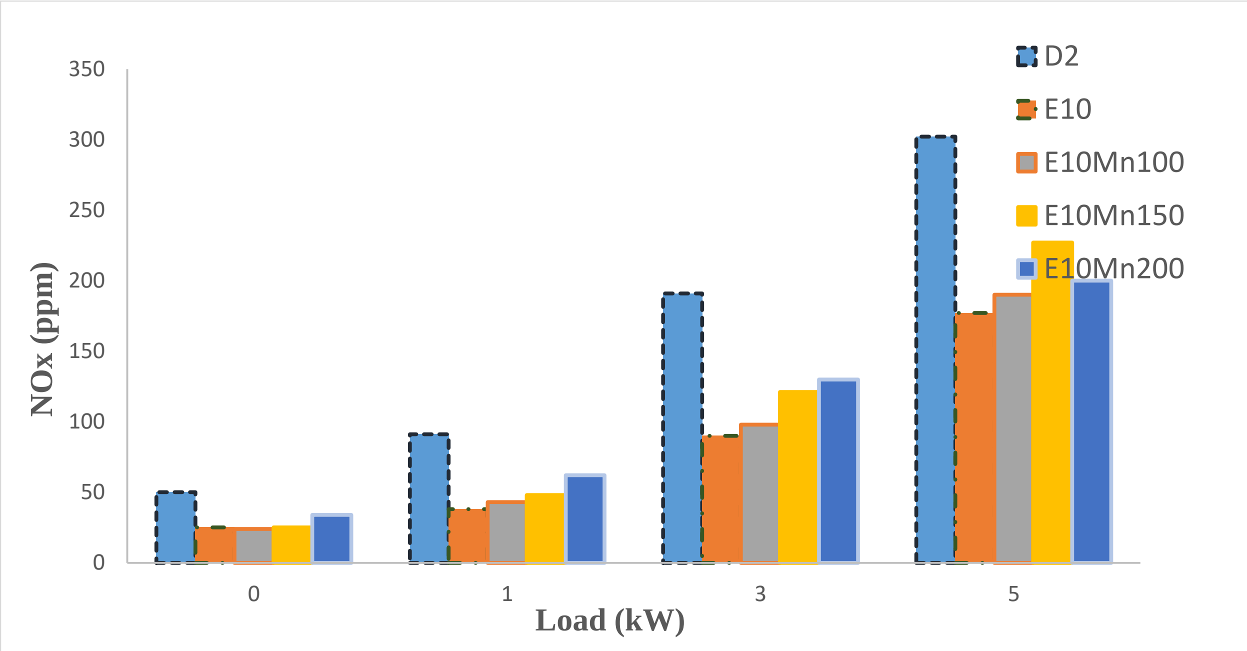

Figure 4. NOx emission graph of tested fuel.

Figure 5 presents the HC emissions of tested fuel. The HC emissions decrease in line as the load increased. The highest HC is reported when fuelled E10200 as compared to other fuels. At full load, the lowest HC was found at E10Mn100, followed by E10200, E10 and E10Mn150. The highest formation of HC was found at D2. This indicates that, by supplementing organic based manganese which acts as additive successfully decreased the HC emissions discharged.

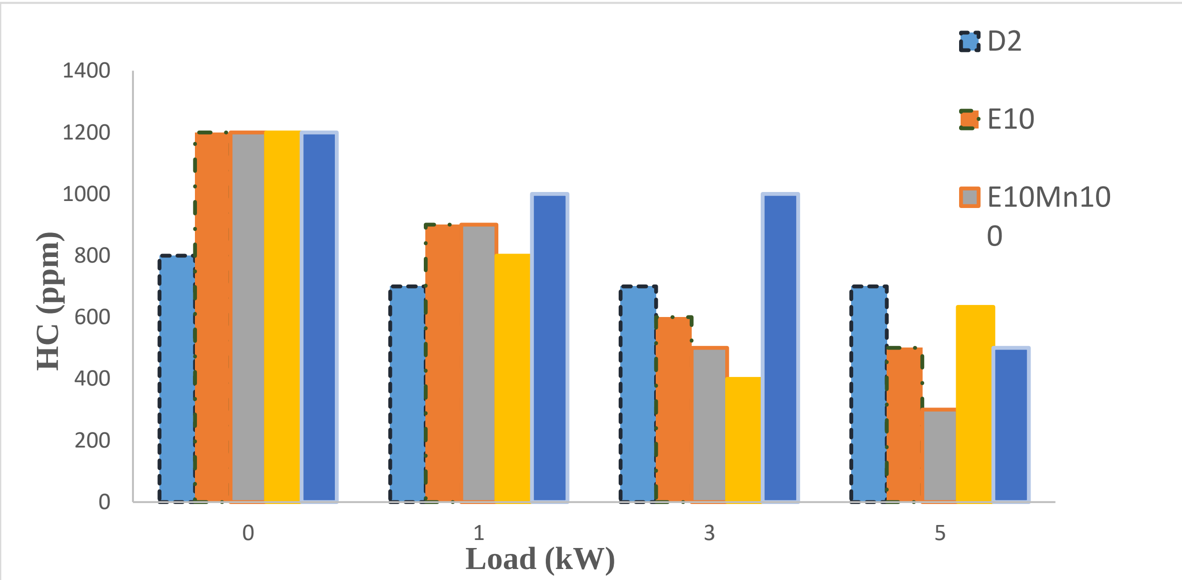

Figure 5. HC emission graph of tested fuel.

Figure 6 presents the exhaust gas temperature of tested fuel. Ignition delay has strong correlation with the increase of the exhaust gas temperature. From that graph shown, it is clearly shows that as the volume of manganese additive are increases, the exhaust gas temperature increased significantly. Maximum of exhaust gas temperature of E10, E10Mn100, E10Mn150, and E10Mn200 were 245 ^{0}C, 293 ^{0}C, 375 ^{0}C, and 399 ^{0}C respectively at full load. The highest exhaust gas temperature was observed to be obtained from E10Mn200 which is 62.86% followed by E10Mn150, E10Mn100, D2, and E10 respectively.

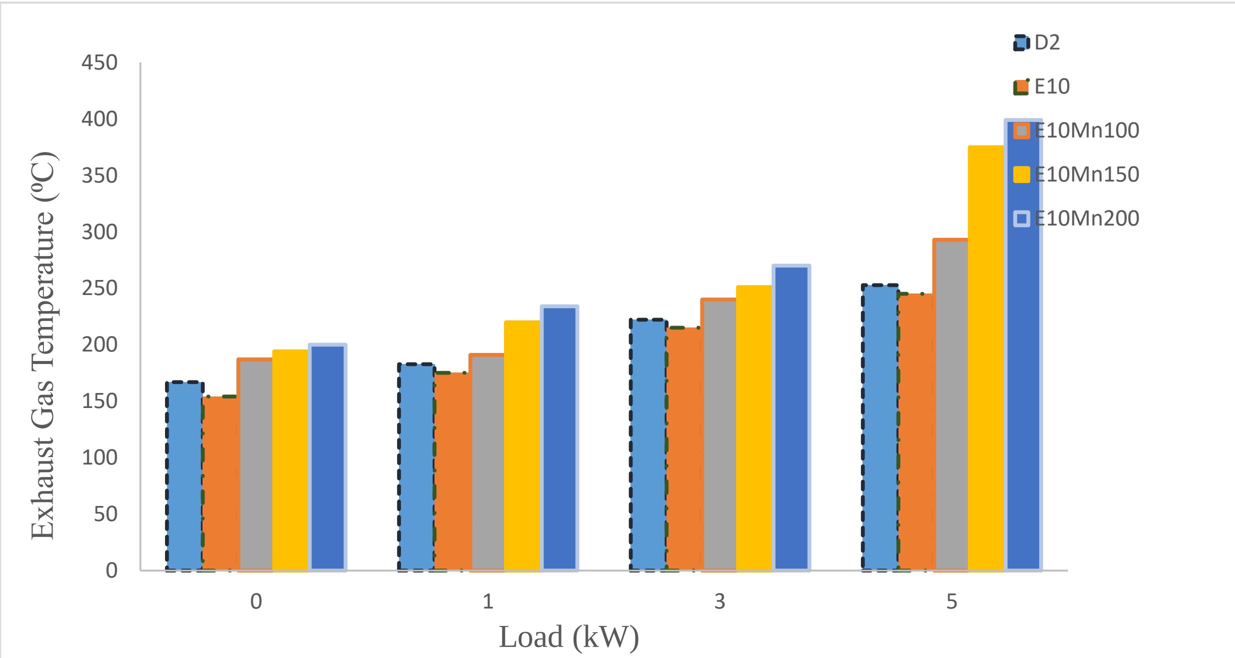

Figure 6. Exhaust gas temperature of tested fuel.

4. Conclusions

The detailed analysis of engine performance and exhaust emission analysis have been conducted using 3 different volume of organic manganese oxide (E10Mn100, E10Mn150, and E10Mn200) into E10 emulsion fuels. Based on the experimental investigations, E10Mn200 achieved the maximum decreased in BSFC. It reduced up to 13.66% of the BSFC in comparison with E10Mn100, and E10Mn150 which only reduced to 2.96%, and 0.49% of the BSFC respectively. The CO emission was reduced to 14.67% when fuelled with E10Mn150 compared to E10. However, E10Mn150 increased the NO_x emissions compared to other emulsions. E10Mn150 reduced the highest percentage of HC emissions at full load condition. Whereas, the highest exhaust gas temperature were achieved from E10Mn200 which it is 62.86% in comparison with E10.Supplementing organic based manganese additive into emulsion fuel promote the reduction of the fuel consumption, CO emissions, and HC emissions discharged from the engine. On the other hand, the manganese blended emulsion fuels slightly increased the NO_x emissions compared to the E10. Organic based manganese proved that able to improve the emulsion fuel performance and reduced the harmful emissions discharged.

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