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Effect of Oxygenated Fuels on Oxidation Reactivity of Particulate Emissions in Diesel Engine

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***Abstract*— *Oxygenated fuels such as biodiesel is consider a useful fuel in reducing particulate matter (PM) emissions of diesel engines over the years. The oxygen content in the biodiesel properties is effect on the reactivity and exposure of particulate matter. The results indicated that the biodiesel enhance the oxidation rate of PM more than diesel fuel. Also, the number of PM decreased in high level during the burning of biodiesel compared with diesel fuel. It is noticed that the different structural characteristics of biodiesel shows that the composition and chemical structure of the fuel has strongly effect on the structure and formation of PM for different engine operating condition. The results showed that the engine emissions decreased during the combustion of biodiesel compared to the diesel. Besides, the brake thermal efficiency also decreased from biodiesel combustion when compared with diesel fuel combustion.*

***Keywords*— *Oxygenated fuel, particulate matter, soot particles, NO_X emissions.*

I. INTRODUCTION

To meet the stringent legislations of energy, emissions and reduce the dependence on petroleum diesel, alternative fuels have recently emerged as a good alternative to diesel fuel over worldwide. It is reported that the particulate matter characteristics effected by the particle formation process during the combustion of fuel [1, 2]. Also, they found that the temperature, residence time, and fuel composition effect on the formation rate of PM. The changes in the nanostructure of soot particles were more dependent on the oxygen content of the parent fuel than on the pressure conditions [3]. Due to increasing the oil depletion, environmental pollution, the use of alternative fuels is consider the good solution for these concerns [4]. The good properties of biodiesel encouraged the researchers to use pure diesel or blended with diesel fuel to use in diesel engines. The both feedstock of biodiesel (edible or non-edible) can offer good alternative conventional diesel fuel in internal combustion (IC) engines [5]. Most of studies reported that biodiesel improve exhaust gas temperature and engine out emissions [6-9]. In addition, the effective reduction in engine emissions and improve engine performance as well as combustion process can be occurred with using biofuel. It is reported that carbon monoxide, hydrocarbon, and PM reduced with a marginal increase in NO_X emissions from biodiesel combustion usage in compression ignition engines. Furthermore, another reason for increase NO_X emissions is due to the presence of fuel bound oxygen, which can improve the combustion of biodiesel [10, 11]. It is observed early occurrence of peak heat release rate and higher peak pressure at lower to medium load conditions during biodiesel combustion in comparison with diesel [12, 13]. The smoke and soot emissions reduced when engine using biodiesel fuel [14-19]. Previous work stated that smoke emissions reduced when retarded fuel injection in the combustion process [8, 20]. In order to reduce the pollution emissions in diesel engine to the atmosphere, the international emission regulations are more and more stringent. Subsequently, various advanced emission reduction technologies, including in-cylinder purification [6, 12, 21]. There are numerous investigations on post injection strategy, but how post injection affects exhaust emissions is still unclear. Therefore, the aim of this study is to study the effect of oxygenated fuel on oxidation reactivity of particulate emissions.

II. EXPERIMENTAL SETUP AND PROCEDURE

The tests were conducted on 4-cylinder, direct injection (DI) diesel engine. Figure 1 presented the outline of the experimental setup and tools. The configuration of engine and tools are shown in Figure 1. The main engine specifications were listed in Table 1. A GW160 electric dynamometer and FC3000 dynamometer controller that was coupled with the engine was used to control and measure the state parameters such as engine torque and speed. The biodiesel and alcohol were employed as alternative fuel and tested as a pure fuel and blended with diesel fuel. The biodiesel used in the current study was produced from sunflower oil, which is collected for biodiesel production. Further, the main properties of diesel and biodiesel are listed in Table 2.

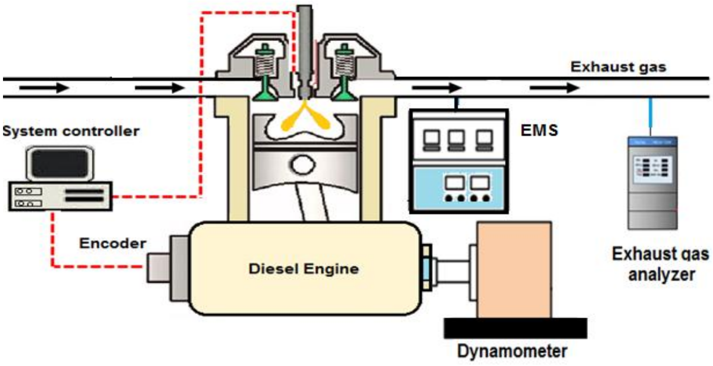

Figure 1: Schematic of the engine test bed and sampling system.

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Table 1: Specifications of diesel engine

Engine parameters	Specifications
Engine type	Diesel Single- Cylinder
Number of cylinders	1
Cylinder bore x stroke (mm)	84 x 90
Connecting rod length (mm)	160
Compression ratio	16.1
Displacement (cc)	499
Maximum engine speed range (rpm)	2000
Fuel pressure range (bar)	500 – 1000

Table 2: Fuels specifications

Properties	Diesel	Biodiesel
Chemical formula	$C_{16}H_{34}$	$C_{19}H_{36}O_2$
Derived cetane number	51.8	62
Latent heat of vaporization (kJ/kg)	242	216
bulk modulus (MPa)	1410	1554
density at 15 °C (kg/m^3)	844.3	896.1
Calorific value (MJ/kg)	45.80	38.90
Falsh & Fire point (°C)	65-70	157-162
Water content by coulometric KF (mg/kg)	40	170
kinematic viscosity at 40 °C (cSt)	2.77	5.0
Stoichiometric air fuel ratio	14.4	-
lubricity at 60 °C(μm)	312	205

III. RESULTS AND DISCUSSION

3.1 Particulate Emissions

The variations of particulate emissions under various injection timing conditions and oxygenated fuel are shown in Figure 2. According to the results, it can be seen that the soot emissions are significantly with biodiesel compared to the diesel. The generation of soot under biodiesel combustion reduced for both fuels. This could be likely that part of the biodiesel fuel is sucked into the main combustion product, resulting in the combustion of the fuel injection in the oxygen-depleted region [5, 22]. Further, the level of soot emissions reduced with biodiesel than to the diesel fuel (Figure 2). The soot emissions reduced from the injection of biodiesel fuel compared to diesel condition [23, 24]. Additional turbulent energy enhanced the particulate oxidation and combustion exothermic provided by the operating conditions [16, 17]. For the same condition, the level of soot emission is relatively high from biodiesel [10, 25]. Biodiesel combustion produces smaller soot particles than to the diesel fuel combustion.

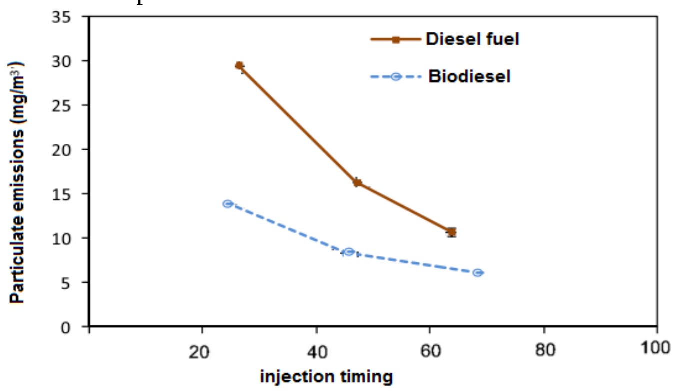

Figure 2: Effect of post-injection and alternative fuels on soot level for diesel and biodiesel.

3.2 Smoke Emissions

The influence of oxygenated fuel on smoke opacity for different engine loads is presented in Figure 3. It can be noticed that smoke opacity were reduced with biodiesel due to high levels of premixing for all the tested blends with respect to the diesel fuel [6]. The availability of time required for premixing and oxygen content, which enabled the reduction of the emitted smoke [26, 27]. The exhaust smoke concentration was lower existence of fuel bound oxygen increases the soot oxidation (Figure 3). This could be attributed to the reduced diffusion combustion phase for biodiesel achieved with the help of fuel bound oxygen, which enhances the combustion rate and smoke emissions. The use of biodiesel reduced the smoke emissions by 23.5% than to the diesel fuel Figure 4).

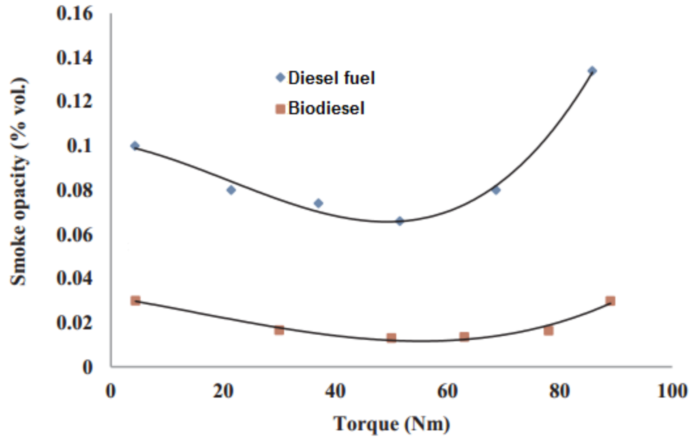

Figure 3: Effect of oxygenated fuel on smoke opacity for diesel and biodiesel

3.3 Oxidation Reactivity of Particulate

Figure 4 shows the particulate oxidation reactions of mass loss from combustion of biodiesel and diesel fuel. According to the Figure 4, it can be observed that high reactivity produced from the combustion of biodiesel compared to the diesel. In addition, it was found that the activation energy to oxidising the particulate emissions higher in case of biodiesel compared to the diesel fuel. This can be beneficial to reduce the total concentration of particulate matter in the combustion cycle and along the exhaust pipe [ ].

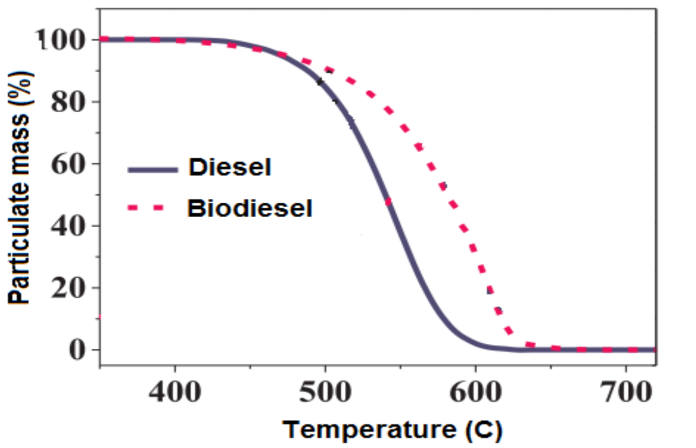

Figure 4: Effect of oxygenated fuel on mass loss of particulate for diesel and biodiesel

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3.4 Engine Performance and Exhaust Gas Emissions

Figure 5 shows the effect of oxygenated fuel on brake thermal efficiency for diesel and biodiesel. It can be noticed that the brake thermal efficiency increased from biodiesel combustion more compared to the diesel fuel. Figure 6 shows the impact of oxygenated fuel on exhaust gas emissions such as carbon monoxide (CO), nitrogen oxide (NO_X), and total hydrocarbons (THC). The level of CO and THC reduced from oxygenated fuel than to the diesel. The two functions of absence aromatic compounds and oxygen content in the biodiesel properties enhance the reduction the gaseous emissions [12]. More complete combustion process consists of the following events including vaporization, mixing, atomization, and combustion. It is stated that alternative fuels produces lower exhaust emissions than to the diesel fuel [8, 14, 28]. The fuel can be relatively completely combusted producing a small quantity of THC emissions, since post injection is activated close to the main injection [26]. Less engine-out CO emissions can be occurred with earlier injection timing [8] in this range can lead to more complete combustion [8]. The engine-out NO_X concentrations decreased for biodiesel mainly because the thermal NO_X formation is inhibited [29]. On the other hand, it is documented in some work that NO_X emissions increased from alternative fuels than to the diesel [30].

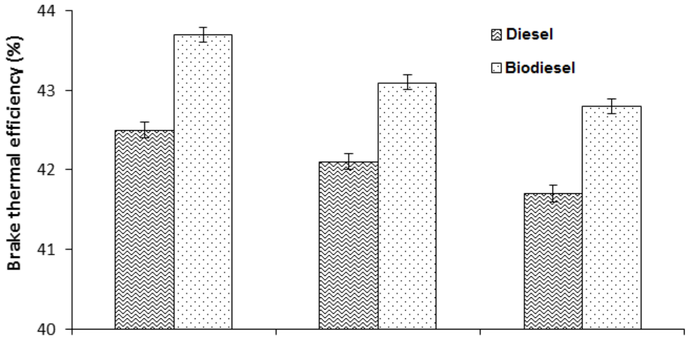

Figure 5: Effect of oxygenated fuel on smoke opacity for diesel and biodiesel

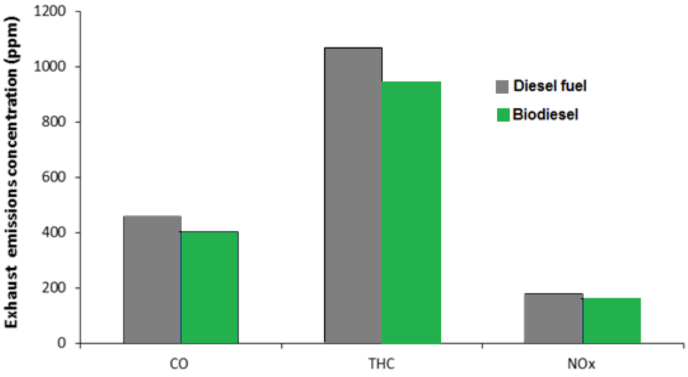

Figure 6: Effect of oxygenated fuel on smoke opacity for diesel and biodiesel

IV. CONCLUSIONS

The influence of oxygenated fuel on oxidation reactivity of particulate emission, soot emissions, engine performance, and exhaust gas emissions was investigated in this study. The results show that the presence of oxygen in biodiesel used in this study is enough to oxidise the soot emissions and increase the activation energy. It was concluded that the high activation energy encourage the oxidation rat of particulate emissions in biodiesel compared to the diesel fuel. The combustion of biodiesel alleviates the exhaust gas emissions and improves the Brake thermal efficiency. It was found that the CO and HC concentrations increased with presented post-injection for diesel and biodiesel. It is concluded that CO, NO_X, and THC reduced when using biodiesel fuel compared with conventional fuel. It was indicated that the combustion of biodiesel producing lower level of smoke opacity than to the diesel. This can be achieved with relative enhancement in brake thermal efficiency. It was found that the smaller particulate emissions produced from biodiesel combustion than to the diesel fuel combustion. The interaction of biodiesel with engine operating conditions has been shown to be a possible for emissions decrease. The presence of the hydroxyl group has been shown to be beneficial in terms of particulate emissions and exhaust gas emissions.

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