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To cite this article: Melati Nurul Insani *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **927** 012026

IOP Conf. Series: Earth and Environmental Science **927** (2021) 012026 doi:10.1088/1755-1315/927/1/012026

Plasma-Ozone Treatment of Air Supply on Performance and Emissions of Diesel Engine

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Abstract. In improving performance and reducing exhaust emissions in combustion engines, the addition of ozone to the air supplied in the combustion chamber was studied. In this research, ozone can be produced using plasma technology (plasma-ozone) which is a simple and eco-friendly technology. Plasma-ozone was generated using the Dielectric Barrier Discharge (DBD) method. Air is passed in plasma-ozone reactors at different voltages with an ozone variation of 3 mg, 12 mg, 15 mg and 18 mg is obtained. Ozone concentration was detected using an Ozone meter O_3 Air Quality Detector and OPA-100 was used to determine exhaust emissions. The result showed that the addition of ozone to the air supply has no significant effect on brake power but is able to increase specific fuel consumption, increase cylinder pressure, shorten combustion processes, and reduce heat release values. The addition of ozone decreases the opacity of exhaust emissions in TV-1 diesel engines become more eco-friendly.

1. Introduction

The diesel engine is the power source of commercial transport, being employed in trucks, buses, trains, and ships, as well as off-road industrial vehicles such as excavation machinery and mining equipment. It has high efficiency, durability, and reliability together with their low-operating cost[1]. However, the global diesel fuel vehicle fleets impose substantial impacts on air quality, human health, and climate change[2][3]. Especially, diesel exhaust gas contains a higher amount of carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbon (HC), sulfur oxide (SOx), particulate matter (PM), and NOx emissions that are responsible for severe environmental and health problems[4][5]. Previous studies indicate that on-road transportation sector emissions are a major contributor to elevated surface $PM_{2.5}$ and O_3 concentrations, which are associated with approximately 165,000–385,000 human premature deaths per year[6]. Because of excess NOx, diesel has typically received more attention than gasoline. Reduction of transportation emissions plays a critical role in achieving. Therefore, the potential scope of mitigation in this sector needs to be assessed.

Previous research has studied fuel modifications to determine the effect of performance and emissions reduction on diesel engines[7][8][9]. In general, the current use of fuel has achieved maximum use of alternative energy (100% biodiesel), so it needs development in innovation. The addition of hydrogen reduces specific fuel consumption, and energy consumption also increases by about 20%[10]. The addition of hydrogen when mixed with air is able to reduce emissions [11] However, storage and handling of hydrogen liquids are also very difficult. Methoxyethyl acetate

(MEA) is also capable of being used to reduce diesel emissions. The results showed a decrease in smoke opacity of about 50% and the thermal efficiency of the engine increased by about 2%[12].

The additives added to natural gas used to be nitrates, peroxides, and many other reactive particles[13]. Ozone is interesting as an accelerator, especially because of its oxidizing properties. Currently, the combustion process can also involve ozone as an oxidizer. The effects of ozone in combustion have been studied during chemical reactions [14][15]. The addition of ozone can also reduce emissions in diesel engines[16]. Compressed ignition (CI) engines in the combustion chamber consume air with ozone, offering low emission potential with improved performance. Ozone gas, which is a species with a very high level of chemical reactivity, can be utilized to control and enhance the combustion process[17][18]. The increased seeded ozone augments energy and exergy efficiency[19]. The results of experiments conducted so far show the benefits resulting from the addition of ozone in terms of fuel consumption and reduction of exhaust gas toxicity[20]. Yamada et al. [21] conducted experimental research in an HCCI engine and proved ozone as one of the most promising promoters of combustion that engenders the reduction in ignition timing and maintains the combustion under low equivalence ratios. Liang et al have studied the burning of ozone in ignition mixed with $H_2/CO/N_2$/air. It was found that a maximum combustion increase of 18.74% at a ratio of $\Phi = 0.7$[22]. Halter et al reported that ozone addition resulting in an increase of 3-8% during 0.8-1.3 cm/s at methane burning speed [23]. In addition, Yagyu et al [24] showed a change in the composition of hydrocarbon compounds with the addition of ozone to internal combustion engines analyzed using FTIR. However, the O_3 concentration produced by the by-product is very low 0.62g/m^3 in the test, although when the injected O_3 exceeds about 2g/m^3, O_3 is emitted as an extra. Previous studies have shown that O_3 can to accelerate ignition[25], change fuel emissions[26], and reaction characteristics[27]. Thus, the improved energy conversion efficiency of internal combustion engines can be done with the addition of ozone.

In this study, ozone was produced by utilizing plasma technology. Plasma-assisted combustion has shown the potential to enhance and control the combustion process[28][29]. A basic principle of plasma-assisted combustion is that the active substances produced by plasma, such as atomic oxygen, excited O_2, and ozone (O_3), can enhance the combustion process. Ozone produced from plasma is called plasma-ozone. Plasma-ozone using the plasma Dielectric Barrier Discharge (DBD) method. This method can produce hundreds of kilograms of ozone per hour with high power consumption (Megawatts). Hence, the addition of plasma-ozone is expected to increase efficiency and reduce exhaust emissions from TV-1 diesel engines. So, this study aims to observe the effect of plasma-ozone addition on the performance and exhaust emissions of TV-1 diesel engines with biodiesel fuel 30% (B30).

2. Methodology

The test was conducted using a VCR engine test setup 1 cylinder, four-stroke with EGR (computerized). Diesel engine connected to eddy current type dynamometer for loading. Engine parameters are shown in Table 1. The experimentations was conducted at a constant engine speed of 1500 rpm with load variation of 1 kg, 3 kg, 5 kg, 7 kg, 9 kg, and 11 kg. Biodiesel 30% (B30) was used as a fuel. Ozone properties are shown in Table 2.

Table 1. Engine Parameters

Parameters	Note	Dimension
Cylinder bore diameter (mm)		87.5
Piston stroke (mm)		110
Number of cylinders		1
Engine speed (RPM)	Constant	1500
Connecting rod length (mm)		234
Diameter of the manifold, (mm)		32

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Power (kW)		3.5
Engine coolant temp	Use up to	60 °C
Compression ratio		18:1

Table 2. Ozone Properties[30]

Density	2.14 kg/m^3
Molecular weight/molar mass	48 g/mole
Boiling point	-112 °C
Melting point	-192.2 °C
Odour	Similar to chlorine
Hydrogen bond acceptor	2

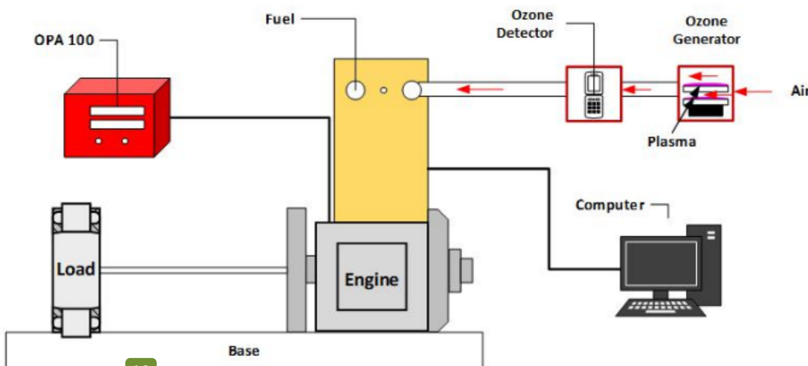


Figure 1. A schematic diagram of the experimental setup

Figure 1 illustrates a schematic diagram of the experimental setup. Plasma-ozone Dielectric Barrier Discharge (DBD) was used as an ozone production tool. Ozone was added into the intake manifold of the engine, a DBD ozone generator was installed in the oxygen gas line, such that the quantity of generated ozone can be adjusted by changing the frequency of the signal to reach the concentration target. Accordingly, it enables a precise calculation of the measured ozone additives. The concentration of ozone variation of 3, 12, 15, and 18 mg. After a while, in a stabilized model, results were recorded every 60 seconds. The quantity of ozone was measured by using an Ozone meter O_3 Air Quality Detector directly at the exit of the ozone generator. The results were evaluated to compare the fuel consumption, temperatures, pressures, and emissions. Exhaust emissions tests used OPA-100 tools.

Result and Discussion

Experimental results, conducted for both conditions with and without the addition of ozone, are presented in figures 2-7.

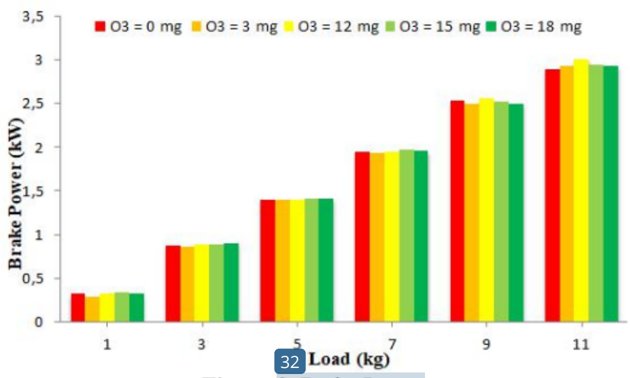


Figure 2. Brake Power

Figure 2 shows the output brake power to the load, where the load is directly proportional to the brake power. This is in line with the results of this study which can be observed for a load of 11 kg with the addition of ozone with a concentration of 12 mg having a brake power of 3 kW and 2.89 kW for a brake power without the addition of ozone. It is not only the addition of an ozone concentration of 12 mg that affects the increase in brake power. Ozone concentration of 15 mg at a load of 7 kg is also able to increase brake power. However, the addition of 12 mg of ozone, the increase in brake power is more stable than other variations of ozone addition. The results of this study indicate that the specific fuel consumption before and after the addition of ozone tends to be the same. So that the air supply has no significant effect on fuel consumption. The rotation in the addition of ozone tends to be slightly larger. It also shows various variations of the addition of ozone which results in greater brake power[19].

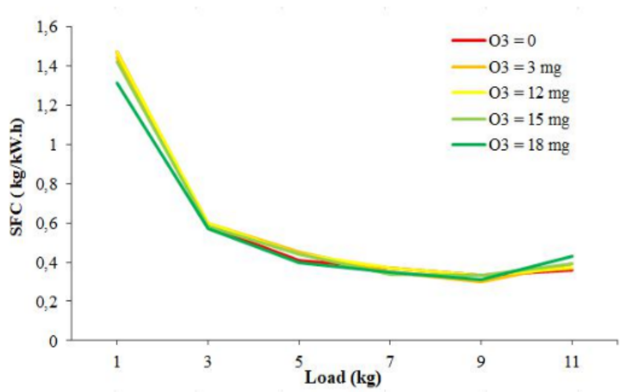


Figure 3. Specific Fuel Consumptions

Figure 3 shows the correlation of specific fuel consumption with load variation (1, 5, 7, 9, and 11 kg) on several variations of ozone addition. As the amount of ozone emitted into the combustion chamber increases, this results in a decrease in SFC. This results in better combustion in diesel engines[10]. It can be seen, at a load of 1 kg the addition of ozone with a concentration of 18 mg has an SFC value of 1.31 kg/kW.h while with the same load without the addition of ozone it has an SFC value of 1.47 kg/kW.h. The results of this study showed that specific fuel consumption before and after the addition of ozone was a noticeable difference. So the air supply has a significant effect on fuel consumption. It should be noted that this study only used the same fuel (biodiesel 30%).

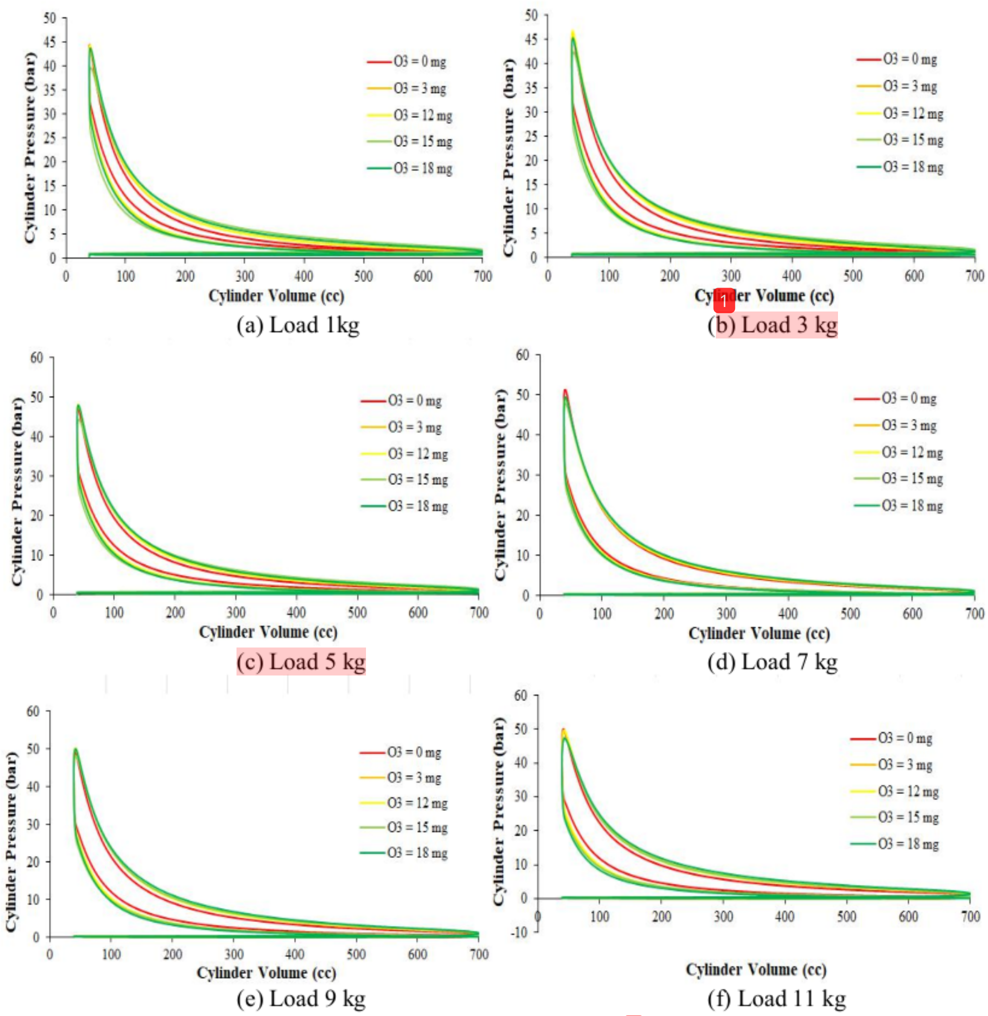
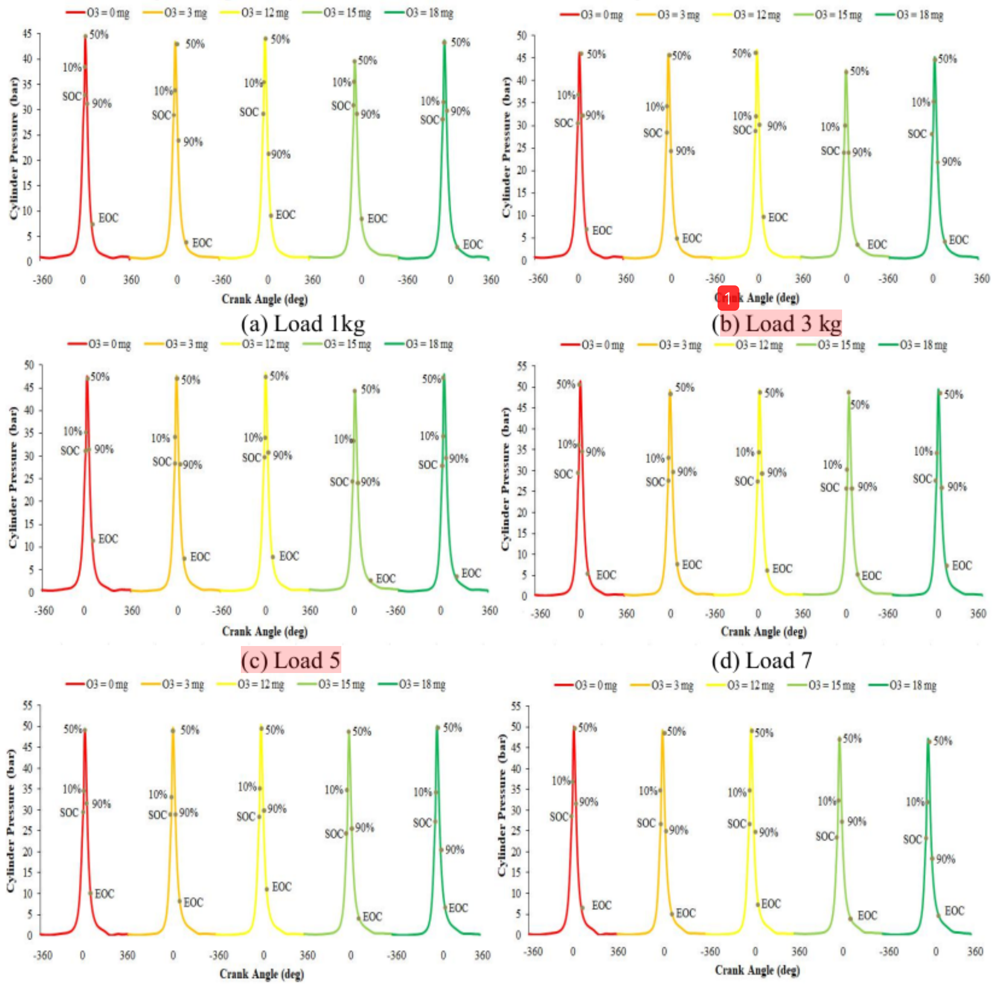


Figure 4. Comparison of cylinder volume to cylinder pressure (a) load 1 kg, (b) load 3 kg, (c) load 5 kg, (d) load 7 kg, (e) load 9 kg, (f) load 11 kg

Figure 4 shows a graph of the ratio of cylinder volume to cylinder pressure at each load (1, 5, 7, 9, and 11 kg) with engine speed considered constant at 1500 rpm. Generally shows that the addition of ozone can affect the cylinder pressure value during the combustion process. The addition of ozone the air into the combustion chamber will cause an increase in the cylinder pressure value. At load 1 the highest peak value of cylinder pressure is 44.34 bar with an ozone concentration of 12 mg. At load 3 the highest peak value of cylinder pressure is 46.81 bar with an ozone concentration of 12 mg. At load 5 the highest cylinder pressure peak value is 48.28 bar with an ozone concentration of 12 mg. at load 7 the peak value of the highest cylinder pressure is 51.42 bar without the addition of ozone. At load 9 the peak value of the highest cylinder pressure is 50.09 bar with an ozone concentration of 12 mg. And at load 11 the highest cylinder pressure peak value is 49.90 bar with no addition. So that from the results of the study it can be seen that in general the addition of ozone affects the cylinder pressure value on the engine, especially at an ozone concentration of 12 mg.



(a) Load 1kg (b) Load 3 kg

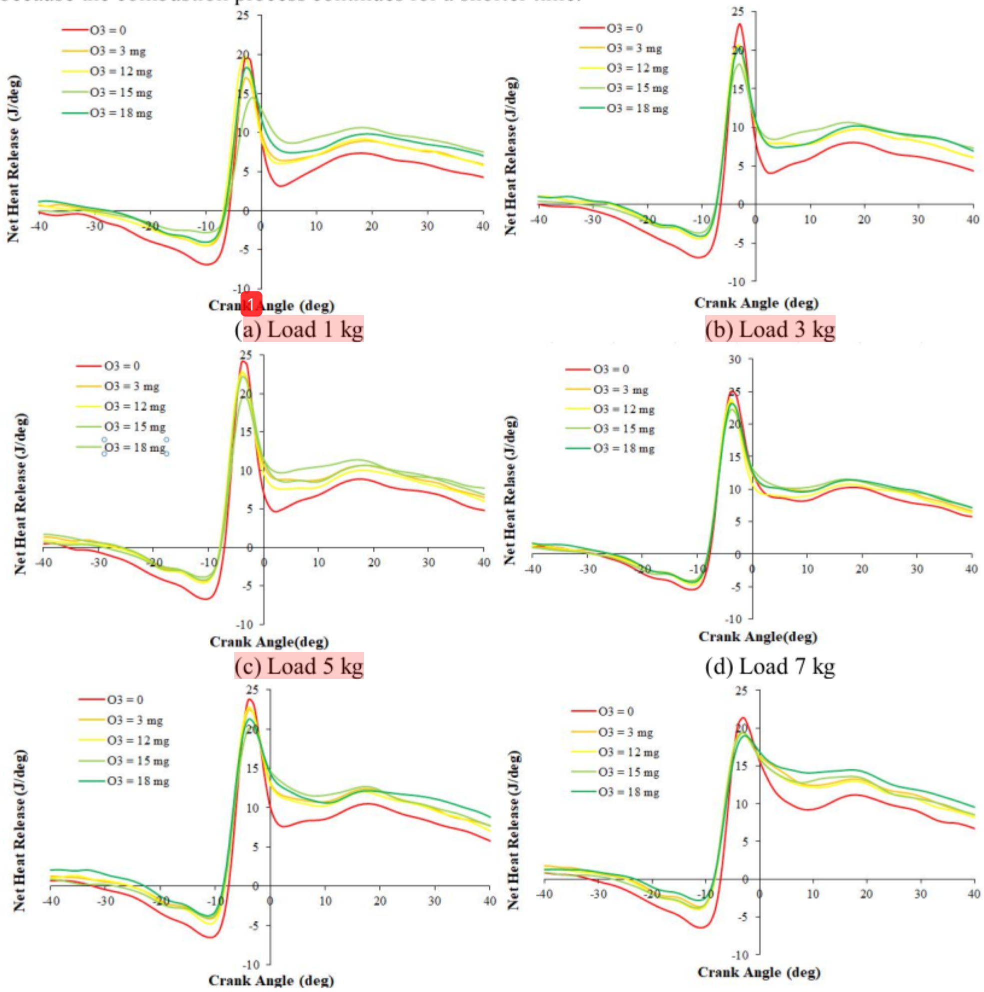
(c) Load 5 (d) Load 7

(e) Load 9 kg (f) Load 11 kg

Figure 5. Comparison of cylinder pressure to crank angle (a) load 1 kg, (b) load 3 kg, (c) load 5 kg, (d) load 7 kg, (e) load 9 kg, (f) load 11 kg

Figure 5 shows the relationship between cylinder pressure and crank angle at each load with variations in ozone concentration which describes the combustion process that occurs in the diesel engine cylinder. the vertical line shows the pressure line and the horizontal line shows the crank angle scale. 30% biodiesel fuel is injected into the cylinder at the end of the compression process, not once injection but for a certain period. As described from the start of combustion (SOC) to the 90% point this period is termed the ignition delay period. At the 10% point the fuel starts to burn. Starting from the 10% point, the graph line continues to rise until the end of fuel injection into the cylinder at the 90% point. After the 90% point, the fuel combustion process continues until the end of combustion

(EOC), but the pressure in the cylinder begins to decrease. In this study, it can be seen that the addition of ozone affects the SOC and EOC distances from the top dead combustion (TDC), where the addition of 12 mg of ozone is better than other variations of the addition of ozone at a certain load. This is because the combustion process continues for a shorter time.



(a) Load 1 kg (b) Load 3 kg (c) Load 5 kg (d) Load 7 kg (e) Load 9 kg (f) Load 11 kg

Figure 6. Comparison of crank angle to net heat release (NHR) at ozone variations (a) load 1 kg, (b) load 3 kg, (c) load 5 kg, (d) load 7 kg, (e) load 9 kg, (f) load 11 kg

Figure 6 shows the ratio of heat release or heat release to the crank angle at 1500 rpm engine speed. Overall the maximum value of heat dissipation at each load was obtained without the addition of ozone. while the most effective decrease in the value of heat release is with the addition of 15 mg of ozone which is indicated by the smallest NHR value. Thus making the least heat wasted. In this study, the addition of ozone seems to affect the rate of heat release.

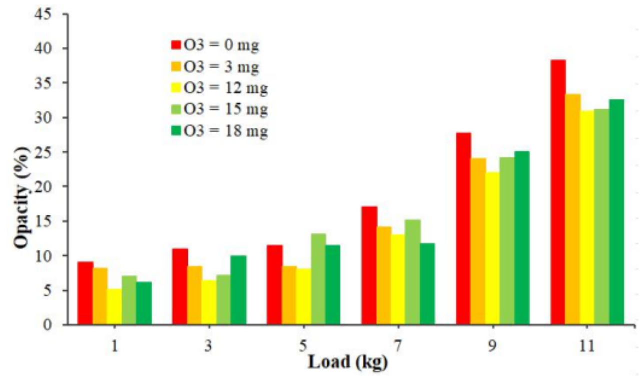


Figure 7. Smoke opacity

As illustrated in Figure 7 where the ratio of the percentage of smoke opacity in relation to the addition of a load where the ozone concentration is varied. The greater the load is given, the greater the percentage of smoke opacity. For example, at maximum load (11 kg) the opacity of smoke was 38.3%, 33.3%, 30.9%, 32.6% and 31.2% for variations in ozone concentration 0 mg (without adding ozone), 3 mg, 12 mg, 15 mg and 18 mg. So that the addition of ozone can reduce the emission of smoke opacity during the combustion process in diesel engines. This is due to the occurrence of oxidation between the fuel mixture and additives such as OH and O, then it can also be produced from changes in ozone (O_3) where the reaction is ($O_3 \rightarrow O_2 + O$)[19]. This is what can improve the combustion process by increasing the reaction rate of the fuel which has an impact on reducing and delaying combustion when compared to the absence of ozone addition.

Conclusions

The performance and emission were investigated successfully, in this study. The diesel engine was analyzed with ozone air mixture as (3 , 12, 15, and 18 mg) at different engine loads (1 kg, 3 kg, 5 kg, 7 kg, 9 kg, 11 kg) and the constant speed, 1500 rpm. The addition of ozone to the air supply has no significant effect on brake powet but is able to increase specific fuel consumption, increase cylinder pressure, shorten combustion processes, and reduce heat release values. While on the smoke opacity the use of ozone tends to be more eco-friendly at all concentration variations.

Acknowledgment
This work is supported by of Hasanuddin University (Grant numbers: 961/UN4.22/PT.01.03/ 2021).

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