Study of alcohol fuel of butanol and ethanol effect on the compression ignition (CI) engine performance, combustion and emission characteristic

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Study of alcohol fuel of butanol and ethanol effect on the compression ignition (CI) engine performance, combustion and emission characteristic

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Abstract. Diesel engine which is one of the larger contributors to total consumption for petroleum is an attractive power unit used widely in many fields. However, diesel engines are among the main contributors to air pollutions for the large amount of emissions, such as CO, CO_2 and NOx lead to an adverse effect on human health. Many researches have been done to find alternative fuels that are clean and efficient. Biodiesel is preferred as an alternative source for diesel engine which produces lower emission of pollutants. This study has focused on the evaluation of diesel and alcohol-diesel fuel properties and also the performance, combustion and exhaust emission from diesel engine fuelled with diesel and alcohol. Butanol and ethanol is blend with diesel fuel at 1:9 ratio. There are three test fuel that is tested which Diesel (100% diesel), D90BU10 (10% Butanol and 90% diesel) and D90E10 (10% Ethanol and 90% diesel). The comparison between diesel and alcohol-diesel blend has been made in terms of fuel properties characterization, engine performance such as brake power (BP) and brake specific fuel consumption (BSFC) also the in cylinder maximum pressure characteristic. Thus, exhaust gas emission of CO, CO_2, NOx and O_2 emission also has been observed at constant load of 50% but in different operating engine speed (1100 rpm, 1400 rpm, 1700 rpm, 2000 rpm and 2300 rpm). The results show the addition of 10% of each butanol and ethanol to diesel fuel had decreased the fuel density about 0.3% to 0.5% compared to mineral diesel. In addition, viscosity and energy content are also decrease. The addition of 10% butanol had improved the fuel cetane number however the ethanol blends react differently. In term of engine performance, as the engine speed increased, BP output also increase respectively. Hence, the alcohol blends fuel generates lower BP compared to diesel, plus BSFC for all test fuel shows decreasing trend at low and medium speed, however increased gradually at higher engine speed. Thus, D90BU10 had higher BSFC compared to mineral diesel and D90E10. In general, the addition of alcohol blend in diesel fuel had increase the BSFC. In term of in cylinder pressure, as the engine speed is increased, the crank angle noted to move away from TDC for all test fuel. The maximum cylinder pressure increased at low and medium speed, but decrease in higher engine speed. The addition of 10% of butanol and ethanol in the mineral diesel decreased the maximum cylinder pressure. Meanwhile, O_2 emission of D90E10 is higher compared to D90BU10 due to higher oxygen content found in ethanol. The CO_2 emission of D90BU10 recorded higher compared to mineral diesel due to the high oxygen contents in the alcohol. CO emission of alcohol blend on the other hand had lower emission at higher engine speed compared to mineral diesel. As engine speed is increased, NOx emission of mineral diesel and D90E10 had decreased gradually. However, D90BU10 had increased of NOx emission at lower to medium engine speed, than gradually decreased at higher engine speed.

1. Introduction

The major air pollution sources are mostly coming transportation, fuel combustion by stationary sources, industrial processes, oil and gas industries solid wastes and many more. In recent decades, the number of vehicles on the roads has steadily increased. The exhaust fumes such as CO, CO_2, NOx and others from this rapidly expanding fleet of vehicles is one of a principal cause of the worsening air quality nowadays.

Research on adverse health effects of air pollution recorded and led to several changes in practices and regulations since the great smog of 1952 in London. Thus, many of the scientist and policy makers work together to solve the problems in different angles of view. The investigation included the epidemiological and the toxicological effect of airborne pollutants. Although the pollution problems are alarming, but the needs of ICE unit in industries, transportation and in other field still getting high demand.

Diesel engine is an example of attractive power unit used widely in many fields due to its great advantages over gasoline engines such as lower fuel consumption, lower carbon monoxide emissions, better torque characteristics and higher reliability [1, 2]. Hence, diesel engine being the main contributors to air pollutions for the large amount of emissions, especially particulates and nitrogen oxides (NOx), diesel engine without a doubt still getting its demand over the years. Therefore, controlling these emissions is one of the most important aspects of modern air quality management.

Moreover, a few studies related comparative engine performance and emission characteristic of different techniques involved in diesel engine as dual-fuel engine operation had being studied by Abedin et al. [3] and reported to have decrease in PM emission in different mode. Besides, Huang et al. reported that by using diesel blends with pine oil under low temperature combustion, the morphology and reactivity of soot emitted was decrease gradually by the engine load condition and fuel composition [4].

Table 1 illustrates how the European Union emission standards for heavy-duty diesel engines have tightened since EURO I, which came into force in 1992. Diesel engines are associated with combustion noise, engine vibration, and the problem of nitrogen oxides (NOx) - particulate matter (PM) trade-off emissions. Researchers have made lots of effort to reduce toxic and greenhouse gases emitted from these engines.

Several advanced technologies for clean diesel engines have been introduced and been categorized into four strategies such as fuel and fuel additive, fuel injection systems including in-cylinder technology, lubricant oil development and exhaust gas after-treatment devices.

All these approaches have been developed into more technology advanced levels since internal combustion (IC) engines are invented with many researchers and engine manufacturers have greatly involved in improving the technology behind the diesel engine [5-7].

Table 1. Past, current and proposed future for European emission standards [8].

Type of emission		**Diesel**			
		EURO4	EURO 5a	EURO 5b	EURO 6
		Jan.2005	Sept. 2009	Sept. 2011	Sept.2014
THC	mg/km	-	-	-	-
NMHC	mg/km	-	-	-	-
HC + NOx		300	230	230	170
NOx	mg/km	250	180	180	80
CO	mg/km	500	500	500	500
PM	mg/km	25	5	4.5	4.5
PN#	#/km	-	-	6.0E+11	6.0E+11

With the internal combustion engine are still leading the needs of industries. The usage of fossil fuel is still the number one fuel for this type on engine. In recent years, the non-renewable energy source is decreasing in amount, becoming more and more limited and surely will be finish in approximately less than 100 years from now. However, thanks to the advancement of technologies, human now days able to create new form of renewable energy sources, that can be replaced in a short period of time. For example, bio fuel is one of the natural alternative renewable energy sources which come out by using ethanol from naturally grown plant. Biodiesel is an example of bio fuel that is eco-friendly fuel made from natural, renewable sources.

Previous studies have been proving that the biodiesel can decrease the emission compare to diesel. However, contain emission such as NOx cannot be reduced. It was reported that by present of water, the NOx can be reduced. Thus, this study is to know the performance, combustion and emission of alcohol blend fuel as alternative fuel. Biodiesel is a pure natural, renewable fuel suitable to be used in any situation where basic petroleum diesel is currently used. Biodiesel is made by combining alcohol with vegetable oil or recycled cooking greases. The physical properties of biodiesel are similar to petroleum diesel, plus it's a cleaner-burning alternative. Biodiesel is biodegradable, nontoxic, and essentially free of sulphur and aromatics. Diesel fuel will lead to the high emission of nitrogen compounds and particulate matter. The emission of these chemicals will lead to acid rain, smog and poor health conditions. However, according to the research, biodiesel will increase the nitric oxide and nitrogen oxide. Nitrogen oxide very dangerous to human and environment. So, by using the biodiesel, the target to decrease the emission cannot be achieve.

Biodiesel with alcohol additives is the combination of biodiesel and alcohol. To investigate whether it practically or not, the experiment on engine testing is carry out to investigate emission properties and what is the effect to the engine performance. This paper will introduce the diesel mixed with alcohol fuel (butanol and ethanol) as a fuel for the compression ignition engine with mineral diesel set as a baseline fuel.

2. Methodology and experimental setup

2.1. Engine setup and specification

Fuel engine testing was conducted at Automotive Engine Centre (AEC) laboratory located in University Malaysia Pahang. Experiment and tests were conducted at Faculty of Mechanical Engineering laboratory located at University Malaysia Pahang. The naturally aspirated YANMAR TF120 single cylinder, horizontal diesel engine with water cooling system, a 15kW eddy current dynamometer equipped with dump load, two fuel beakers which can accommodate up to 1 liter, a Meriam Laminar Flow Element (LFE) for air intake system and TFX data acquisition system as well as a KANE Autoplus 5-2 gas analyser is used for this research. Thus, Figure 1 shows the overall project test rig schematic and Table 2 shows the specification of the engine.
Figure 1: Schematic diagram of the test rig.

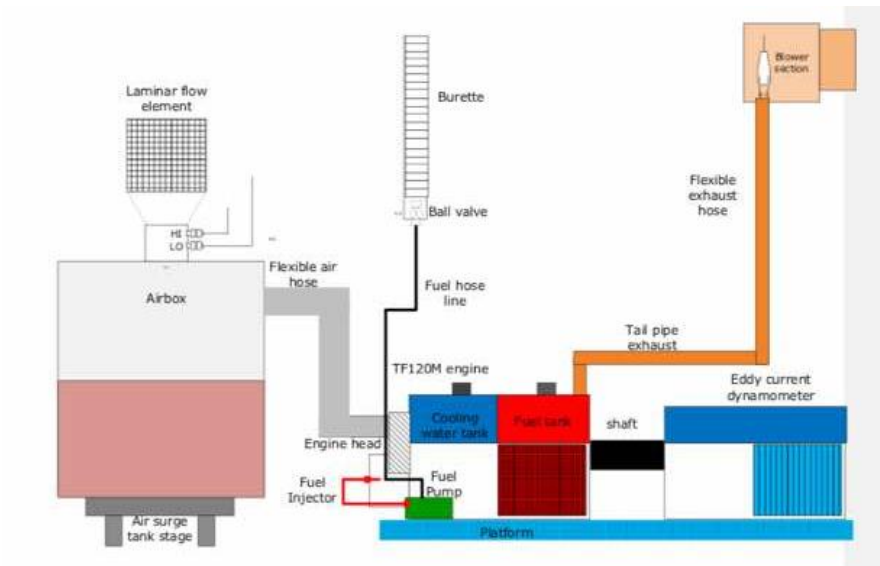

Figure 1. Schematic diagram of the test rig.

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Table 2. Engine specification.

Description	Specification
Engine model	YANMAR TF120
Engine type	Horizontal, diesel 4 stroke cycle
Combustion system	Direct injection
Number of cylinders	1
Bore x Stroke (mm)	92 x 96
Displacement (L)	0.638
Dimensions (mm)	Length: 776 Height: 621 Width: 379.5
Injection timing	17° BTDC
Fuel injection pump	Bosch injection
Pressure (kg/cm2)	200
Compression ratio	17.7
Continuous output (HP)	10.5 HP at 2400 RPM
Rated output (HP)	12 HP at 2400 RPM cooling
System	Water cooled (radiator type) cooling water
Capacity (L)	2.3
Dry weight (kg)	102
Connecting rod length (mm)	149.5

2.2. Test fuel preparation and measurement

For experiment testing, three different type of fuel are going to be experimented which is diesel, D90BU10, and D90E10. Diesel fuel will have 100% diesel, while D90BU10 will contain 10% of butanol, 90% of diesel fuel and for D90E10 contains 10% of ethanol and 90% of diesel fuel. Sample of diesel fuel is mixed with alcohol (butanol and ethanol) and mixed at low stirring rate using electric magnetic. For 15 minutes, the mixture is blended continuously, at room temperature.

In order to measure the viscosity of sample made, The Standard Test Method which is specified for Kinematic Viscosity of Transparent and Opaque Liquids is ASTM Standard D445-88. This test method is frequently used to measure the kinematic viscosity of liquid petroleum products. Based on ASTM Standard, the measurement is repeated twice with the tolerance between those two results is 0.02 [9]. Kinematic viscosity values were determined with Cannon-Fenske viscometers [10]. The manufacturer of the Cannon-Fenske type viscometer tubes supplied calibration constants at 40 and 100°C. These constants were generally different by approximately 0.5%, probably due to dimensional changes in the tubes at different temperatures. Density can be measured referring to standard ASTM D1298 using Portable Density/Specific Gravity Meter model DA-130N from industry. The sample is measured at temperature of 15°C. This is a microprocessor controlled system with an LED display. It has a range of 0.0000 to 2.0000 g/cm^3 with an accuracy of +/- 0.001 g/cm^3. In order to measure the heating value of blended fuel, standard that needed to follow is ASTM D4809. Calorimeter system is used when there is a heat leak during the calometric pre-period

The test procedure of cetane number has been subject to criteria based on the difference between the cetane numbers test configuration and operating condition. The test procedure to determine cetane number is complicated and might involves considerable uncertainty due to experimental error. The test needs engine while testing. One of the ways of solving the problem of this properties determination is to develop models to predict the cetane number when some parameters are known. The predicated CN of biodiesel is comparable to that of the actual CN of the biodiesel, and it has been concluded that the CN of biodiesel can be predicted based on thermal properties. In determining cetane number, ignition quality tester is used referring standard of ASTM D613. The measured Cetane number and physical properties of the biofuels were analysed to obtain regression equation and to rank the physical properties based on R2 values.

2.3. Operating condition
The tests were carried out at a steady-state testing condition. It was conducted with 3 different test fuels (diesel fuel, D90BU10 and D90E10) at 5 different engine speeds which were 1100 rpm, 1400 rpm, 1700 rpm, 2000 rpm and 2300 rpm. The load applied on the engine was kept constant at 50%.

3. Results and discussion

3.1. Analysis of fuel properties
Summarized fuel properties are illustrated in Table 3.

Table 3. Fuel properties summary.

Properties	Testing standard	Types of fuel				
		Reference fuel		Test fuel		
		Ethanol	Butanol	Diesel	D90BU10	D90E10
Formula		C2H5OH	CH3CH(OH)CH2CH3 / C4H9OH	C12H24		
Viscosity (mm2/s) (cSt)	D 445	1.2	4.21	5.144	3.576	3.674
Density at 25^{o}C(g/m^{3})		0.79	0.81	0.8264	0.8236	0.8226
Cetane number	D 613	8	25	47.8	51	43.82
Energy content (MJ/kg)		26.8	32.5	44.8	43.57	43

3.1.1. Fuel density. Figure 2 (a) below shows the test fuel density for Diesel, D90BU10 and D90E10. From the result obtained, test fuel density ranging from 0.8226 9 g/cm³ to 0.8264 g/cm³. Baseline diesel fuel 100% density is 0.8264 g/cm³. The addition of 10% of butanol and ethanol both have different effect on the test fuel density. The addition of 10% butanol to diesel fuel had resulted in decreased of fuel density approximately 0.34% of fuel density. In addition to that, the addition of 10% ethanol had resulted in decreased of fuel density about 0.5%.

3.1.2. Fuel viscosity. Figure 2 (b) shows the test fuel viscosity for diesel fuel, D90BU10 and D90E10 respectively. The viscosities of fuels fall between the ranges of 3.576 to 5.144 mm²/s, where diesel fuel have the highest fuel viscosity compare to the other two test fuel. The addition of alcohol to diesel shows similar result where the test fuel viscosity is decreased. The addition of 10% of butanol and ethanol to diesel had decreased the fuel viscosity approximately 30%. The decrease of viscosity of fuel will decrease the fuel resistivity to the flow of liquid which is due to the internal friction in the moving fluid.

3.1.3. Energy content. Figure 2 (c) show the energy content for Diesel fuel 100%, D90BU10 and D90E10 respectively. Diesel fuel have the highest energy content at 44.8 MJ/Kg while D90BU10 and D90E10 had 43.57 MJ/Kg and 43.0 MJ/Kg of energy content respectively. From the graph we can see that the addition of alcohol to the diesel fuel will decrease the test fuel energy content.

3.1.4. Cetane number. The cetane number is one of the most commonly cited indicators of diesel fuel quality. It measures the readiness of the fuel to auto ignite when injected into the engine. It is generally dependent on the composition of the fuel and can impact the engine’s start ability, noise level, and exhaust emissions [11]. Higher cetane number means that the fuel auto ignites more easily in the engine cylinder. Figure 2 (d) shows the cetane number for Diesel 100%, D90BU10 and D90E10 respectively. The higher the cetane number, the easier for the fuel to ignite the engine. Diesel fuel had lower cetane number compared to D90BU10. However, D90E10 recorded to have lower cetane number compared to diesel fuel 100%.

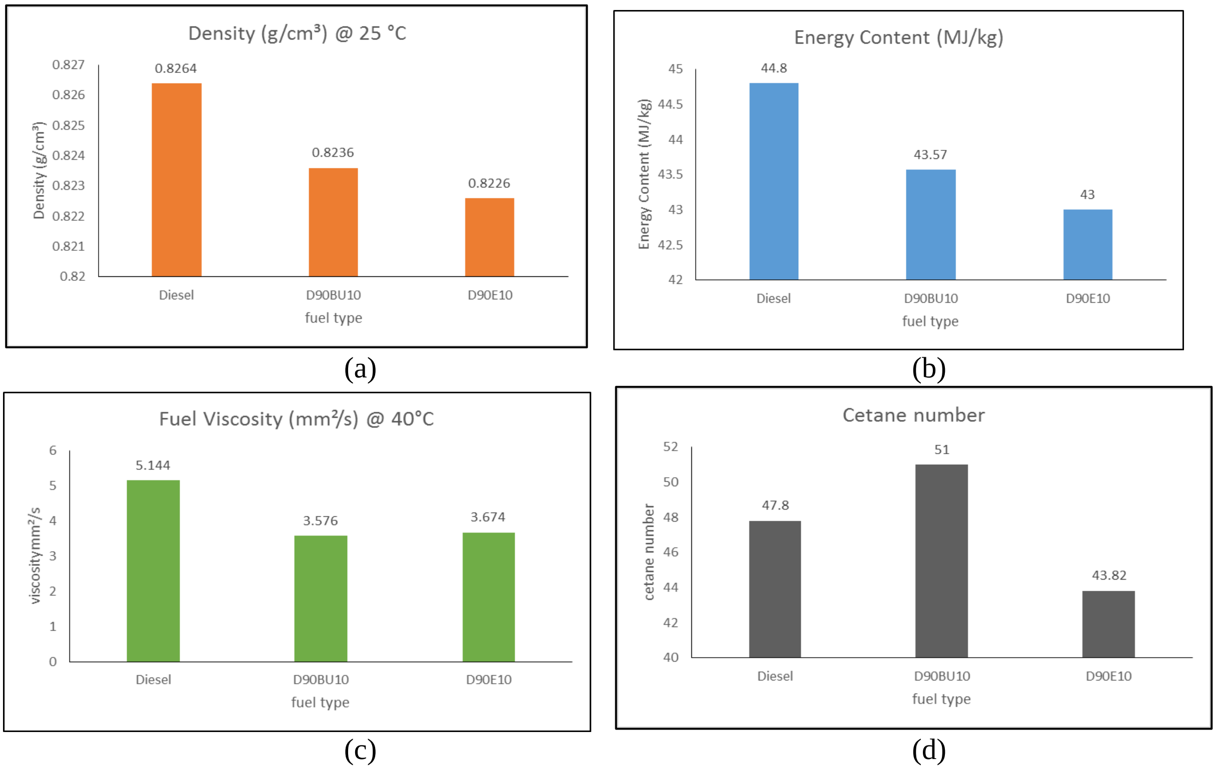

Figure 2. (a) Density, (b) Energy content, (c) Fuel viscosity and (d) Cetane number

3.2. Analysis of engine performance

3.2.1. Brake Power (BP). Figure 3 shows the comparison of engine brake power (BP) output of Diesel, D90BU10 and B90E10 at difference engine speeds. Engine brake power indicates the amount of work of one engine does per unit of time. The output curves are plotted in Fig A with engine speed ranging from 1000 RPM to 2400 RPM.

Some researchers in their respective studies also found similar trend for BP versus RPM [12, 13]. Diesel BP output found to be higher at 1100 RPM and 2300 RPM compared to other two dual fuels. Thus, diesel BP output recorded higher compared to D90E10 at 1700 RPM and 2000 RPM. However, Diesel fuel BP output are lower, compared to D90BU10 at 1400 RPM to 2000 RPM. The maximum BP output recorded at 2000 RPM of 3.5kW for D90BU10, which is 11% higher compared to diesel fuel BP output.

Diesel, D90BU10 and D90E10 have approximately similar density at range of 0.8226 to 0.8286 g/cm3, however due to alcohol blends, the fuel viscosity in dual fuel blend mode is lower compared to diesel fuel. Moreover, lower fuel viscosities lead to greater injector leakage reducing maximum fuel delivery and ultimately reducing the engine power output [14].

Referring from the previous studies of Tuccar et al., the engine brake power output reduced with the butanol addition in the fuel. The decreased in brake power value of the engine was due to the lower energy content of butanol additive compared to the diesel fuel. In addition, oxygen content of the fuel blends also lead to decrease in brake torque [15].

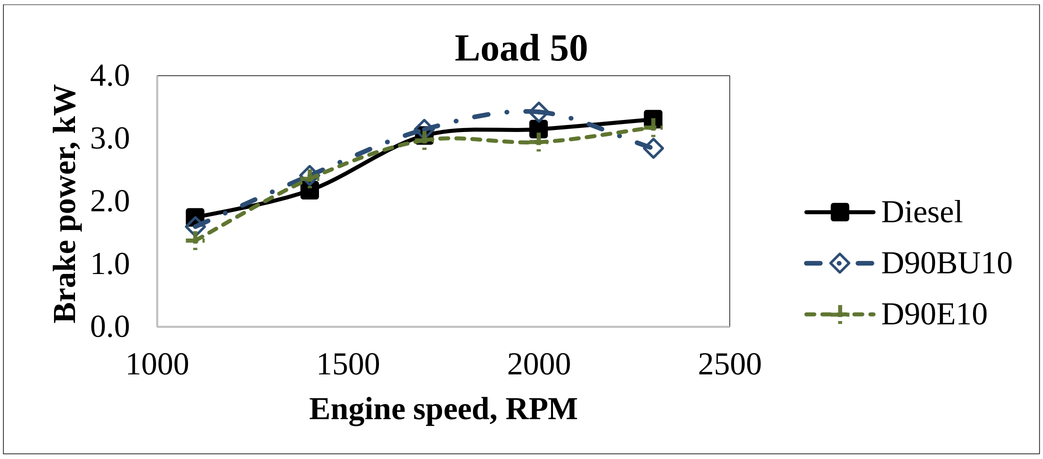

Figure 3. Brake Power versus Engine Speed at 50% load.

3.2.2. Brake Specific Fuel Consumption (BSFC). Brake specific fuel consumption (BSFC) is the amount of engine fuel consume in a certain period to produce one kilowatt of brake power. The brake specific fuel consumption is influenced by physiochemical properties of fuel such as the fuel viscosity, density, cetane number and heating value. Generally, the specific fuel consumption of the alcohol blended fuel is more because of the lower heating value of alcohol.

The analysis result of BSFC in this study can be found in Figure 4. From the graph, shows the BSFC of diesel fuel, D90BU10 and D90E10 at 50% engine load versus engine speed ranging from 1100 RPM to 2300 RPM. BSFC for all test fuel initially shows the decreasing trend from 1100 RPM to 1700 RPM. However gradually increase until 2300 RPM. The increase of BSFC at high speed is due to the increased of friction. At lower speeds. BSFC increase due to increased time for heat losses from the gas too engine cylinder and pistons wall [16].

D90BU10 have higher BSFC output compared to diesel and D90E10 at all engine speed. At 1400 RPM to 2100 RPM, D90BU10 recorded 15.92%, 5.83%, 6.94% and 5.16% higher BSFC output compared to diesel fuel. Thus, D90BU10 recorded highest BSFC output at 2300 RPM with 26.87% higher compared to diesel fuel. While D90E10 recorded lowest BSFC at 1400 RPM with 22.04% lower compared to diesel fuel BSFC. This is incline with the previous studies where the addition of butanol and ethanol in the diesel fuel increases the engine fuel consumption for alcohol and diesel fuel blends due to the lower calorific value [17]. Meaning that, more fuel is needed during combustion stage in order to generate same amount of energy when using pure diesel fuel.

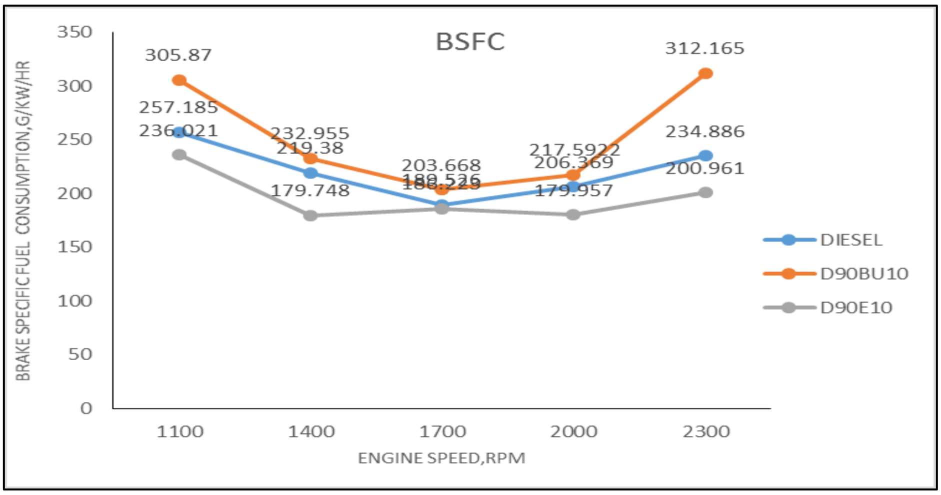

Figure 4. BSFC versus Engine Speed at 50% load.

3.3. Analysis of engine combustion

3.3.1. In cylinder pressure. In cylinder pressure data must be analysed to understand the engine combustion process and events occurring in the combustion chamber. The relationship between the in cylinder pressure and crank angle indicates the performance of the engine. Few factors that will affect peak pressure for example are, compression ratio, types of fuel used, air fuel mixture ratio and engine type. Figure 5 (a) to (e) shows the crank angle versus the peak pressure at different engine speed ranging from 1100 RPM to 2300 RPM for Diesel, D90BU10 and D90E10.

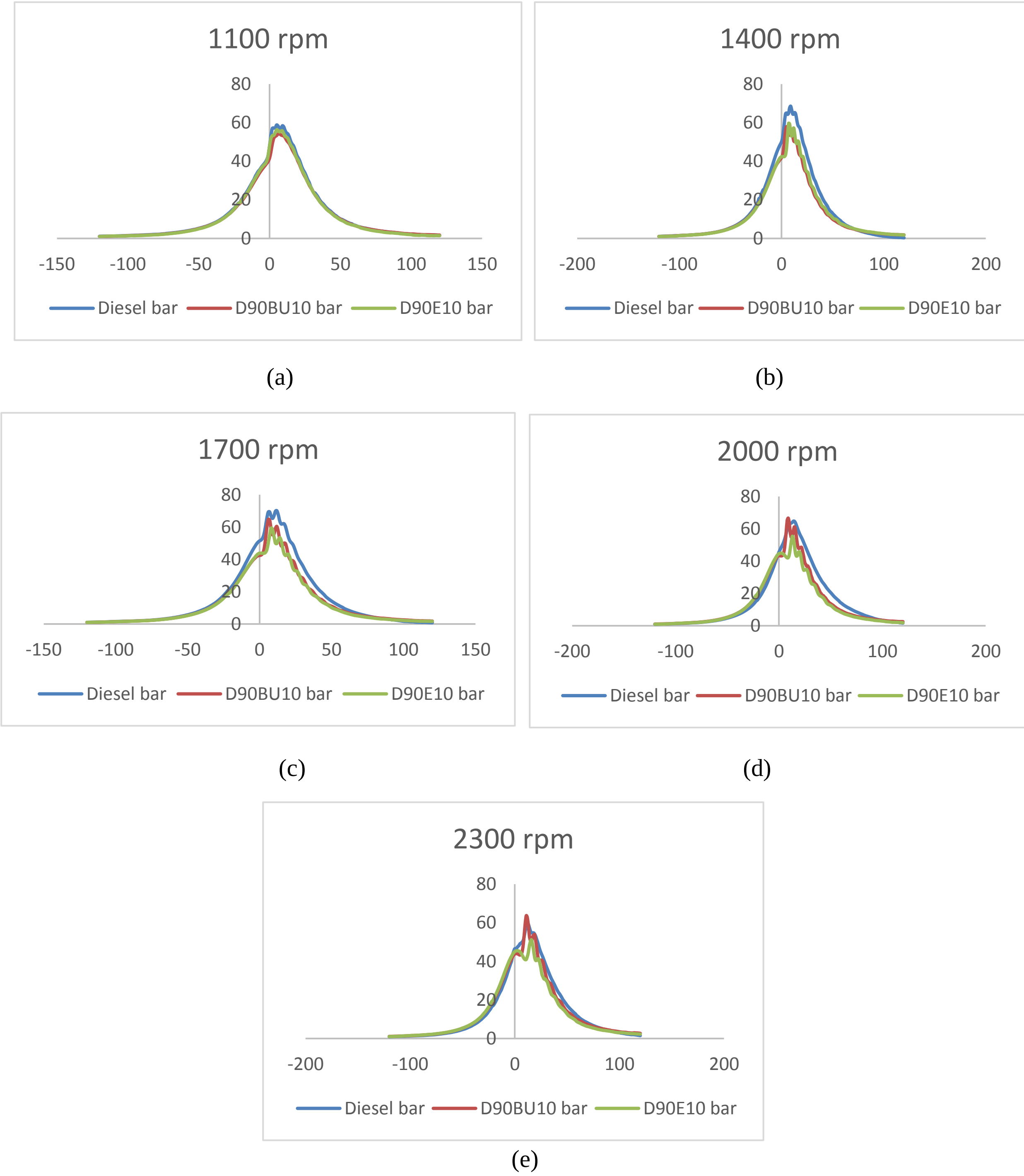

Figure 5. In Cylinder Pressure versus Engine Speed at 50% load.

At 1100 RPM, diesel fuel recorded peak pressure 58.8 bar at 5° ATDC where D90BU10 and D90E10 recorded 54.22 bar at 7° ATDC and 56.27 bar at 5° ATDC respectively. As the engine speed increase, the peak pressure for diesel fuel increase to 68.55 bar at 9° ATDC and 70.09 bar at 12° ATDC respectively for 1400 RPM and 1700 RPM. While for D90BU10, the peak pressure increases to 57.95 bar at 5° ATDC and 64.65 bar at 6° ATDC. D90E10 on the other hand recorded 59.64 bar and 59.34 bar peak pressure at 7° and 8° ATDC respectively for 1400 and 1700 RPM.
At 2000 RPM, diesel fuel and D90E10 in cylinder pressure start to decrease to 64.75 at 14° ATDC and 55.38 bar at 13° ATDC and continue to decrease at 2300 RPM where diesel recorded 59.76 bar at 12° ATDC and D90E10 recorded 51.16 bar at 16° ATDC. Meanwhile, D90BU10 continue to increase in pressure at 2000 RPM where it recorded 66.63 bar at 9° ATDC but the pressure drop to 63.66 bar at 11° ATDC at 2300 RPM.

Datta and Mandal in their reports found that the maximum pressure is noted after TDC and the addition of ethanol and methanol moves the maximum pressure away from the TDC [17]. Compare to the result in this study, the addition of butanol and ethanol not showing similar trends. In average, diesel fuel in cylinder pressure recorded to be in higher number compared to D90BU10 and D90E10. In cylinder pressure of diesel fuel greater than the alcohol mixture fuel is due to the prolong ignition delay of alcohol mixture fuel that causing the combustion period become shorter [18].

3.4. Analysis of engine gas emission

3.4.1. Oxygen (O_2). Figure 6 shows the oxygen, O_2 emission of diesel fuel, D90BU10 and D90E10 at 50% engine load with engine speed ranging from 1100RPM to 2300RPM. Diesel fuel recorded highest O2 emission at 2000 RPM with 17.46% emission. While both D90BU10 and D90E10 recorded highest O_2 emission at engine speed 1100 RPM with 17.28% and 17.40% emission. D90BU10 recorded a decreasing trend as engine speed increase from 1100 RPM to 2300 RPM. D90E10 found to have a higher O_2 emission compared to D90BU10 at all engine speed due to the higher oxygen content found in D90E10 compared to D90BU10.

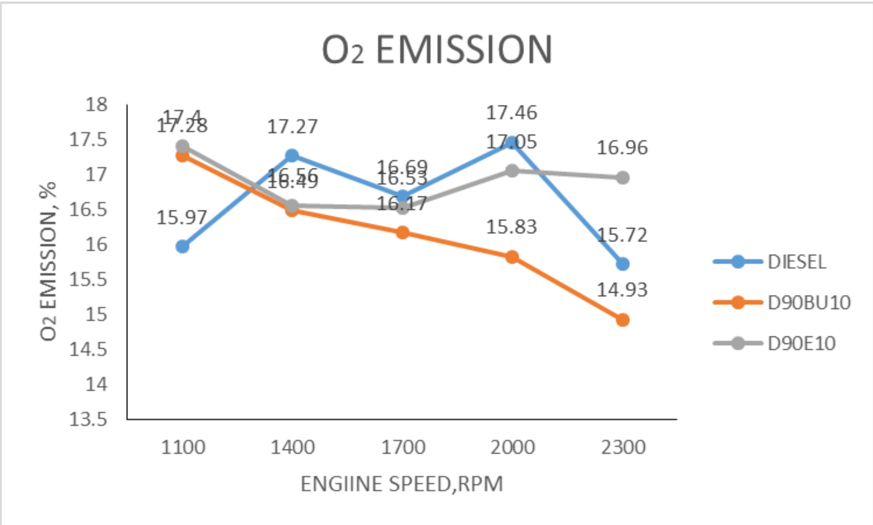

Figure 6. Emission of Oxygen at 50% load.

3.4.2. Carbon Dioxide (CO_2). Carbon dioxide (CO_2) is an ordinary end combustion product of each fuel that contains carbon (biomass, wood, coal, and its variations, oil and petroleum) When enough oxygen is available, hydroxyl radical OH is one of the principal oxiding agents that converts CO into CO_2 [12]. Plus, it is a well-known fact that complete combustion inside the engine combustion chamber will increased the CO_2 emissions. Although there is no possibility of perfect or complete combustion occurs, there may be a near complete or near perfect combustion happen. Hence, that's depends on the engine operating condition and the nature of fuel used to run the engine [17].

Figure 7 shows the CO_2 emissions of diesel fuel, D90BU10 and D90E10 at engine speed ranging from 1100 RPM to 2300 RPM. CO_2 emission from D90BU10 shows an increasing trend and recorded highest emission at 2300 RPM. CO_2 emission of diesel fuel at 1100 RPM is 26% and 30% higher compared to D90BU10 and D90E10 and also recorded highest emission at 2300 RPM. CO_2 emission for D90E10 shows no significant changes as engine speed increased. Higher CO_2 emission in alcohol blend fuel could be due to their high oxygen contents which may improve the combustion quality, thus increase the CO_2 emission [19].

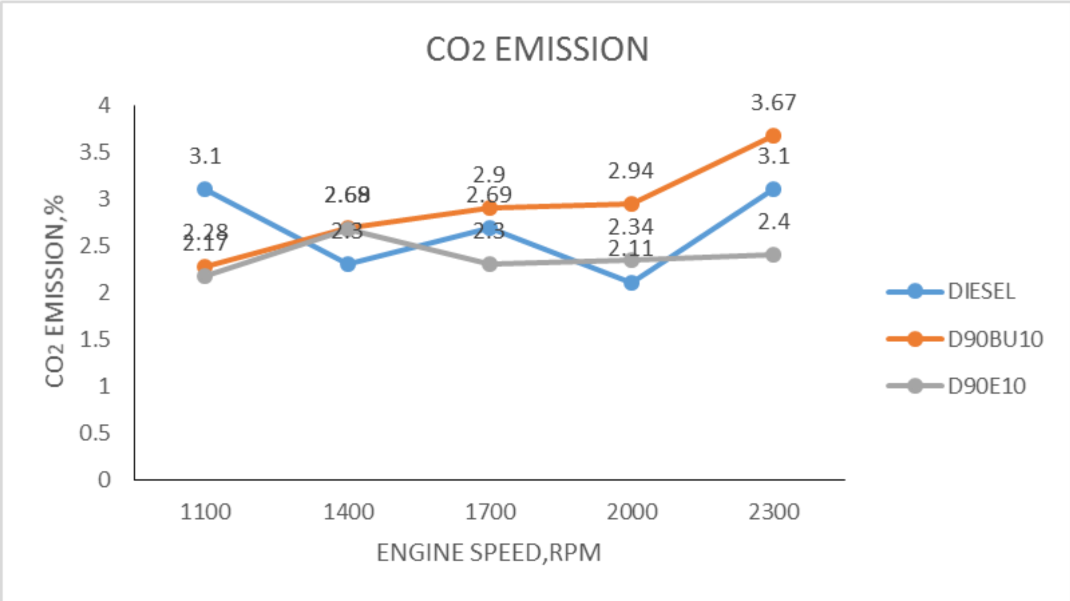

Figure 7. Emission of Carbon Dioxide at 50% load.

3.4.3. Carbon Monoxide (CO). Carbon monoxide, (CO) can be produced into the engine cylinder when combustion occurred with insufficient air flow and low flame temperature. However, formation of CO generally occurs during rich air and fuel mixture as a result of O_2 inaccessibility to totally oxidize all CO proportion in the fuel [12]. Figure 8 shows the engine CO emissions versus the engine speed at 50% load.

As reported by Imdadul et al., in comparative study of alcohol blend in term of diesel engine performance and emissions. The CO emission decreased as engine speed increased, thus with increase of alcohol blends in the fuel the CO emission also decreased. The lower density of alcohols blends compared to diesel making the alcohol blends fuel evaporates easily in the combustion chamber. Plus, the length of splash entrance become smaller and this will help blending process and at the same time decrease the CO emission. Furthermore, alcohol content in the blend fuel provide more oxygen and that will lower the stoichiometric air/fuel ration of alcohols, thus lowering CO emission [12]. Same findings also reported by Sanli et al. [19].

In this study, no significant trend can be observed. Referring to the graph of CO emission in Figure 8, diesel fuel recorded highest CO emission at 2300 RPM with 28.6% higher compared to D90BU10 and D90E10. D90BU10 and D90E10 both recorded highest CO emission at 1700 RPM with 20% and 33.3% higher compared to diesel fuel CO emissions.

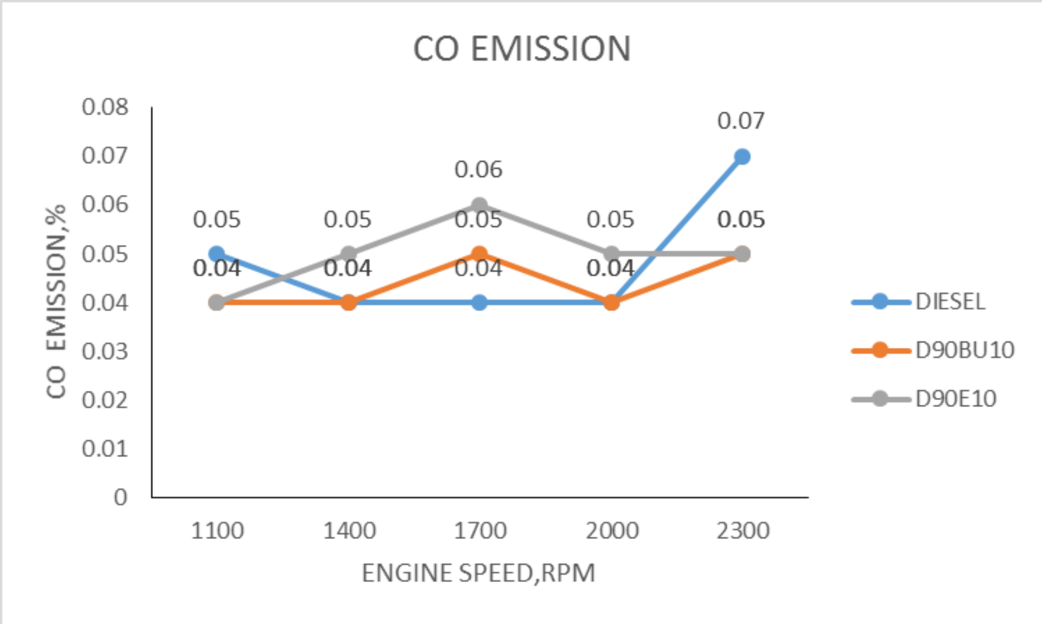

Figure 8. Carbon Monoxide Emission at 50% load.

3.4.4. Oxide of Nitrogen (NOx). NOx emission is a function of residence time related to oxygen concentration and also related to combustion chamber temperature. NOx formation rates increase with increase on combustion temperatures and oxygen concentrations [20]. Figure 9 shows the NOx emission for diesel fuel, D90BU10 and D90E10 with respect of engine speed at 50% engine load in speed ranging from 1100 RPM to 2300 RPM.

As reported in many research, as engine speed increase, and the alcohol mixture increase in the diesel fuel. The emission of NOx emission will increase respectively [4, 12, 15, 21, 22]. More oxygen content exists in the alcohol blends which attributed to the amount of NOx formation. Plus, higher atomic weight species combust in delayed combustion stages due to the lower atomization at the beginning of controlled combustion [23]. Atmanli reported that NOx emission increased as engine speed increased. However, Atmanli [23] reported that NOx emission decreases in the presence of higher alcohol in diesel or biodiesel blends. Similar finding also reported by Tuccar et al. [15] where NOx emission is lower in high engine speed and in butanol blends fuel compared to diesel fuel.

NOx emission for the test diesel fuel, D90BU10 and D90E10 react slightly different. Diesel fuel show a decrease trend of NOx emission, however at 1700 RPM the NOx emission is slightly high compared to the emission at 1400 RPM. Where, for D90BU10 the NOx emission increase from 1100 RPM to 1700 RPM, however starting to decrease from 1700 RPM to 2300 RPM. D90E10 on the other hand, shows decreasing trend for both graph. The decreasing trend of NOx emission may due to the lower calorific value and higher heat of evaporation of alcohol which leading to higher temperature during premixed part of combustion [15].

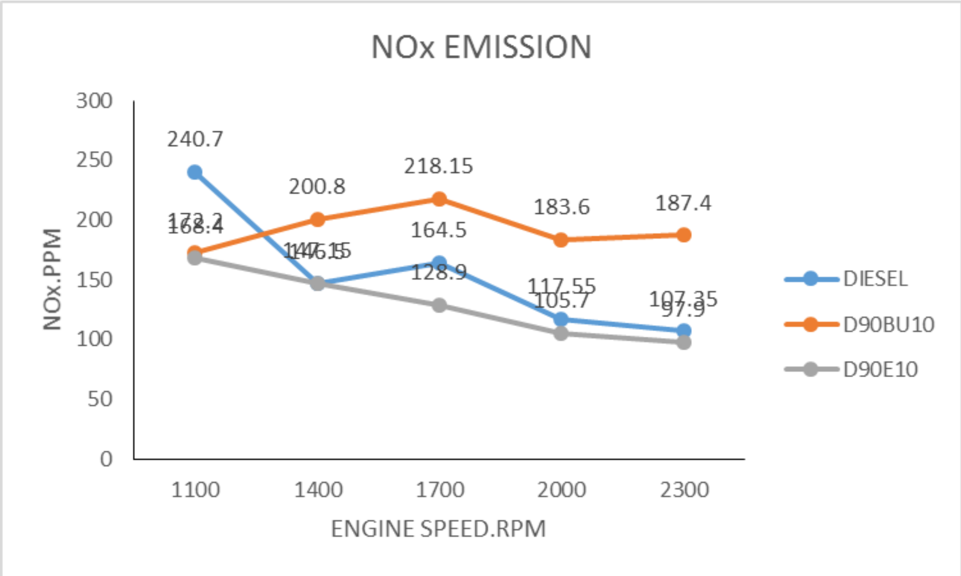

Figure 9. NOx Emission at 50% load.

4. Conclusions

Engine brake power indicated the amount of work of one engine does per unit of time. The engine BP output is increased for all test fuel as the speed is increased. Here, we can conclude that the brake power output depends extensively on engine speed. In addition of that, at 10% of alcohol mixture, the density of alcohol and diesel blends and mineral diesel does not have a significant effect on the BP. Hence, the difference in viscosity of test fuel bring effect on the BP output at higher engine speed as the diesel generated highest BP compared to the other two test fuel. The lower fuel viscosities in both alcohol and diesel blends mode leads to the greater injector leaking, thus resulting reduce in maximum fuel delivery and ultimately reducing the engine power output. On top of that, the lower energy content of dual-fuel compared to diesel fuel may resulted in decreased of engine BP value.

Brake specific fuel consumption is the amount of engine fuel consume in a certain period to produce one kilowatt of brake power. Generally, engine BSFC will increased as the engine speed increased, and addition of alcohol mixture in the test fuel. Although the BSFC in this study have a decreasing trend at lower engine speed, it gradually increased at higher engine speed. The increase of BSFC was due to the lower heating values of dual fuel compared with mineral diesel. Most studies found that the diesel-alcohol mixture have a lower heating values and could cause significant increases in BSFC.

It can be concluded from the overall results that at lower engine speed, in cylinder maximum pressure at lower engine speed increase as the engine speed is increased for all test fuel. However, there is a decreased for the maximum cylinder pressure at the higher engine speed. Thus, mineral diesel maximum cylinder pressure was higher compared to the alcohol and diesel blend fuel. However, D90BU10 produces closest maximum cylinder pressure compared to mineral diesel. From previous researched had found that the maximum cylinder pressure is noted after TDC and the addition of ethanol mixes the maximum cylinder pressure away from TDC.

Dual fuel recorded a decreasing trend of O_2 emission, especially for D90BU10. For D90E10, O_2 emission decreased at lower rpm however gradually increase at higher engine rpm. Ethanol fuel mixture found to have higher O_2 content compared to mineral diesel and butanol fuel mixture. It is due to higher O_2 content in ethanol compared to the butanol. CO_2 is an ordinary exhaust gas of each fuel that contains carbon. Should there is enough O_2 available during combustion stage, hydroxyl radical OH will react and converts CO into CO_2. CO_2 emission from D90BU10 and D90E10 are increased as engine speed is increased. Higher CO_2 emission in alcohol and diesel fuel was due to their high O_2 contents which improve combustion quality, thus increase the CO_2 emission. On the other hand, no significant trend can be observed for CO emission. Looking at the higher side rpm, diesel generates more CO compare to the alcohol and diesel blend fuels and it can be conclude that addition of alcohol to mineral diesel will lower the CO emission. In line with most of the previous studies, NOx emission for diesel and D90E10 test fuel showing a decreasing NOx emission as engine speed is increased. However, for D90BU10, NOx emission was higher at low or medium engine speed, then gradually decreased at higher engine speed. The addition of 10% ethanol to mineral fuel can reduce NOx emission.

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