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Assessing the Impact of Dual Alcohol Blends on Diesel Engine Performance and Exhaust Emissions

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ABSTRACT

The increasing reliance on diesel fuel has heightened concerns about depleting fossil fuel reserves and environmental impacts. In response, researchers are exploring alternative fuel options, such as blends of alcohol and diesel, to improve sustainability. This study investigates the performance and emissions characteristics of several ethanol, methanol, and diethyl ether (DEE) blends with biodiesel and diesel. The tested fuel blends include B10 (90% diesel, 10% biodiesel), BDE (75% diesel, 10% biodiesel, 15% ethanol), BDE2DEE (75% diesel, 10% biodiesel, 15% ethanol, 2% DEE), BDE5DEE (75% diesel, 10% biodiesel, 15% ethanol, 5% DEE), and MBD2DEE (75% diesel, 10% biodiesel, 15% methanol, 2% DEE). Engine performance was evaluated in terms of brake-specific fuel consumption (BSFC), brake power, exhaust gas temperature, and mass and volume flow rates at varying engine loads. The results demonstrate that fuel blends with diethyl ether, particularly BDE5DEE, exhibited superior performance in reducing emissions. NOx emissions decreased by up to 16.2%, while CO2 emissions were reduced by 15.0%. Additionally, blends with diethyl ether lowered brake-specific fuel consumption by 30.7% compared to standard diesel (B10). The blend MBD2DEE, which includes methanol, delivered the highest brake power at higher loads (75%), peaking at 2.91 kW, indicating its strong potential for high-load applications. These findings suggest that dual alcohol-diesel blends, especially those containing diethyl ethers, offer a promising route for improving fuel efficiency and reducing harmful emissions, making them viable alternatives to traditional diesel fuel.

Keywords: biodiesel; ethanol; methanol; diethyl ethers.

Nomenclature (Greek symbols towards the end)

CO	Carbon monoxide
CO_2	Carbon dioxide
NO_x	Nitrogen oxide

Abbreviations

EBD	15% ethanol 10% biodiesel and 75% diesel
EBD2DEE	15% ethanol 10% biodiesel 75% diesel with 2% diethyl ethers
EBD5DEE	15% ethanol 10% biodiesel 75% diesel with 5% diethyl ethers
MBD2DEE	15% methanol, 10% biodiesel, 75% diesel with 2% diethyl ethers
B10	Commercial diesel fuel with 10% biodiesel and 90% diesel
bsfc	brake-specific fuel consumption
LHV	lower heating value

1.0 INTRODUCTION

The growing demand for diesel and petroleum due to the expanding automotive industry is creating worldwide challenges. In recent years, it has become clear that fossil fuels are running out. Even though there is still enough diesel fuel being produced, extracting each barrel of crude oil is getting harder because the reserves are located farther away, deeper underground, and in harder-to-reach places. This makes extraction more difficult and increases production and distribution costs [1]. Environmental concerns are also important. Air quality, human health, and climate change are all affected by engine exhaust emissions like nitrogen oxides (NO_x), particulate matter (PM), and carbon monoxide (CO) [2]. Diesel engines are widely used because they provide good power and are fuel-efficient. Also, compared to gasoline engines, they produce fewer pollutants like CO and unburned hydrocarbons [3]. However, NO_x emissions from diesel engines can react with hydrocarbons in sunlight to create smog. Improving the efficiency and reducing emissions of these engines will lead to better fuel economy and less pollution. To do this, it is often recommended to switch from diesel fuel to an alternative fuel made from non-petroleum sources [4].

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Alternative fuels for engines, such as biofuels like alcohols and biodiesel, have been suggested. Biodiesel has gained a lot of attention as a diesel fuel substitute because it is biodegradable, non-toxic, and can significantly reduce exhaust emissions and overall CO_2 emissions when used as fuel [5]. Biodiesel is made by converting plant oils or animal fats into esters through a process called transesterification. It is an oxygenated fuel that can often be used in diesel engines with little or no modification, as shown by many experimental studies [6]. Using biodiesel in diesel engines has been found to lower emissions of CO, hydrocarbons, and particulate matter, though it might increase NO_x emissions [7], [8]. The main drawback of biodiesel is its high viscosity and low volatility, which can lead to inefficient combustion in diesel engines. Transesterification helps reduce viscosity, making combustion more efficient [9].

Ethanol production has grown significantly as it competes with traditional diesel, driven by the desire to blend ethanol with diesel to reduce emissions. Ethanol is also attractive as a renewable resource [10]. Alcohol-diesel blends are often used to cut greenhouse gas emissions and improve some fuel properties. Alcohols have high burning power because they contain oxygen, which improves combustion efficiency [2]. However, blending alcohol with diesel can be challenging for diesel engines because of the lower heating value (LHV) and potential issues with blend miscibility and stability [11]. Adding more diethyl ether to a mix of diesel, biodiesel, and ethanol might improve the lower heating value. Research shows that the amount of oxygen in the fuel blend is crucial for reducing particulate matter emissions, even more so than factors like volatility or chemical composition. Ethanol and diethyl ether can increase the oxygen content in diesel blends and biodiesel, which may lead to even greater reductions in particulate matter emissions [5]. These facts highlight the urgent need for alternative fuel sources to supplement shrinking fossil fuel reserves and reduce emissions of harmful pollutants like NO_x and CO_2, which are high in today's commercial fuels [12]. A blend that includes renewable sources, such as an ethanol-diesel mix, is needed to improve engine performance and reduce harmful emissions [13]. Research on blends of biodiesel, diesel, and ethanol as alternative fuels often points out challenges like lower heating value with higher ethanol content, potential phase separation, and storage and transport issues [14]. This study aims to evaluate engine performance and emissions using a blend of biodiesel, diesel, and alcohol with added diethyl ether. By comparing the results, the goal is to find the most effective alternative fuel option.

2.0 METHODOLOGY

2.1 Test fuel

In this experiment, the blends of biodiesel diesel and alcohol (ethanol and methanol) with additional diethyl ether were tested. The mixing process was made based on the volume ratio. All fuel blends' engine performance and emissions were collected on the dynamometer connected to the diesel engine and the gas analyser. The brake power of the engine was collected based on the torque and speed shown on the panel of the dynamometer, while the emission gas of the engine was gathered using the gas analysers.

Five test fuels consisted of one commercial diesel fuel (B10) collected from a public diesel fuel pump and four blends mixing biodiesel-diesel and alcohols with additional diethyl ether. Methanol, ethanol, and diethyl ether were supplied by our laboratory store at UiTM Shah Alam. The ethanol used for this research was ethyl alcohol 99.5% pure. The mixing of all fuel was conducted on a magnetic stirrer with a volumetric basis and no heat input. Ten minutes were taken to mix the fuel and then the mixing fuels were placed at room temperature for around 2 to 3 hours. The mixing fuel was observed and subjected to further experimentation. The blend was mixed with a ratio of biodiesel (10%), diesel (75%), and ethanol (15%) named BDE. The next blend was BDE2DEE mixed with a ratio of biodiesel (10%), diesel (75%), and ethanol (15%) with an addition of diethyl ether (2%). Another two blends were BDE5DEE and MBD5DEE mixed of ratio biodiesel (10%), diesel (75%), and ethanol (15%) with additional diethyl ether (5%), and biodiesel (10%), diesel (75%) and methanol (15%) with additional diethyl ether (2%). The main properties of blending fuel are shown in Table 1.

Table 1: Main properties of blending fuels

Properties	**B10**	**Ethanol**	**Methanol**	**Diethyl ether**
Density @ 20°C (kg m^{-3})	841	790	795	718
Kinematic viscosity @ 40°C (mm2/s)	2.89	1.2	0.59	0.23
Lower calorific value (MJ/kg)	43.43	26.8	19.7	33.9
Cetane number	-	6	<5	>125
Flash point (°C)	86.5	13	11	-45
Latent heat of vaporization (kJ/kg)	-	840	1109	350
Oxygen content (%)	-	34.8	50	21.6
Carbon content (%)	80.12	52.18	37.5	64.9

2.2 Experimental equipment and engine test procedure

The engine's power and torque were recorded using the eddy current (EC) dynamometer of the eddy current type as shown in Fig. 1. The engine's speed was displayed on the dynamometer panel. The fuel consumption was timed using a stopwatch. The volumetric flow rate was calculated based on the fuel consumption by taking the time for 10 ml drops at different loads. Based on all the data collected, brake-specific fuel consumptions, exhaust gas temperature, and brake power were observed to verify the engine performance on different fuel blends. A Mru-gas analyser model by Vario Plus Industrial was used to check the engine's emission. The CO, CO_2, and NO_x emissions were gathered by printing out the receipt from the gas analyser. The schematic diagram of the experimental set-up is shown in Fig. 2.

The testing was carried out on a diesel engine model Yanmar L70N 6.7HP Industrial Diesel Engine connected with an eddy current dynamometer. Table 2 shows the specifications of the engine. The experiment was performed at five load intervals from 0% to 100%. This is equivalent to 5V, 10V, 15V, 20V, and 25V. The engine tank was replaced with a measuring cylinder to ease in measuring the fuel consumption. The engine speed was maintained at 2000 rpm for each load. Before testing, the engine was filled with diesel and ran for 5 minutes until all the fuel was consumed. This ensures the engine's residual fuel is used completely before filling the tanks with the fuel blends.

Table 2: Engine specifications (diesel) and EC dynamometer

Components	Specifications
Engine	
Engine type	Four-stroke (Single cylinder)
Engine model	Yanmar L70N 6.7HP
No. of cylinders	1
Displacement	0.32 litres
Bore and stroke	78 mm and 67 mm
Rated power	4.9 kW @ 3600 rpm
Starting system	Electric start
Engine speed	2000 rpm (constant)
Dynamometer	
Type	Eddy Current
Torque Capacity	20-30 Nm
RPM Range	0-4000 rpm
Cooling system	Integrated water cooling
Gas analyser	
Dimension	21”x19”x12”
Fuel types	Natural gas, liquid gas, oil light, pellet, wood, coal and user-definable fuels.
Measuring components/range	O2 (±21 Vol % abs), CO (4000 ppm), NO (1000 ppm), NO2 (200 ppm), SO2 (2000 ppm), H2 (1%).
Operation temperature	40°F - 100°F, max 95% RH, non-condensing.
Power supply	250 V.

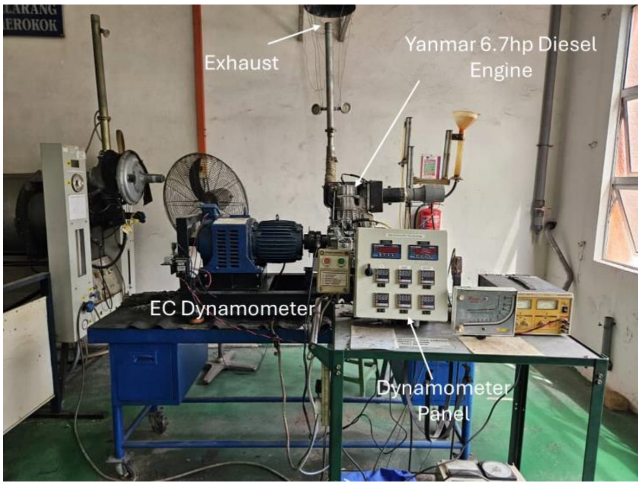

Figure 1. Experimental setup

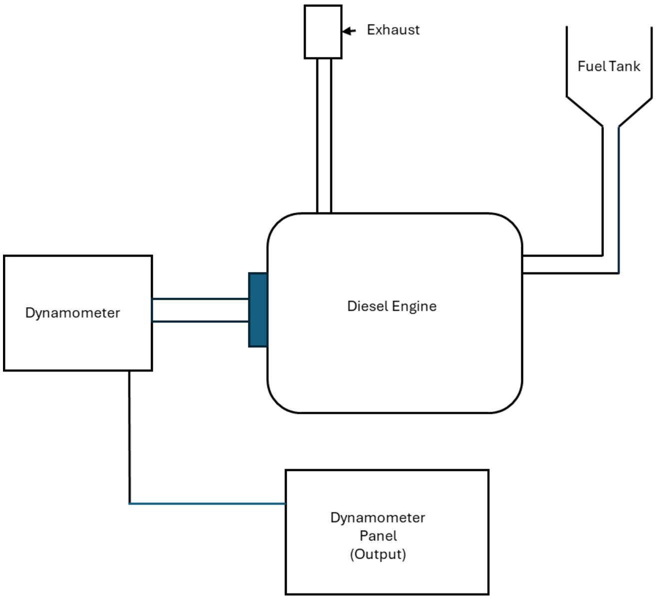

Figure 2. Schematic representation of engine test system

3.0 RESULTS AND DISCUSSION

3.1 Brake Power

The variation of brake power (BP) for the blends of biodiesel-diesel-ethanol with additional diethyl ether in single-cylinder direct injection diesel engines is shown in Fig. 3. It is stated that with increasing load, the gradient proportionally increase the brake power of the blends directly [15]. The MBD2DEE reached the peak power of 2.91 kW at 75% load but at 100% load, the engine started to underpower. BDE5DEE has the highest brake power with a peak power of 2.20 kW at higher loads. In comparison, BDE showed the lowest peak power which is 1.92 kW at the highest load. The high oxygen content in the ethanol and diethyl ether improves the heating value compared to commercial diesel fuel B10. As a result, the oxygen content of ethanol and diethyl ether improves the combustion condition of the engine.

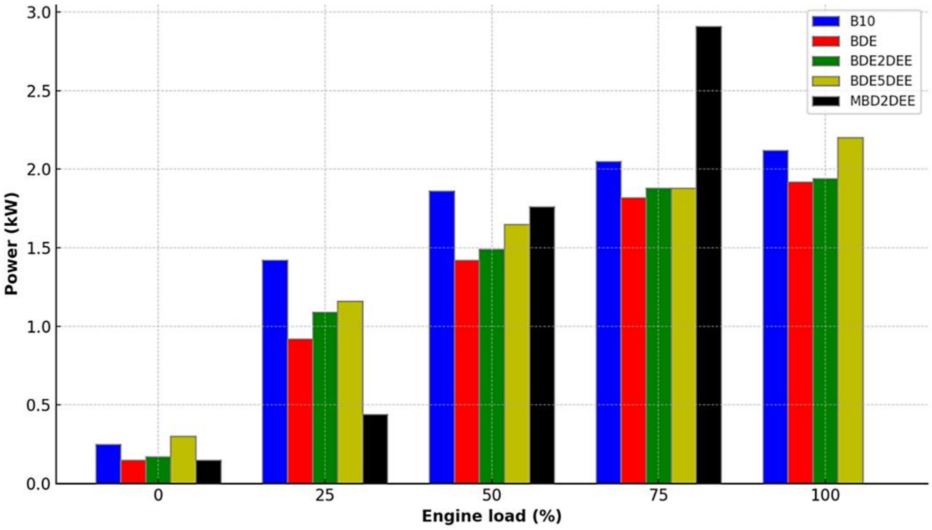

Figure 3. Variation of brake power against engine loads

3.2 Brake-Specific Fuel Consumption (BSFC)

Fig. 4 shows the line graph of brake-specific fuel consumption against loads off all fuel blends. Brake-specific fuel consumption is defined as the amount of fuel (mass flow rate) used for every created brake power. It is also the measurement of the amount of fuel the engine uses to produce a particular amount of brake power.

The bsfc drops until 75% of load which then has a slight increase at 100% of loads due to higher brake power generated at high loads. The primary cause of this might be the fact that the percentage increase in fuel needed to run the engine is lower than the percentage increase in brake power since a smaller percentage of heat losses occur at higher loads [16]. At the lower loads, BDE5DEE has the lowest bsfc compared to other fuel blends while at the higher loads, BDE drops below the BDE5DEE. This could be as a result of improved of combustion process due to high volatility of ethanol and diethyl ether that enhances the mixing velocity of fuel mixture.

3.3 Exhaust gas emission (EGT)

The variation of exhaust gas temperature for the blends of biodiesel-diesel-ethanol with additional diethyl ether in single-cylinder direct injection diesel engine is shown in Fig. 5. The exhaust gas temperature indicates the quantity of heat emitted during the combustion process inside the cylinder. The exhaust gas temperature is directly proportional to the engine loads, which means as the engine load increases, the exhaust gas temperature increases. With the constant speed of 2000 rpm, B10 is increasing constantly and reaching the highest EGT at 100% load which is 173.1^{o}C. This is because B10 comprises of more energy per gallon as well as high number of torque than other blend fuel.

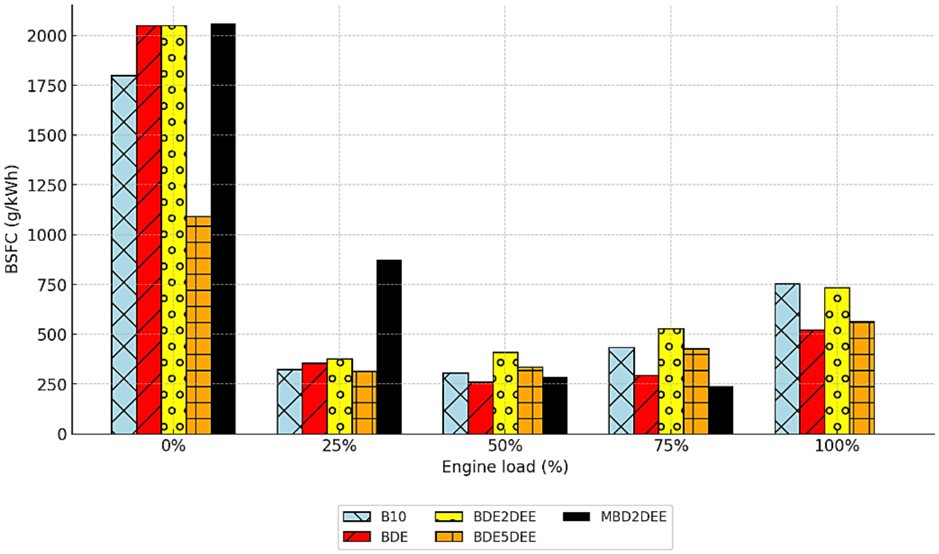

Figure 4. Variation of brake specific fuel consumption against engine loads

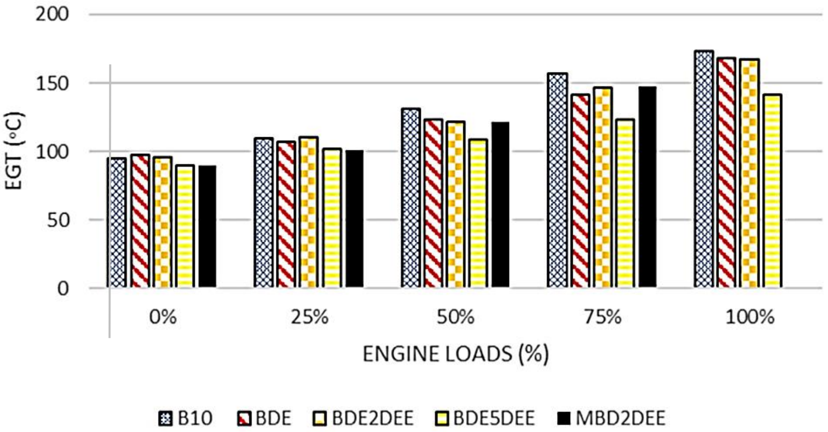

Figure 5. Variation of exhaust gas temperature against engine loads

3.4 Carbon Monoxide (CO)

Fig. 6 shows the variation carbon monoxide (CO) emissions for commercial diesel fuel (B10), BDE, BDE2DEE, BDE5DEE and MBD2DEE regarding the engine loads. The primary factors affecting CO emissions from a DI diesel engine are the fuel's physical and chemical characteristics. Alcohol present in the fuel blends alters the properties of the fuel spray, the oxygen content, the rate of oxidation, the temperatures in the cylinders, and the development of the ignition center, which affect the generation of CO [17]. From the graph, it was observed that the CO emission decreases gradually as the brake power increases and then spikes highly at 100% load. BDE5DEE emits higher carbon monoxide at higher loads compared to commercial diesel fuel (B10). Incomplete combustion might be the factor that BDE5DEE emits high CO particles. BDE has lower CO formation at lower load, showing that the present oxygen-containing fuel can enhance the combustion in the cylinder at relatively low loads. Higher loads result in more fuel entering the cylinder, and more fuel entering the cylinder with less energy causes incomplete combustion, which raises CO emissions [18].

3.5 Nitrogen Oxide (NO_x)

Fig. 7 shows the abnormality of nitrogen oxide (NO_x) emissions throughout the increase of the engine loads for all fuel blends. Traditional diesel engines often emit nitrous oxide (NO), nitrogen dioxide (NO_2), and nitrogen monoxide (NO) as part of their NOx emissions (N2O). Most of the time, NO makes up more than 90% of all NO_x, with NO_2 making up less than 10% and N_2O typically being little enough to be ignored. The rise in NO_x is caused by the increased heat created by the fuel during high-torque combustion, which causes atmospheric nitrogen to burn with oxygen at the exhaust pipe [19]. At the lower load, it can be observed that BDE has significantly higher emission of NO_x than B10 until 50% of loads [20]. The main factor that BDE presents higher NO_x emissions than B10 is due to the absence of any additives and the presence of pure ethanol, which function as a dominant factor in raising the in-cylinder temperature and pressure, followed by greater NO_x. Except at 75% loads, the emission of NO_x for B10 increases gradually while BDE5DEE emits the lowest NO_x particle. This might be due to the oxygenated blends in which BDE5DEE increases in ignition delay due to high oxygen content causing lower gas residual temperature and wall temperature that will make the emissions of NO_x lesser.

3.6 Carbon dioxide (CO_2)

When a hydrocarbon fuel is completely burned, the byproducts are thought to be carbon dioxide and water vapor. Increased CO_2 emissions from engines indicate better fuel oxidation. The generation of CO_2 during combustion is influenced by the elemental carbon content, C/H ratio, mixture density, and total oxygen available. From Fig. 8, it shows that the emissions of CO_2 increase as the loads of the engine increase [17]. Initially, B10 has the highest emissions of CO_2 at lower loads but at higher loads, BDE2DEE has higher emissions of CO_2. This is due to the oxygen content in the oxygenated fuel enhancing the air-fuel combustion inside the cylinder.

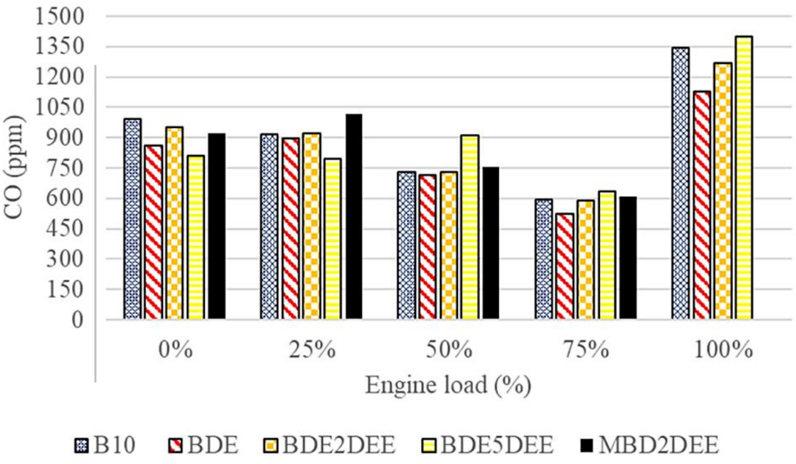

Figure 6. Effect of engine load carbon monoxide (CO)

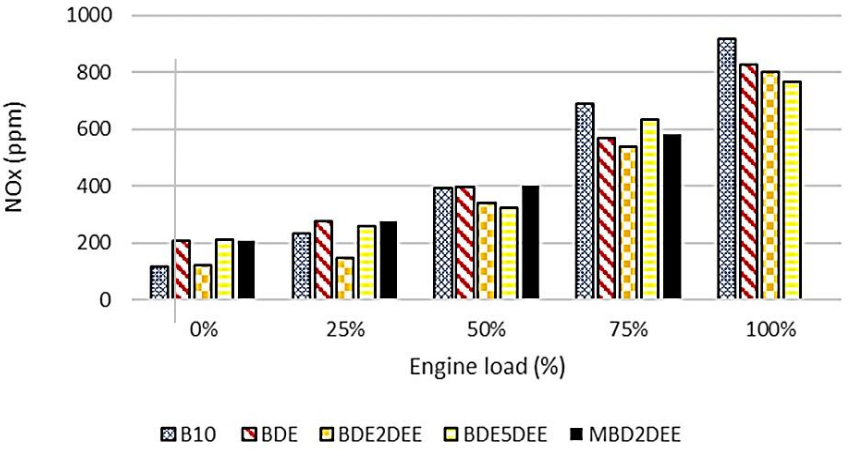

Figure 7. Effect of engine load on nitrogen oxide (NOx)

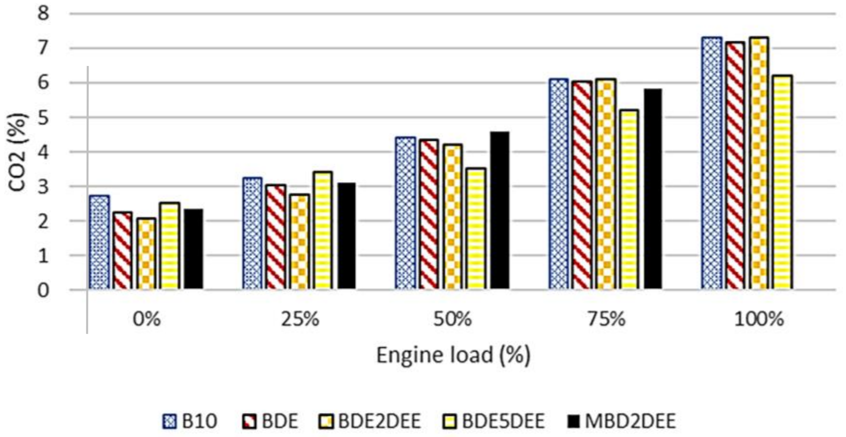

Figure 8. Effect of engine load on carbon dioxide (CO_2)

4.0 CONCLUSION

The study investigates the performance of various biodiesel-diesel-ethanol blends, enhanced with or without diethyl ether, in terms of engine power, fuel efficiency, exhaust temperature, and emissions. As engine load increases, MBD2DEE reaches the highest brake power at 75%, while BDE5DEE shows superior performance at higher loads. Brake-specific fuel consumption (BSFC) decreases until 75% load but rises slightly at 100%, with BDE5DEE demonstrating the best fuel efficiency at both low and high loads. Exhaust gas temperature (EGT) increases proportionally with engine load, with B10 showing the highest temperature at full load due to its higher energy content. In terms of emissions, carbon monoxide (CO) decreases with higher loads but spikes at full load, with BDE5DEE emitting more CO at higher loads due to incomplete combustion, while BDE produces less CO at lower loads because of better oxidation. Nitrogen oxides (NOx) emissions rise with load for all blends, with BDE generating higher NOx than B10 until 50% load, while BDE5DEE shows lower NOx at high loads due to better combustion. Carbon dioxide (CO_2) emissions increase with engine load, with B10 producing the most CO_2 at lower loads, but BDE2DEE surpasses it at higher loads because of its improved oxygen content, enhancing combustion. Overall, the blends exhibit different behaviours in power output, efficiency, and emissions, highlighting the impact of blend composition and oxygen content on engine performance.

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REFERENCES

[1] G. Labeckas, S. Slavinskas, and M. Mažeika, “The effect of ethanol-diesel-biodiesel blends on combustion, performance and emissions of a direct injection diesel engine,” Energy Conversion and Management, vol. 79, pp. 698–720, Mar. 2014, doi: 10.1016/j.enconman.2013.12.064.

[2] M. I. Gregorio Arenas, M. D. Redel-Macías, A. Ortega, F. R. Lara, and M. P. Dorado, “Alcohol-diesel fuel blends and their effect in performance and exhaust emissions,” Renewable Energy and Power Quality Journal, vol. 1, no. 12, pp. 990–994, Apr. 2014, doi: 10.24084/repqj12.558.

[3] A. O. Emiroğlu and M. Şen, “Combustion, performance and exhaust emission characterizations of a diesel engine operating with a ternary blend (alcohol-biodiesel-diesel fuel),” Applied Thermal Engineering, vol. 133, pp. 371–380, Mar. 2018, doi: 10.1016/j.applthermaleng.2018.01.069.

[4] H. Bayraktar, “An experimental study on the performance parameters of an experimental CI engine fueled with diesel-methanol-dodecanol blends,” Fuel, vol. 87, no. 2, pp. 158–164, Feb. 2008, doi: 10.1016/j.fuel.2007.04.021.

[5] D. H. Qi, H. Chen, L. M. Geng, and Y. Z. Bian, “Effect of diethyl ether and ethanol additives on the combustion and emission characteristics of biodiesel-diesel blended fuel engine,” Renewable Energy, vol. 36, no. 4, pp. 1252–1258, Apr. 2011, doi: 10.1016/j.renene.2010.09.021.

[6] D. H. Qi, L. M. Geng, H. Chen, Y. Z. Bian, J. Liu, and X. C. Ren, “Combustion and performance evaluation of a diesel engine fueled with biodiesel produced from soybean crude oil,” Renewable Energy, vol. 34, no. 12, pp. 2706–2713, Dec. 2009, doi: 10.1016/j.renene.2009.05.004.

[7] D. Agarwal, S. Sinha, and A. K. Agarwal, “Experimental investigation of control of NOx emissions in biodiesel-fueled compression ignition engine,” Renewable Energy, vol. 31, no. 14, pp. 2356–2369, Nov. 2006, doi: 10.1016/j.renene.2005.12.003.

[8] C. D. Rakopoulos, K. A. Antonopoulos, and D. C. Rakopoulos, “Experimental heat release analysis and emissions of a HSDI diesel engine fueled with ethanol-diesel fuel blends,” Energy, vol. 32, no. 10, pp. 1791–1808, 2007, doi: 10.1016/j.energy.2007.03.005.

[9] S. A. Basha, K. R. Gopal, and S. Jebaraj, “A review on biodiesel production, combustion, emissions and performance,” Renewable and Sustainable Energy Reviews, vol. 13, no. 6–7. pp. 1628–1634, Aug. 2009. doi: 10.1016/j.rser.2008.09.031.

[10] A. C. Hansen, Q. Zhang, and P. W. L. Lyne, “Ethanol-diesel fuel blends - A review,” Bioresource Technology, vol. 96, no. 3, pp. 277–285, 2005, doi: 10.1016/j.biortech.2004.04.007.

[11] E. E. Ecklund, R. L. Bechtold, T. J. Timbario, and P. W. Mccallum, “State-of-the-Art Report on the Use of Alcohols in Diesel Engines,” 2018.

[12] K. A. Abed, M. S. Gad, A. K. el Morsi, M. M. Sayed, and S. A. Elyazeed, “Effect of biodiesel fuels on diesel engine emissions,” Egyptian Journal of Petroleum, vol. 28, no. 2, pp. 183–188, Jun. 2019, doi: 10.1016/j.ejpe.2019.03.001.

[13] M. Q. M. Tamam, N. R. Abdullah, W. J. Yahya, H. A. Kadir, Y. Putrasari, and M. A. Ahmad, “Effects of Ethanol Blending with Methanol-Gasoline fuel on Spark Ignition Engine Performance and Emissions,” Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, vol. 83, no. 2, pp. 54–72, 2021, doi: 10.37934/ARFMTS.83.2.5472.

[14] S. A. Shahir, H. H. Masjuki, M. A. Kalam, A. Imran, I. M. R. Fattah, and A. Sanjid, “Feasibility of diesel-biodiesel-ethanol/bioethanol blend as existing CI engine fuel: An assessment of properties, material compatibility, safety and combustion,” Renewable and Sustainable Energy Reviews, vol. 32. pp. 379–395, Apr. 2014. doi: 10.1016/j.rser.2014.01.029.

[15] G. Khoobbakht, M. Karimi, and K. Kheiralipour, “Effects of biodiesel-ethanol-diesel blends on the performance indicators of a diesel engine: A study by response surface modeling,” Applied Thermal Engineering, vol. 148, pp. 1385–1394, Feb. 2019, doi: 10.1016/j.applthermaleng.2018.08.025.

[16] H. Raheman and S. v. Ghadge, “Performance of compression ignition engine with mahua (Madhuca indica) biodiesel,” Fuel, vol. 86, no. 16, pp. 2568–2573, Nov. 2007, doi: 10.1016/j.fuel.2007.02.019.

[17] H. Venu and V. Madhavan, “Influence of diethyl ether (DEE) addition in ethanol-biodiesel-diesel (EBD) and methanol-biodiesel-diesel (MBD) blends in a diesel engine,” Fuel, vol. 189, pp. 377–390, Feb. 2017, doi: 10.1016/j.fuel.2016.10.101.

[18] J. Liang, Q. Zhang, Q. Ma, Z. Chen, and Z. Zheng, “Effect of various ethanol/diesel cosolvents addition on combustion and emission characteristics of a CRDI heavy diesel engine,” Energy Reports, vol. 8, pp. 735–748, Nov. 2022, doi: 10.1016/j.egyr.2021.12.011.

[19] L. Wei, C. Yao, Q. Wang, W. Pan, and G. Han, “Combustion and emission characteristics of a turbocharged diesel engine using high premixed ratio of methanol and diesel fuel,” Fuel, vol. 140, pp. 156–163, Jan. 2015, doi: 10.1016/j.fuel.2014.09.070.

[20] O. Ogunkunle and N. A. Ahmed, “Exhaust emissions and engine performance analysis of a marine diesel engine fuelled with Parinari polyandra biodiesel–diesel blends,” Energy Reports, vol. 6, pp. 2999–3007, Nov. 2020, doi: 10.1016/j.egyr.2020.10.070.