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Optimizing Performance and Exhaust Emission of a Direct Injection Diesel Engine Running on Fuel Additives with Variable Loads: An Experimental Investigation

Faisal Mahroogi, Mahmoud Bady

Mechanical Engineering Department, Islamic University of Madinah, Saudi Arabia

Abstract: Saudi Arabia is dedicated to sustainable development and clean energy. It uses cutting-edge approaches to address energy-related issues, including the circular carbon economy and a more varied energy mix. For Saudi Arabia to achieve its Vision 2030 goal of having a net zero future by 2060, sustainability is essential. By addressing the energy and climate issues of the modern world with responsibility and innovation, Vision 2030 is turning into a global role model for the transition to a sustainable future. The current study, which presents an experimental analysis of a diesel engine's performance and exhaust emissions mainly running on waste cooking oil (WCO), plays a crucial role in this transition. The engine type utilized is a single-cylinder direct injection diesel engine with constant speed and natural aspiration. The research was done on the engine's performance and emission parameters when fueled with two blends. The first is a mixture of 10% butanol, 70% diesel, 10% WCO, and 10% diethyl ether (D85B5W5DD5), while the second is a mixture of 5% butanol, 85% diesel, 5% WCO, and 5% diethyl ether (D85B5W5DD5). The study's findings demonstrated that engine emissions of nitrogen oxides (NO_X) and carbon monoxide (CO) varied significantly depending on the applied load. The brake thermal efficiency and cylinder pressure were all impacted by load change. Also, the engine emissions change considerably with the engine load.

تحسين الأداء وانبعاثات العادم لمحرك ديزل يعمل بالحقن المباشر على إضافات الوقود بأحمال متغيرة: دراسة تجريبية

الملخص: تلتزم المملكة العربية السعودية بالتنمية المستدامة والطاقة النظيفة. وهي تستخدم مناهج متطورة لمعالجة القضايا المتعلقة بالطاقة، بما في ذلك اقتصاد الكربون الدائري ومزيج الطاقة الأكثر تنوعًا. ولكي تحقق المملكة العربية السعودية هدف رؤيتها 2030 المتمثل في مستقبل خالٍ من الانبعاثات بحلول عام 2060، فإن الاستدامة ضرورية. ومن خلال معالجة قضايا الطاقة والمناخ في العالم الحديث بالمسؤولية والابتكار، تتحول رؤية 2030 إلى نموذج عالمي يحتذى به للانتقال إلى مستقبل مستدام. تلعب الدراسة الحالية، التي تقدم تحليلاً تجريبيًا لأداء محرك ديزل وانبعاثات العادم التي تعمل بشكل أساسي على زيت الطهي المستعمل (WCO)، دورًا حاسمًا في هذا التحول. نوع المحرك المستخدم هو محرك ديزل أحادي الأسطوانة يعمل بالحقن المباشر بسرعة ثابتة وسحب طبيعي. تم إجراء البحث على أداء المحرك ومعايير الانبعاثات عند تشغيله بمزيجين. الأول عبارة عن مزيج من 10٪ بيوتانول و 70٪ ديزل و 10٪ WCO و 10٪ ثنائي إيثيل الأثير (D85B5W5DD5)، بينما الثاني عبارة عن مزيج من 5٪ بيوتانول و 85٪ ديزل و 5٪ WCO و 5٪ ثنائي إيثيل الأثير (D85B5W5DD5). أظهرت نتائج الدراسة أن انبعاثات المحرك من أكاسيد النيتروجين (NOX) وأول أكسيد الكربون (CO) تختلف بشكل كبير اعتمادًا على الحمل المطبق. تأثرت الكفاءة الحرارية للفرامل وضغط الأسطوانة بتغير الحمل. أيضًا، تتغير انبعاثات المحرك بشكل كبير مع حمل المحرك.

1. Introduction

The growing global concern over air pollution and depleting fossil fuel resources has driven extensive research in improving the efficiency and emission profiles of internal combustion engines, particularly diesel engines. Diesel engines, widely used in transportation, agriculture, and power generation, are known for their high thermal efficiency but also their significant contribution to harmful emissions such as nitrogen oxides (NO_x), particulate matter (PM), and hydrocarbons (HC) [1]. The current study, which explores alternative fuels and fuel additives, significantly contributes to this area, offering potential solutions to mitigate these environmental impacts and instilling hope for a cleaner and sustainable future.

Fuel additives, particularly in biodiesel-diesel blends, have shown promise in enhancing combustion efficiency and reducing emissions in diesel engines [2]. These additives can alter the physical and chemical properties of the fuel, influencing key factors such as combustion temperature, fuel atomization, and soot formation [3]. However, the performance and emission characteristics of engines running on fuel additives vary significantly with engine load, making it crucial to evaluate their behavior under different operational conditions [4].

Several renewable resources can be used to produce biodiesel, which is recyclable, toxic-free, and pleasant to our planet. In gas turbines, Habib et al. [5] investigated blended biodiesel made of soybean, canola, recycled rapeseed, and hog fat against Jet A1. They observed a decrease in HC, CO, NO_x, and static thrust compared to Jet A-1. Moreover, waste cooking oil (WCO) can be utilized to make biodiesel, which helps lessen the worldwide food shortage brought on by foreign conflicts, particularly the war between Russia and Ukraine [6].

Waste cooking oil has been put to the test by certain scholars as an additive to fuel for diesel-powered engines [7]. Waste cooking oil is classified as a third-generation substrate, along with fat chicken oil, fish oil, and microalgae, by Radwan et al. [8]. These substrates are frequently utilized to produce biodiesel [9]. Thus, waste cooking oil is explored experimentally in this work as a potential substitute fuel supplement for compression ignition engines [10]. The regular usage of CI engines in all arenas releases toxic gases like NO_x, CO, and HC, triggering significant environmental emissions, ozone layer depletion, and bronchial diseases [11].

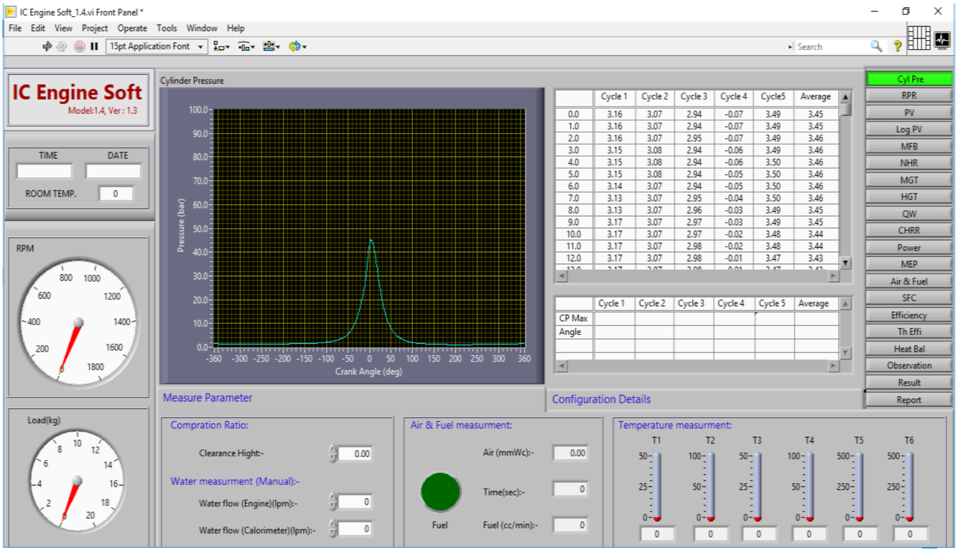
This paper presents an experimental investigation into the performance and exhaust emissions of a direct injection diesel engine operating on different fuel blends with additives under variable engine loads. Thus, extensive experiments are conducted on a diesel fuel blended with WCO (W), butanol (B), and diethyl ether (DD). Blend 1, D70B10W10DD10, composed of 70% diesel, 10% butanol,10% WCO, and 10% diethyl-ether, and blend 2, D85B5W5DD5, consisting of 85% diesel, 5% butanol,5% WCO, and 5% diethyl-ether are investigated. The engine performance parameters and exhaust emission concentrations are compared and evaluated against pure diesel fuel under 0%, 25%, 50%, 75%, and 100% loads. Also, a comprehensive analysis of the effects of these fuel blends on engine performance parameters, such as the pressure history diagram inside the cylinder, the indicator diagram, thermal efficiency, and the emission characteristics, including NO_x, CO, and HC. By understanding the impact of fuel additives across various engine loads, this study seeks to offer insights into optimizing fuel formulations for improved engine performance and reduced environmental impact.

2. Experimental setup

A four-stroke, single-cylinder, water-cooled diesel engine was operated as an experimental bed exclusively designed for research in the field of automotive engineering, as illustrated in Fig. 1. The setup encompasses a single-cylinder, four-stroke diesel engine fixed to an eddy current dynamometer that regulates engine loading. The engine's bore is 87.5 mm, its stroke length is 110 mm, and the total swept volume is 661.5 cm^3. The trials were carried out at a compression ratio of 17.9 with a steady speed of 1630 rpm. The paraphernalia essential for measuring in-cylinder pressure and crank angle was installed in the engine. In addition, interfaces for load measurement, temperature, airflow, and fuel flow were all installed. For determining the P0-PV diagrams, these engine signals are interfaced to a computer via a data logger device. The configuration facilitates the analysis of engine performance for the following parameters: mechanical efficiency (ME), volumetric efficiency (VE), specific fuel consumption (SFC), air-fuel (A/F) ratio, heat balance, brake mean effective pressure (BMEP), brake power (BP), frictional power (FP), brake thermal efficiency (BTE), indicated thermal efficiency (ITE), and brake mean effective pressure (IMEP). The setup consists of an isolated panel box with an air box, a fuel tank, and transmitters that monitor air and fuel flow. "ICEngine _ SoftL V9 .1" is the application program for engine recital assessment. A model of the software interface is shown in Fig. 2.

A flue gas analyzer is installed on the engine exhaust pipe to measure and record the exhaust gas components and their concentrations. To ensure precise and high-performing procedures, each gas sample is dried and cleaned using specialized gas specimen conditioner equipment. Via an inlet and a particulate filter, an inner pump sucks a gas stream into the sensor's chamber. The device was designed to detect the concentration of 6 species: CO, CO_2, C_xH_y, NO_x, O_2, and SO_x.

Fig. 1 The test engine used in the experimental investigation



TIME
DATE
ROOM TEMP. 0

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle5	Average
0.0	3.16	3.07	2.94	-0.07	3.49	3.45
1.0	3.16	3.07	2.94	-0.07	3.49	3.45
2.0	3.16	3.07	2.95	-0.07	3.49	3.46
3.0	3.15	3.08	2.94	-0.06	3.49	3.46
4.0	3.15	3.08	2.94	-0.06	3.50	3.46
5.0	3.15	3.08	2.94	-0.05	3.50	3.46
6.0	3.14	3.07	2.94	-0.05	3.50	3.46
7.0	3.13	3.07	2.95	-0.04	3.50	3.46
8.0	3.13	3.07	2.96	-0.03	3.49	3.45
9.0	3.17	3.07	2.97	-0.03	3.49	3.45
10.0	3.17	3.07	2.97	-0.02	3.48	3.44
11.0	3.17	3.07	2.98	-0.02	3.48	3.44
12.0	3.17	3.07	2.98	-0.01	3.47	3.43

	Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5	Average
CP Max						
Angle						

Clearance Hight:- 0.00

Water flow (Engine)(lpm):- 0

Water flow (Calorimeter)(lpm):- 0

Air (mmWc):- 0.00

Time(sec):- 0

Fuel (cc/min):- 0

T1 0

T2 0

T3 0

T4 0

T5 0

T6 0

Fig. 2 Front panel of the engine performance software.

Table 1 presents the properties of pure diesel and the two blends. Blend 1 (D70B10W10DD10) has the highest viscosity, which could affect fuel injection and flow characteristics compared to pure diesel. Blend 2 (D85B5W5DD5) has a lower viscosity than Blend 1 but is still higher than pure diesel. Also, the table shows that all blends have lower heating values than pure diesel, with Blend 1 being the lowest. This indicates that the blends may produce less energy upon combustion than pure diesel. At the same time, the densities of both blends are slightly lower than that of pure diesel, reflecting the influence of the lighter components (butanol and diethyl ether) in the blends.

Table 1: Physical and chemical properties of the fuels used in the investigation

	Diesel	Blend 1	Blend 2
Composition	Pure diesel fuel	D70B10W10DD10	D85B5W5DD5
Viscosity	3.0 cSt at 40°C.	5.9 cSt at 40°C.	4.4 cSt at 40°C
LHV	42.5 MJ/kg.	40.5 MJ/kg	41.8 MJ/kg
Density	0.850 g/cm³	0.831 g/cm³	0.836 g/cm³

3. Results and discussions

3.1. Performance parameters

Figure 3 presents the p-theta diagram of the engine for the three fuels at zero load and 75% load. The peak pressure is around 50 bar and occurs slightly after the top dead center (TDC, at 0° crank angle), typical in diesel engines. The pressure for pure diesel rises gradually as the crank angle approaches TDC. It reaches a peak pressure of just over 50 bar around TDC and gradually drops afterward. Blend 1 exhibits a slightly higher peak pressure than pure diesel, peaking at around 50-52 bar. The pressure rise begins earlier than pure diesel, indicating faster combustion or better ignition characteristics. Blend 2 shows the highest peak pressure of the three, peaking just above 52 bar. Like Blend 1, it has an earlier pressure rise than pure diesel, suggesting more rapid combustion.

Blends 1 and 2 produce higher peak pressures than pure diesel, indicating more efficient combustion at zero load. This could be attributed to the improved ignition or combustion characteristics of the additives in the blends. Blend 2, in particular, shows the highest pressure, implying it has the most enhanced combustion behavior. The earlier pressure rise in Blends 1 and 2 suggests better fuel atomization, quicker ignition, and possibly oxygenated additives, which promote faster combustion. Pure diesel has a slightly delayed pressure build-up, which might indicate a less aggressive combustion at zero load. After the pressure peaks, all curves follow a similar pattern, gradually dropping in pressure. However, the blends maintain higher pressure values for slightly longer after TDC, suggesting a more sustained combustion phase than pure diesel.

Both blends perform better in peak pressure and faster combustion, indicating improved engine performance and potentially lower fuel consumption or fewer unburnt hydrocarbons. Blend 2 shows the highest pressure and fastest combustion among the blends. This could indicate that blend 2 might provide better energy output performance, but the increased peak pressure might also lead to higher NO_x emissions.

The pressure history at 75% load has the same trend as the zero load. However, the greater the load, the greater the peak pressure inside the cylinder. In both figures, blend 2 exhibits the maximum pressure among the three fuels. At zero load, the maximum pressure is 53 bar, while at 75%, the peak pressure is 74 bar.

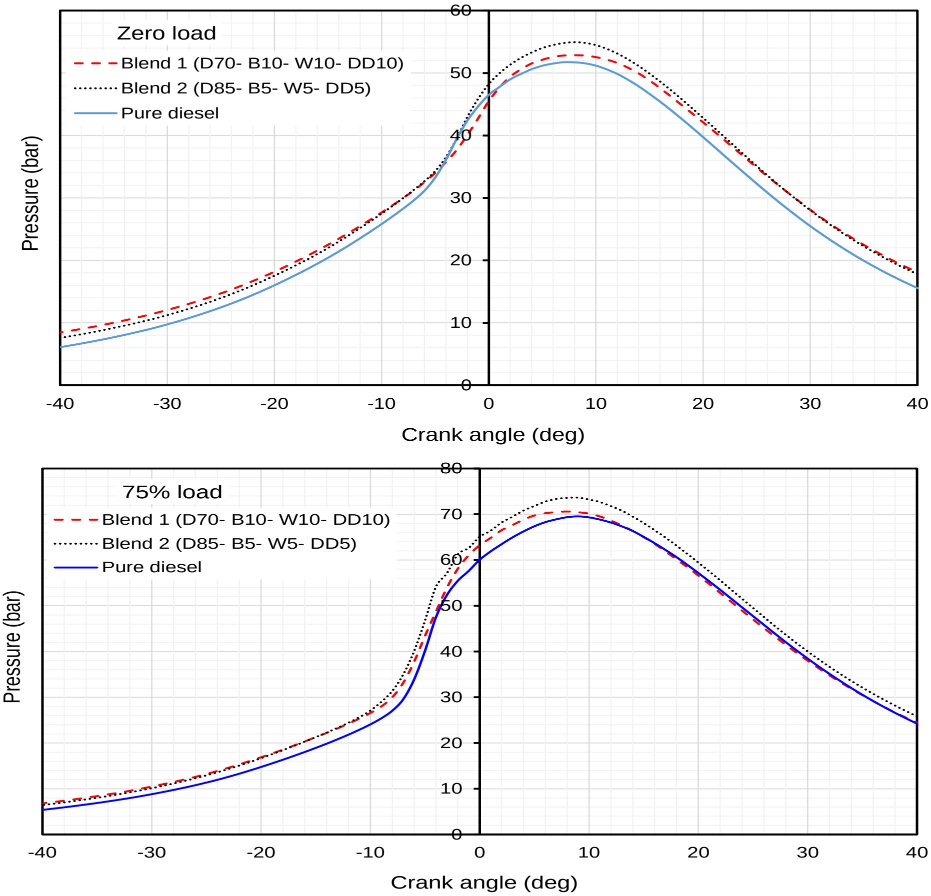


Fig. 3 The p-theta diagram for the three fuels: at zero load and 75% load.

Figure 4 shows the p-v indicator diagram of the three fuels at no load and 75% load. This type of P-V diagram helps evaluate the efficiency and combustion characteristics of different fuel blends, which is essential when assessing alternatives to pure diesel for improved performance and reduced emissions. For the zero load case, pure diesel shows the pressure rise and fall during the engine cycle for pure diesel fuel. Peak pressure occurs early, around 50 bar, then rapidly drops as the volume increases. Blend 1 results in a slightly higher peak pressure than pure diesel, with a peak around 53 bar. The curve shape closely follows the diesel curve but suggests a marginally more powerful combustion phase. Blend 2 shows a peak pressure similar to Blend 1, around 53 bar, with a slightly faster pressure drop-off than the other curves, indicating a quicker release of energy during combustion. Blends 1 and 2 demonstrate slightly higher peak pressures than pure diesel, which could improve engine performance.

The differences in pressure distribution and drop-off rates suggest slight variations in how each blend combusts within the engine. Blend 2 may release energy more quickly, leading to quicker combustion phases. No significant difference is noted for the 75% load case, which has almost the same trend but with higher peak pressure than the no-load case.

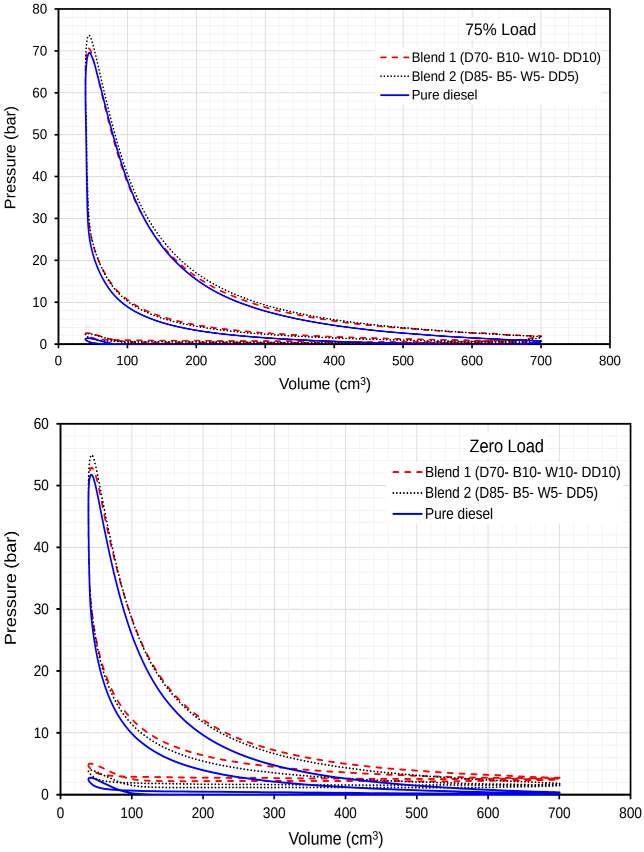


Fig. 4 The indicator diagram for the three fuels at zero load and 75% load.

Figure 5 illustrates the brake thermal efficiency (BTE) of two fuel blends compared to conventional diesel at varying engine loads. Blend 1 shows an increase in brake thermal efficiency from 0% to 50% load, peaking around 50%, then gradually decreasing beyond that point. Blend 2 shows a much higher peak brake thermal efficiency at around 75% load, surpassing Blend 1 and Diesel at mid to high load conditions, but drops quickly afterward. Pure diesel shows a relatively stable and moderate increase in efficiency, peaking at around 75% load, but it doesn't reach the levels of the other two blends. Blend 2 offers the highest efficiency at higher loads (around 75%), outperforming Blend 1 and diesel.

Also, Blend 1 has a strong performance at mid loads (50%) but falls off more sharply beyond that compared to diesel. Diesel maintains a more consistent performance across various loads but doesn't excel at any particular point compared to the blends.

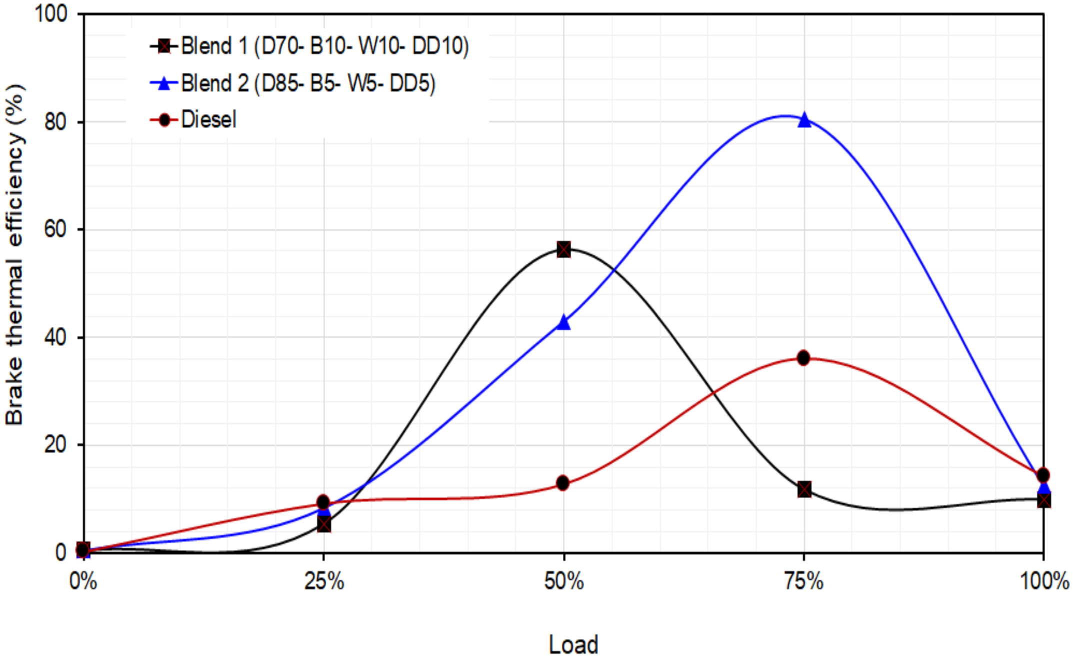


Fig. 5 Variation of the brake thermal efficiency with the applied load for the different fuels.

3.2. Engine emissions

Figure 6 compares three fuel blends' nitrogen oxide emissions under varying load conditions. The fuels compared are Blend 1 (D70-B10-W10-DD10), represented by black squares; Blend 2 (D85-B5-W5-DD5), represented by blue triangles; and Diesel, represented by orange circles. Blend 1 starts at approximately 50 ppm NO_x at 0% load and increases steadily, peaking around 150 ppm at 75%. At 100% load, it decreases slightly. Blend 2 starts at around 100 ppm NO_x at 0% load, rises sharply to about 200 ppm at 50% load, then stabilizes and slightly decreases as the load increases to 100%. Diesel exhibits much lower NO_x emissions than both blends, starting around 50 ppm at 0% load, maintaining a relatively stable level until around 50% load. Afterward, it begins to rise but remains significantly lower than the two blends, even at full load. The important note is that higher NO_x emissions from Blends 1 and 2, where both blends produce significantly higher NO_x emissions than conventional diesel, particularly at higher loads.

Blend 2 exhibits a steeper increase in NO_x emissions as the load increases, peaking earlier at around 50% load. Diesel fuel shows more consistent NO_x emissions across the load spectrum, remaining comparatively low, though it does begin to rise at higher loads.

The components of Blend 1 and Blend 2 might contribute to different combustion characteristics, leading to variations in NO_x emissions. Also, adding waste cooking oil to fuel blends reduces combustion temperatures, which can sometimes lower NO_x emissions.

However, the specific amounts in these blends may not be sufficient to achieve this effect, especially as the load increases. While butanol and other alcoholic fuels can offer renewable or lower-carbon advantages, they may also lead to higher NO_x emissions due to their combustion properties.

DEE is oxygenated like butanol and can increase combustion efficiency, possibly producing higher local temperatures and NO_x emissions. Both butanol and DEE introduce more oxygen into the combustion process, which can enhance combustion and pose a risk of increased NO_x due to higher local combustion temperatures.

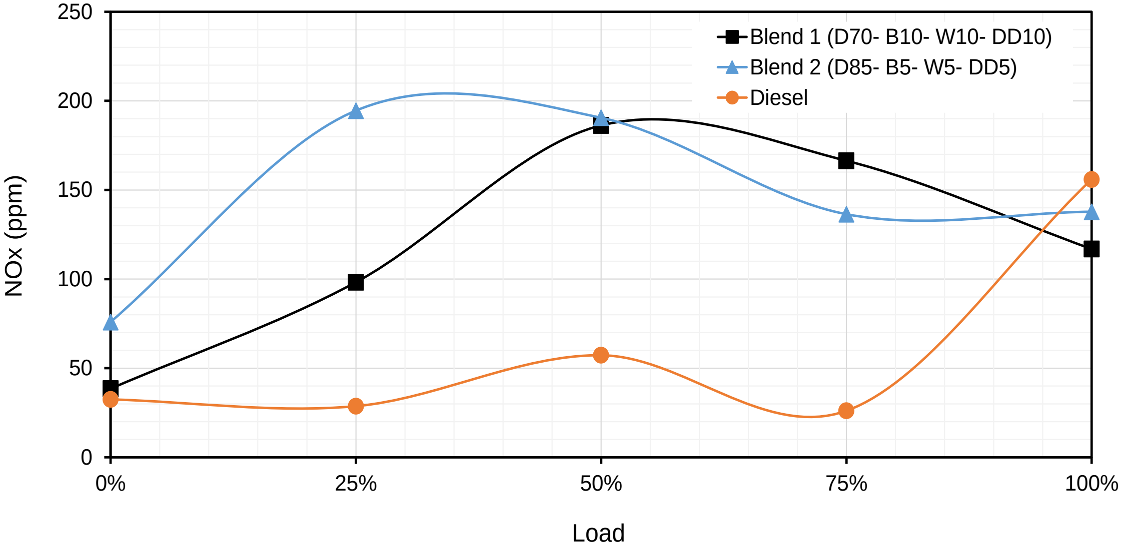


Fig. 6 Variation of the NOx emissions with load for the different blends.

Figure 7 presents the carbon monoxide emissions as a percentage (%) for three different fuel blends under varying load conditions. Diesel fuel starts at around 0.03% CO at 0% load, decreasing slightly at 25%, then rises steeply after 50%, peaking around 0.17% at 100% load. Blend 1 begins slightly above 0.03% CO at 0% load. It shows a mild decrease as load increases, staying relatively stable up to 75% load, then increasing slightly to around 0.05% at 100% load. Blend 2 shows a slight increase in CO emissions as load increases, starting at around 0.03% at 0% load, peaking just above 0.06% at 75% load, and then slightly decreasing at 100% compared to pure diesel.

Diesel shows the steepest increase in CO emissions at higher loads, indicating that its combustion efficiency significantly decreases as the load increases. This trend suggests that diesel may not burn as cleanly at higher loads, leading to incomplete combustion and higher CO production. Blend 1 demonstrates more stability across the load spectrum, with lower overall CO emissions than diesel, especially at higher loads. This could indicate better combustion characteristics under high-load conditions. Blend 2 shows a moderate rise in CO emissions, peaking at around 75% load, then decreases slightly by 100%. This suggests that its combustion process might stabilize or become more efficient at full load than diesel.

The CO emissions are typically a sign of incomplete combustion. Diesel emits more CO at higher loads, suggesting that its combustion efficiency declines as the load increases. On the other hand, both blends seem to maintain more stable or improved combustion at higher loads, likely due to the butanol or waste cooking oil components improving fuel combustion characteristics.

Both blends' waste cooking oil and diesel-diluted components (W and DD) could contribute to complete combustion and lower CO emissions, particularly in Blend 1. The waste cooking oil in fuel blends often leads to more complete combustion by reducing combustion temperatures, while additives may enhance combustion efficiency.

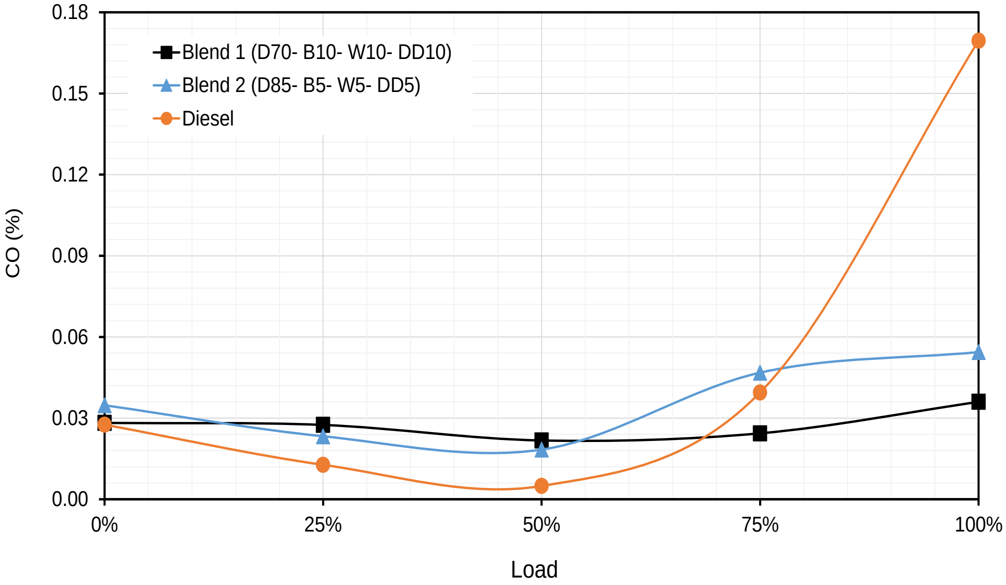
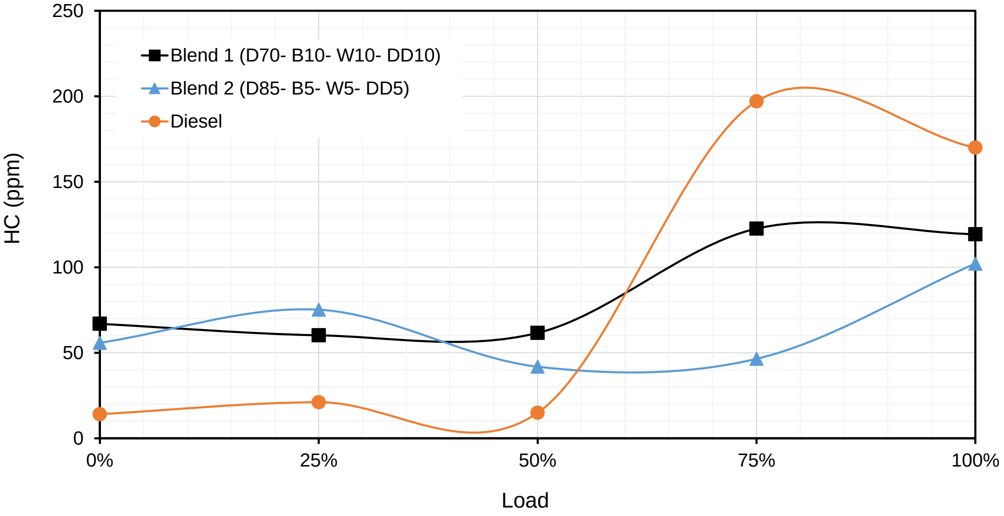


Fig. 7 Variation of the CO emissions with load for the different blends.

Figure 8 shows the variation of the emitted hydrocarbons with the engine load for the three studied fuels. At low loads (0% to 25%), diesel has the lowest HC emissions, with values under 50 ppm. The HC emissions increase significantly at higher loads (75% to 100%), peaking around 200 ppm at 75% load before dropping slightly at 100%. Diesel's HC emissions sharply increase with load, significantly beyond 50%, suggesting it produces more hydrocarbons at high engine loads.

For Blend 1, this fuel blend maintains a reasonably consistent HC emission level across the load range. The highest emissions are observed at 25% and 100% load, but emissions remain below 100 ppm even at their peak. It shows the most stable behavior regarding HC emissions across different loads.Blend 2's HC starts moderately low and increases to 50% load, where emissions peak near 100 ppm. After 50% load, the emissions drop significantly, making it the lowest emitting blend at high loads (75% to 100%). Such a blend emits more HC at lower to mid loads (25% to 50%) but performs better at high loads, reducing emissions significantly after 50%.

Fig. 8 Variation of the HC emissions with load for the different blends



4. Conclusions

The current study presents an experimental analysis of a diesel engine's performance and exhaust emissions mainly running on waste cooking oil (WCO). The engine type utilized is a single-cylinder direct injection diesel engine with constant speed and natural aspiration. The research was done on the engine's performance and emission parameters when fueled with a mixture of 5% butanol, 85% diesel, 5% WCO, and 5% diethyl ether (D85B5W5DD5). The study's findings demonstrated that engine emissions of nitrogen oxides (NO_X) and carbon monoxide (CO) varied significantly depending on the applied load. The brake thermal efficiency and cylinder pressure were all impacted by load change.

Also, the engine emissions change considerably with the engine load. Based on the study findings, the following points arise:

1. Blends 1 and 2 perform better in peak pressure and faster combustion, indicating improved engine performance and potentially lower fuel consumption or fewer unburnt hydrocarbons. Blend 2 shows the highest pressure and fastest combustion among the blends. This reflects that blend 2 provides better energy output performance, but the increased peak pressure might also lead to higher NOx emissions.
2. The differences in pressure distribution and drop-off rates suggest slight variations in how each blend combusts within the engine. Blend 2 releases energy more quickly, leading to quicker combustion phases. No significant difference is noted for the 75% load case, which has almost the same trend.

3. Blend 2 shows a much higher peak brake thermal efficiency at around 75% load, surpassing Blend 1 and Diesel at mid to high load conditions, but drops quickly afterward.
4. Diesel exhibits much lower NO_x emissions than both blends, starting around 50 ppm at 0% load, maintaining a relatively stable level until around 50% load. Afterward, it begins to rise but remains significantly lower than the two blends, even at full load. The studied blends can interact in intricate ways. For example, the oxygen concentration of butanol and waste cooking oil can boost combustion efficiency, while DEE's high cetane number can increase ignition quality. These factors can all contribute to increases in NOx emissions, although the overall effect depends on the blend ratios and engine operating circumstances.
5. Blend 2 shows a slight increase in CO emissions as load increases, starting at around 0.03% at zero-load, peaking just above 0.06% at 75% load, and then slightly decreasing at 100% compared to pure diesel.
6. Blend 2's HC starts moderately low and increases to 50% load, where emissions peak near 100 ppm. After 50% load, the emissions drop significantly, making it the lowest emitting blend at high loads (75% to 100%). Such a blend emits more HC at lower to mid loads (25% to 50%) but performs better at high loads, reducing emissions significantly after 50%.
7. There will be many challenges faced when implementing biodiesel-diesel blends because the complexity of the fuel and the additives in the combustion process where high temperature existed, and no one can predict the products of the combustion unless the experimental testing is done to find the final percentage of the gas results for each new blend.

In conclusion, research involving experimentation and mathematical modeling is necessary to accurately assess the effect of different fuel blends on NOx, CO, and HC emission levels. Blend 2 reduces overall emission levels compared to pure diesel fuel. Still, more investigations will be done to understand the emission behavior in the experimental work by adding different additives like nano particles or improving the biodiesel mixture characteristics.

References

[1] Agarwal AK, Krishnamoorthi M. Review of morphological and chemical characteristics of particulates from compression ignition engines. International Journal of Engine Research. 2023;24(7):2807-2865. https://doi:10.1177/14680874221114532.

[2] Lv, J.; Wang, S.; Meng, B. The Effects of Nano-Additives Added to Diesel-Biodiesel Fuel Blends on Combustion and Emission Characteristics of Diesel Engine: A Review. *Energies* **2022**, *15*, 1032. https://doi.org/10.3390/en15031032.

[3] Musculus, Mark P, and Dietz, Jeff. Effects of diesel fuel combustion-modifier additives on In-cylinder soot formation in a heavy-duty Dl diesel engine. United States: N. p., 2005. Web. https://doi:10.2172/876311.

[4] Modi, A., Gosai, D., Gillawat, A. (2024). 'Impact of nano-fuel additives and nano-lubricant oil additives on diesel engine performance and emission characteristics', Journal of Heat and Mass Transfer Research, https://doi: 10.22075/jhmtr.2024.33460.1531

[5] Habib Z, Parthasarathy R, and Gollahalli S. Performance and emission characteristics of biofuel in a small-scale gas turbine engine. Applied Energy 87 (2010).

[6] Esfandabadi ZS, Ranjbari M, Scagnelli SD. The imbalance of food and biofuel markets amid Ukraine-Russia crisis: a systems thinking perspective. Biofuel Resources Journal 9 (2022).

[7] EL-Seesy A., Waly M., Zhixia H., El-Batsh H., Nasser A., and Radwan M., Influence of quaternary combinations of biodiesel/methanol/n-octanol/ diethyl ether from waste cooking oil on combustion, emission, and stability aspects of a diesel engine. Energy Conversion and Management 240 (2021).

[8] Radwan M., Ahmed S., Huzayyin A.S., and EL-Seesy A., Effect of diethyl ether addition to waste cooking oil biodiesel on the combustion and emission characteristics of a swirl-stabilized premixed flame. Energy Conversion and Management 286 (2023).

[9] Sandouqa A, and Al-Hamamre Z. Energy analysis of biodiesel production from jojoba seed oil. Renewable Energy 130 (2019).

[10] El-Seesy A., Hamdy H., Latif I., Zhixia H. and Manzoore E., Combustion, emission, and phase stability features of a diesel engine fueled by Jatropha/ ethanol blends and n-butanol as co-solvent. International Journal of Green Energy 17:12, 793-804, DOI: 10.1080/15435075.2020.1798770.

[11] Venkatesan P. E., B Dhinesh., Samuel O.D., Kaisan M.U., Murugesan P. (2021) Effect of Hybrid Nanoparticle on DI Diesel Engine Performance, Combustion, and Emission Studies. In: Singh A.P., Agarwal A.K. (eds) Novel Internal Combustion Engine Technologies for Performance Improvement and Emission Reduction. Energy, Environment, and Sustainability. Springer, Singapore. https://doi.org/10.1007/978-981-16-1582-5_10.