e-ISSN: 2146 - 9067

International Journal of Automotive Engineering and Technologies

journal homepage:

https://dergipark.org.tr/en/pub/ijaet

Original Research Article

Investigation of high percentage of dimethyl ether on biodiesel usage in a diesel engine

hosted by Turkish JournalPark ACADEMIC

Yahya Çelebi[1] *, Hüseyin Aydın[2], Hüsna Topkaya[3]

[1 *] Şırnak University, Departman of Motor Vehicles and Transportation Technologies, 73000, Şırnak, Türkiye.
[2] Batman University, Department of Mechanical Engineering, 72050, Batman, Türkiye.
[3] Batman University, Department of Machinery and Metal Technologies, 72050, Batman, Türkiye.

ARTICLE INFO

Orcid Numbers

1. 0000-0002-4686-9794
2. 0000-0002-5415-0405
3. 0000-0002-7867-4086

Doi: 10.18245/ijaet.1351218

* Corresponding author
yahya.celebi@outlook.com

Received: Agu 28, 2023
Accepted: Jul 11, 2024

Published: 30 Sep 2024

Published by Editorial Board Members of IJAET

ABSTRACT

Demand for cleaner energy sources both as additive and alternative fuels that can substitute or contribute to the usage of conventional fuels is growing. Researchers have mainly focused on improving or finding a renewable fuel from vegetable oil or addition of chemicals and alcohols for IC engine. This study analyzed the effects of a high percentage of dimethyl ether (DME) combined with biodiesel in a diesel engine. Transesterification method was selected for conversion of pure safflower oil to biodiesel. DME was blended with biodiesel at concentrations of 50% and 25% on a volume basis, respectively. Engine performance and emissions tests demonstrated that the thermal efficiency values were increased at high load operation when the engine was fueled with high percentage of DME. Furthermore, compared to conventional diesel, there has been a notable decrease in NO_x emissions. Nevertheless, the introduction of DME blend had negligible effects on CO_2 emissions. However, when using a high ratio of DME blend, HC emissions were found to increase, whereas a low ratio of DME blend resulted in decreased HC emissions. Apart from these, some irregularities were observed both on heat release rate and cylinder pressure especially for 50% of DME usage. Finally, the values for both brake-specific fuel consumption and mass fuel of DME-blended fuels were deteriorated.

Keywords: Biodiesel, Dimethyl ether, DME, Diesel engine, Safflower

1. Introduction

Global energy demand is expected to increase in parallel with the growth in human population and industrial sector extension. As a result of increasing energy demand, fossil fuels are depleting and deteriorating the air quality and causes global warming which arouses attention for solutions by lawmakers and researchers. Apart from these issues, oil price is increasing due to high cost of refining and production of petroleum based conventional fuels [1]. However, it is expected that oil price will be increased more and more. Currently, many countries including the USA, and EU are using biodiesel or alcohols as additive in the conventional fuels [2, 3]. Besides, the biofuel share in the transportation sector is increasing due to its convenient properties such as its cleaner exhaust gas emissions, low cost and abundant reservoir [1, 4].

Safflower plant is originated from the Middle East and is also cultivated throughout United States and Europe. Safflower plant reaches one meter height and has plentiful crops in the world. Also, the plant needs no abundant water and can sustain its growth in the high temperature and semiarid climates [5, 6]. Transesterification method is a process that consists of the physical and chemical processes for biodiesel production [7]. In this experimental study, Transesterification method was selected for biodiesel production from safflower oil. Despite that alcohols are not proper for use as the sole fuel in compression ignition engine, biodiesel can be used without any engine alteration which makes it more advantageous for the engine [8], [9]. In the present research, a blend of DME and safflower biodiesel could give us compelling results for compression ignition engines.

DME has an organic chemical structure, and its formula is CH3OCH3. DME can be obtained through direct or indirect synthetic methods from both natural gas and methanol [10]. DME has higher cetane number and oxygen molecule in comparison with conventional diesel fuel which is regarded as advantageous properties in diesel combustion [11]. However, DME is described as clean fuel thanks to no carbon-carbon bonds and 35% of oxygen content within its molecular structure. Apart from that, its combustion characteristic is similar to liquefied petroleum gas (LPG) [12, 13].

Theinnoi et al. [14] used DME and diesel in an engine to reveal the effect of performance in a diesel engine. DME was injected from in-port while diesel fuel was injected from in-cylinder. Authors stated that optimum DME proportion was 30%. According to the experiments, thermal efficiency was improved while exhaust gases were decreased when the engine run with DME port injection compared to base diesel fuel. Additionally, fuel consumption was reduced up to 22.6%.

Roh et al. [15] made an experimental investigation to display the changes of ternary fuels of DME, diesel and biodiesel mixtures on the emissions and combustion in a passenger car diesel engine. They per performed two distinct injection strategies (single and pilot injection modes) for the test mixtures. DME was blended with biodiesel. The mixture of diesel and DME was used with the proportion of 80% in the blends while biodiesel percentage was 20%. According to the test results, NOx gases were the highest for DME-biodiesel blend along all the test fuel and pilot injection mode was resulted in a significant increase of NOx in comparison with single mode. In addition, DME was showed excellent improvement for Soot reduction which decreased the value to near zero for both injection modes. Also, DME was showed a higher in-cylinder pressure but lower peak pressure in pilot injection mode.

An experimental study using DME-diesel mixtures was made by Li et al. [16]. They found that the engine output power fueled with DME was higher at low engine operations whereas it showed lower value at higher engine operations. HC and NOx emissions were slightly lowered at all engine loads compare to that of diesel while smoke emission was lower 30% at medium and high loads.

The purpose of this experimental study is to reveal the impacts of DME and biodiesel mixtures on emission, performance, and combustion in diesel engines. In the literature, many researchers examined the effect of a mixture of DME and diesel, DME was not run with only biodiesel. In this paper, high percentages of DME were used in the mixtures. Furthermore, biodiesel and ultra-low sulfur diesel were also tested to assess the impact of DME on diesel engine performance.

2. Methodology

2.1. Testing materials and equipment

Safflower oil was obtained by a commercial company. The chemical and physical reactions were made according to transesterification method to produce biodiesel from safflower [17]. DME was blended with biodiesel to optimize the mixture with enabling high percentage of biodiesel in the engine. Five test blends were prepared for the experiments. DME was blended with biodiesel up to 50% in volume basis. Apart from DME blended fuels, biodiesel, diesel and their mixture were also prepared for the tests. It is aimed that the evaluation of the experimental test results could be given a better view by doing so.

The specifications of neat form of the pure test fuels were provided in Table 1. D100 has the highest calorific value compared to the other test fuels. However, DME has a lower calorific value, which reduces the average calorific value of the blend when it is used in the mixture. Therefore, it can be predicted that blends with DME will consume more energy, resulting in higher BSC values.

The test fuels were made up of B75DME25 (75% biodiesel and 25% DME in vol.), B50DME50 (50% biodiesel and 50% DME in vol.), biodiesel-diesel mixture (B50, 50% biodiesel and 50% diesel in vol.), standard diesel fuel (D2) and pure biodiesel (B100). The tests were conducted at various engine conditions, including idling, 20% load, 40% load, medium load equivalent to 60% load of the generator, all while maintaining a steady speed of 1500 rpm. Load intensity was controlled by electrical resistances. However, a total of three repetitions were conducted for each test in the engine and their values were averaged for each parameter. These average values were presented in figures.

The experiments were conducted at Batman University using a 4-cylinder, 4-stroke, water-cooled, direct injection, diesel engine generator. The schematic diagram presented in Figure 1 represents the experimental setup used in the study. For the measurement of the test fuel emissions, an exhaust gas analyzer was employed. The specifications of the engine used in study are depicted in Table 2. To obtain exhaust gas temperature data, an infrared temperature measurement device was utilized where measurements taken from the exhaust pipes of the engine. A heat resistant unit and an air conditioner were placed in the test environment to keep the tests on ambient conditions.

Table 1. Specifications of fuels used in tests.

Property/Fuel	**Diesel**	**DME**	**B100**	**B75DME25**	**B50DME50**
Chemical formula	Various	C_2H_6O	Various	Various	Various
Viscosity (mm^2/s), (@40°C)	2.7	0.15	5.2	3.9375	2.675
Density (g/cm^3) (@20°C)	0.84	0.66	0.88	0.825	0.77
Adiabatic flame temperature (K)	2.225	1.954	2,680	2498.5	2317
Auto-ignition temperature (°C) (@1 atm)	206	235	260	253.75	247.5
Lower calorific value (MJ/kg)	42.5	24.3	38.1	34.65	31.2
Flash point (°C)	78	-41	148	100.75	53.5
Boiling point(°C)	200-350	-25	310-360	-	-
Cetane number	53	55	56.82	56.365	55.91
Oxygen content (%wt.)	0	34.8	10.95	16.9125	22.875

Table 2. Properties of the engine.

Power output (@1500 *rpm*)	**18 kW**
Manufacturer	NWK22
Engine model	4DW81-23D
Engine cooling system	Water cooling
Displacement (cm^3)	2400
Bore *X* stroke (*mm*)	85*x*100
Number of cylinders	4
Intake system	Naturally aspirates
Number of injector nozzle	4
Compression ratio	17:1

Table 3. Technical specifications of the test devices.

Brand	Parameter	Measurement range	Accuracy
Raytek Raynger ST4	Exhaust temperature	−32 to 400 °C	± 1%
AutoPSI−S	Cylinder pressure sensor	0–200 bar	≤± 0.5%
Dikomsan ACS–Z–3	Fuel consumption	0.5–3000 g	± 0.5 g
IFM RO1378	Speed	0–12000 rpm	± 0.1% [º]
	CO	0–15 %	± 0.001%
	CO_2	0–20 %	± 0.1%
CAPELEC CAP 3200	HC	0–20000 ppm	± 1 ppm
	NO_x	0–5000 ppm	± 1 ppm
	O_2	0–21.7 %	± 0.01%

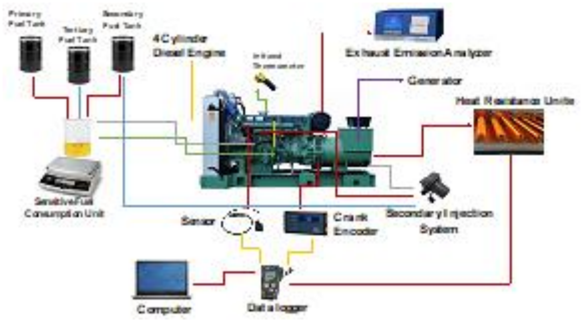

Figure 1. Schematic diagram of experimental setup.

For collecting data and analysis, a combustion analysis software [18] was used. The FEBRIS software was utilized to collect data on combustion parameters including heat release rate (HRR), peak pressure, mean gas temperature (MGT) and cylinder pressure as a function of crank angle (CA). In-cylinder pressures were gathered using a piezoelectric transducer positioned within the combustion chamber. The in-cylinder pressure data was captured at intervals of 1 degree of the CA using an encoder. At every operating point, the cylinder pressure data from 100 cycles were collected, and subsequent parameter calculations were performed using the software based on the first law analysis of thermodynamics. The test of fuel mixtures was run at idle, 20%, 40% and 60% of engine load operations. Table 3 provides the technical specifications of the test devices.

2. Experimental procedures and combustion calculations

The heat release rate is given as $dQ/d\theta$ which was calculated by following equation.

$$\frac{dQ}{d\theta} = \frac{\gamma}{\gamma-1} P \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dP}{d\theta} \quad (1)$$

$$\int dQ = \int \left(\frac{\gamma}{\gamma-1}\right) p(dV) + \left(\frac{1}{(\gamma-1)}\right) V(dP) \quad (2)$$

where γ is the specific heat ratio and it is taken as 1.32, θ is crank angle, P is in-cylinder gas pressure that measured by the pressure sensor, and V is cylinder volume in the equation [19]. The mean gas temperature values are calculated from the local averaging of gas temperature in the combustion chamber. Since the combustion chamber system is usually seen as an ideally mixed volume, the mean gas temperature is easy to determine from the equation for an ideal gas [25]. For the piston and the cylinder, usually local constant temperatures are used. Expansion stroke is assumed as polytrophic and the following equation is used in order to calculate the average gas temperature.

$$T_i = P_i V_i \frac{T_{ref}}{P_{ref} V_{ref}} \quad (3)$$

Here, T_i is average gas temperature, P_i and V_i are simultaneous pressure and cylinder volume T_{ref}, P_{ref} and V_{ref} are reference parameters at any point of polytrophic curve of expansion.

3. Results and discussions

3.1. Combustion results

Figures 2-5 demonstrate the relationship between in-cylinder pressure and the CA for various load conditions during the combustion of test fuels. The peak in-cylinder pressure values were obtained for DME blend with high percentage at idle and all the engine loads. The main cause of highest cylinder pressure for DME is attributed to be due to the high amount of the fuel burned during the premixed combustion stage [26]. Even though the cetane numbers of the mixtures of DME and biodiesel is high enough to shorten the ignition delay and so the smooth pressure rise, its higher latent heat of vaporization causes to a low temperature in the combustion chamber. Thus, the maximum peak pressure was occurred for B75DME25 probably due to inconvenient atomization caused from higher viscosity of biodiesel. Additionally, another reason could be unfavorable mixing properties of biodiesel and DME. Overall, B50DME50 fuel seems to lead the irregular cylinder pressure, and the start of combustion was considerably delayed in comparison to the other test fuels under all the engine loads, especially at high loads. This is probably due to fuel properties of DME such as its low temperature combustion and lower adiabatic flame temperature and lower heating value. The maximum in-cylinder pressure values were predominantly recorded for DME blends. As it can be seen from the cylinder pressure graphs, neat biodiesel exhibited poor combustion performance due to its low heating value and evaporation characteristics. However, when DME was used with neat biodiesel, pressure values were improved. This change can be attributed to the lower viscosity of DME which leads to better evaporation and mixing.

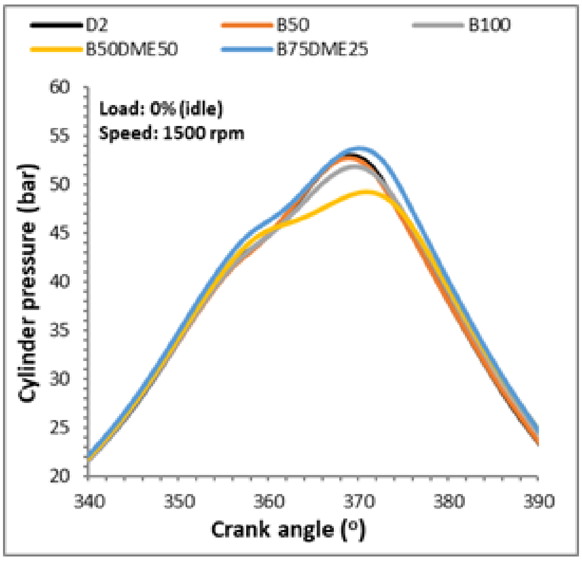

Figure 2. Cylinder pressure change at idle.

Additionally, the lower latent heat of vaporization of DME is considered as a contributing factor to a longer ignition delay, thereby resulting in a delayed increase in cylinder pressure.

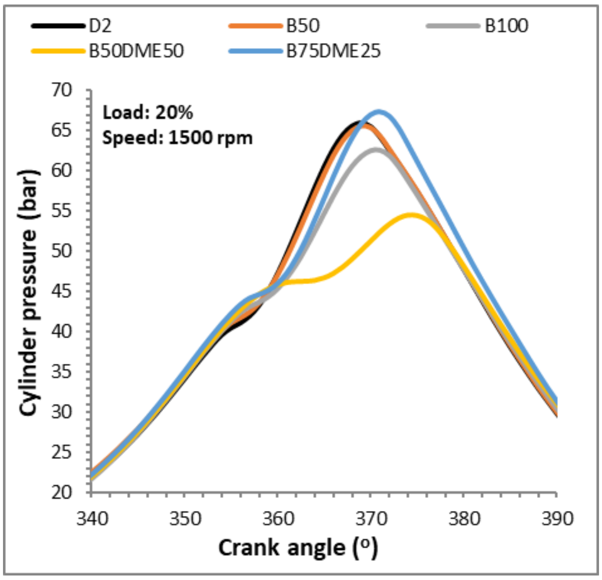

Figure 3. Cylinder pressure change at 20% load.

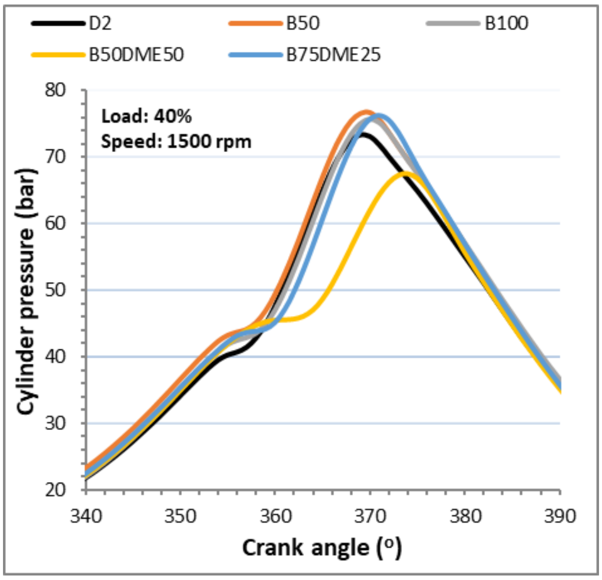

Figure 4. Cylinder pressure change at 40% load.

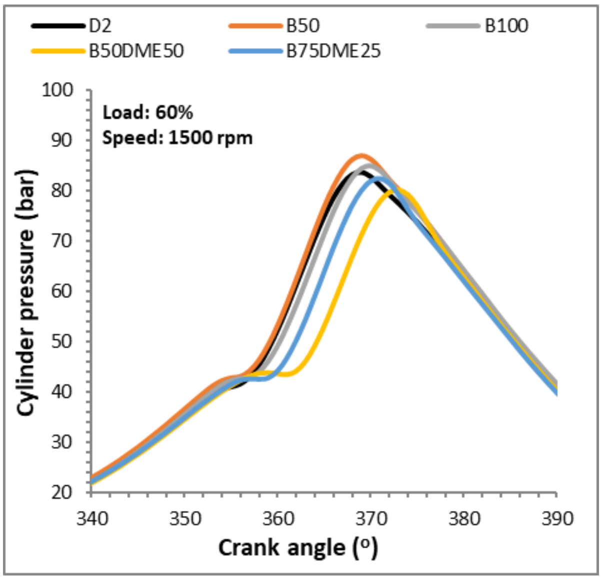

Figure 5. Cylinder pressure change at 60% load.

Additionally, the combustion characteristic of B75DME25 blend was quite similar to diesel fuel. The observed combustion characteristic of B50DME50 was unexpected, considering that both biodiesel and DME have sufficiently high cetane numbers, which typically result in shorter ignition delays and earlier combustion initiation. The reason why high amount DME-included blends showed longer combustion start are identified above. Figures 6-9 display the diagrams illustrating the HRR versus the CA for all the test fuels under different engine loads. The figures demonstrate a decline in the HRR between 350^o and 358^o CA, indicating a period of heat loss occurring in the combustion chamber. This heat loss is primarily attributed to the evaporation of the injected fuel during the ignition delay period. It can clearly be observed from the HRR figures that the combustion for B50DME50 begins the latest in all experiments. The highest values of the HRR are influenced by the ignition delay, which in turn determines the timing of the combustion initiation. When the beginning of combustion is delayed, the highest values of the HRR exhibit an increase. HRR diagram gives ideas related combustion process.

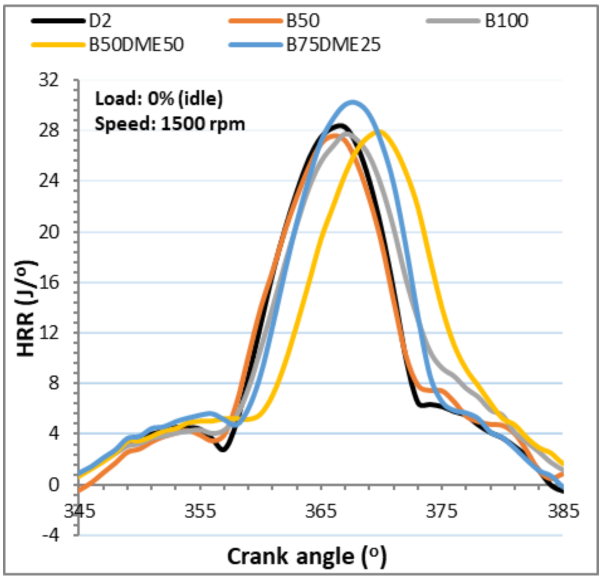

Figure 6. HRR change at idle.

As it can be seen from the figures of HRR, the HRR values of B50DME50 was obtained the farthest from the top dead center due to the delayed ignition caused from DME, higher latent heat of vaporization of the blend and lower cylinder temperature duel to low adiabatic flame temperature. Figures 10-13 depict the fluctuations in average gas temperature relative to the CA for various engine load conditions.

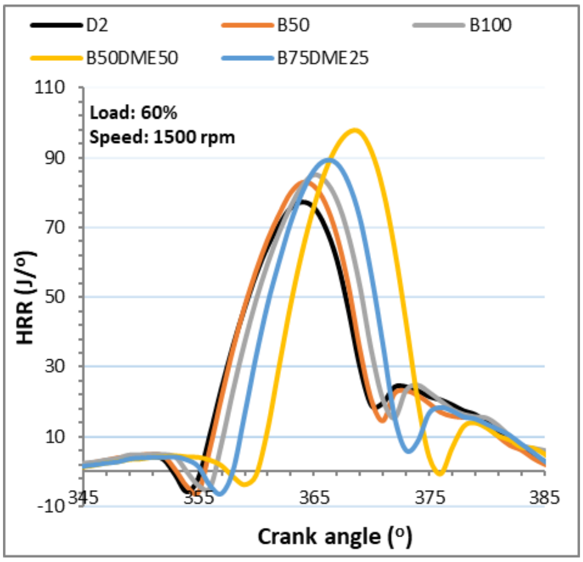

Figure 9. HRR change at 60% engine load.

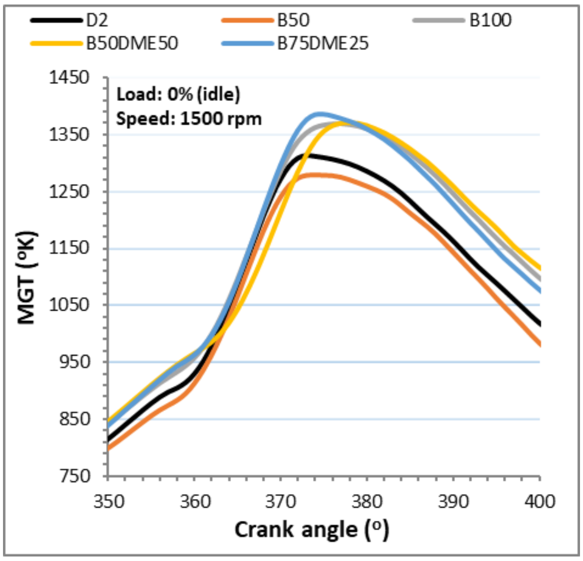

Figure 10. MGT change at idle engine load.

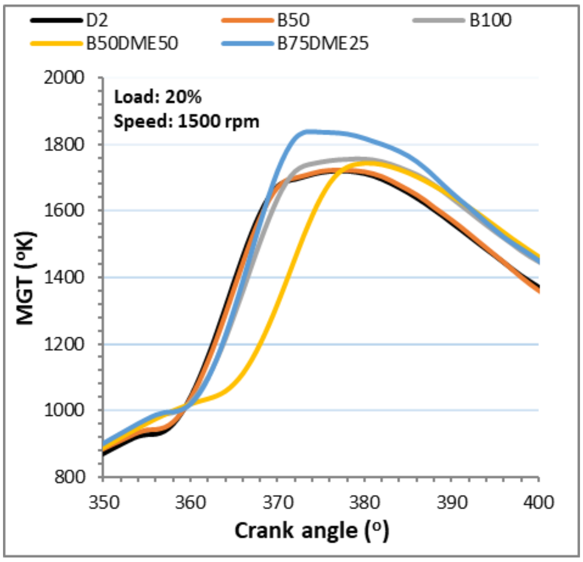

Figure 11. MGT change at 20% engine load.

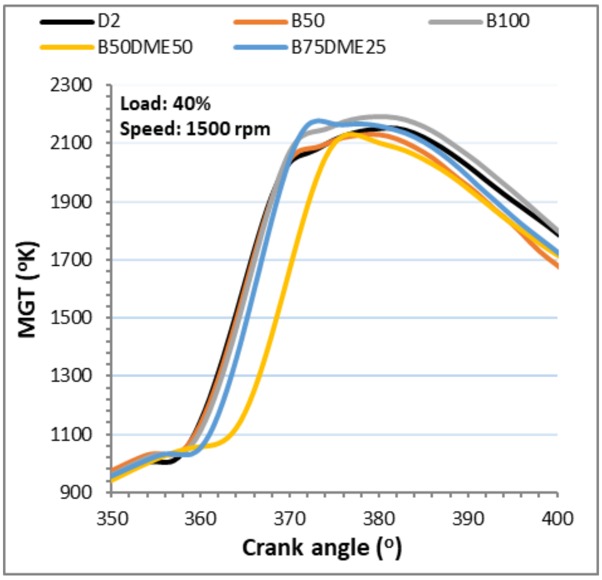

Figure 12. MGT change at 40% engine load.

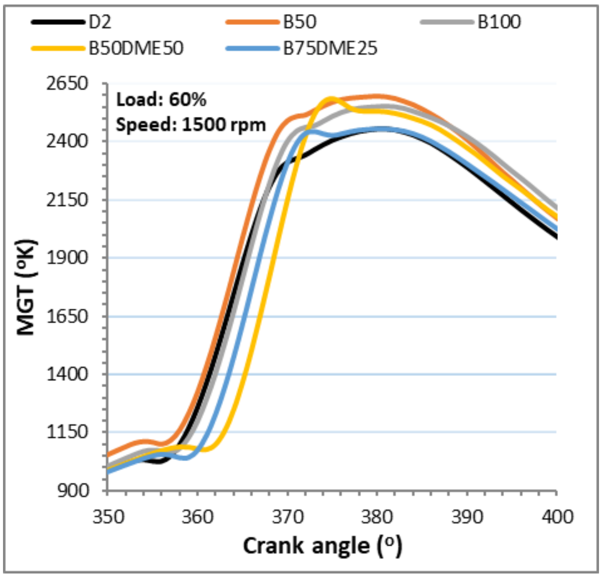

Figure 13. MGT change at 60% engine load.

The biodiesel test fuel demonstrated the highest average gas temperature, which can be attributed to its higher adiabatic flame temperature value. The peak MGT is mainly depended on the burned fuel rate. MGT value for each fuel increases with increasing load operation as it can be observed from the figures of MGT. The temperature increase observed in the cylinder chamber of the B75DME25 engine can be influenced by the higher adiabatic temperature associated with biodiesel.

3.2. Performance results

Figure 14 illustrates the brake specific fuel consumption (BSFC) values for all the test fuels at different engine loads while maintaining a constant engine speed of 1500 rpm. The figure clearly indicates that biodiesel fuel exhibited the highest brake specific fuel consumption (BSFC) during low load operations. The highest BSFC values were obtained for B75DME25 blend for all-engine operations. The primary reason for this result is attributed to the lower calorific value of DME and its higher percentage within the fuel mixture. As it is expected, the lowest BSFC was occurred for petroleum diesel fuel owing to its highest calorific value among the experimental fuels.

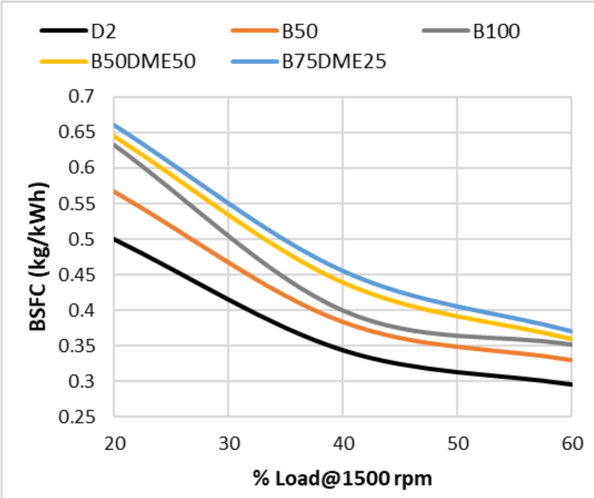

Figure 14. BSFC change with engine load.

Figure 15 illustrates the change in mass fuel consumption (MFC) for different engine loads and a steady engine speed of 1500 rpm. With a similar trend in BSFC, the highest MFC values were obtained for the B75DME25 mixture for all engine operations, except at an engine load of 10% and idle.

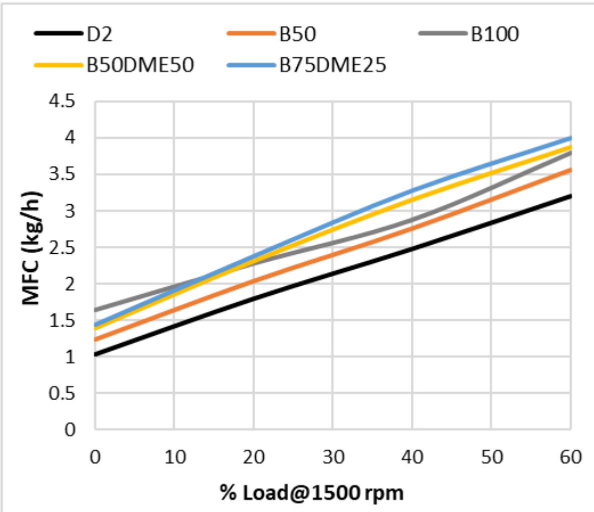

Figure 15. MFC change with engine load.

Figure 16 depicts the change of efficiency for the different fuels at a steady engine speed as a function of engine load percentage. The brake thermal efficiency was increased with increasing engine loads. The thermal efficiency values were followed similar pattern with slight differences. Nevertheless, the B50DME50 fuel exhibited the highest thermal efficiency, with a slight variation observed at 60% engine loads. This result gives us a sign that the high proportion of DME with biodiesel could increase the efficiency at medium load condition.

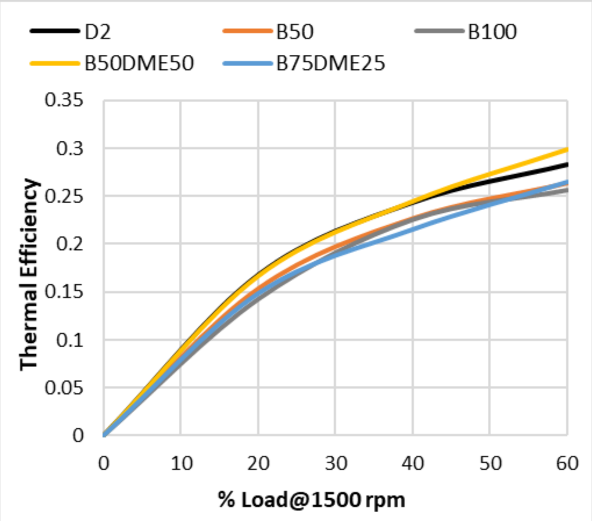

Figure 16. Thermal efficiency values with loads.

3.3. Emission results

Figure 17 presents a comparison of CO emissions for the experimental test fuels as a function of engine loads at a steady speed of 1500 rpm. CO forms mainly due to rich fuel in the absence of enough oxygen. As illustrated in Figure 17, CO emissions were increased for all the test mixtures in comparison to diesel fuel. The B50DME50 blend exhibited the highest concentration of CO emissions, whereas diesel fuel displayed the lowest concentration under low engine load operations. The higher heat of vaporization in the case of the B50DME50 blend is considered to be the reason for the reduced in-cylinder temperature, leading to poor vaporization and atomization of the fuel mixture. This phenomenon can contribute to the higher CO emissions observed. Additionally, CO emissions was increased with increasing DME in the blend, but the increasing ratio of CO was remarkably diminished with increasing engine load. The CO emission differences between the test fuel were not significant at 60% engine load and CO values were considerably lower at high loads due to improved combustion environment with increased temperature. Changes in NO_x emissions for experimental test blends under constant engine speed versus engine load percentage are given in Figure 18. In comparison to petroleum diesel fuel, all the test fuels exhibited a decrease in NO_x emissions. NO_x emissions were obtained zero for B50DME50 blend at idle but it is possibly due to an error from the exhaust emission device or the emission level was as low as the device could be unable to detect. However, overall, B50DME50 was shown the best improvement on NO_x emissions compared to the other blends. DME showed a considerable reduction in NO_x emission. As can be seen in the figures of mean gas temperature, temperature was observed under 1800 ºK at low load but temperature was increased with increasing load. As it is well known, the NO_x emissions form after 1800 ºK in the presence of high amount of oxygen [27]. The high oxygen content and the higher adiabatic flame temperature are the factors resulting in NO_x emissions. Despite biodiesel and DME having higher oxygen content, biodiesel leads to a reduction in NOx emissions due to its leaner stoichiometry of combustion, which results in lower temperatures [28, 29]. The reason for this reduction is that low pressure and temperature in the combustion chamber as it can be accepted as the low temperature combustion mode. Besides, B75DME25 had also lower values of NO_x concentration. The primary reason for these reductions is attributed to the vaporization of the DME blend, which absorbs more heat from the combustion chamber. This leads to a decrease in the combustion temperature, thereby resulting in reduced formation of NO_x emissions. It is a strong due that DME could reduce NO_x emissions based on the test results. The highest concentrations of NO_x were observed for both diesel and biodiesel fuels.

Figure 19 illustrates the variation of HC (hydrocarbon) emissions for the test fuels as a function of engine load percentage at a constant engine speed of 1500 rpm. As given in the figure, the highest HC concentration was obtained for the blend with high percentage of

DME while the HC level was lower for the low percentage of DME in comparison with neat diesel fuel. As the oxygen level of B50DME50 is higher than the rest of the test fuel, it was expected that HC emissions could be lowered but this increment happened due to lower efficiency and boiling point of biodiesel. The lowest HC emissions were obtained for neat biodiesel for all the engine operation that it is believed it results from the final distillation temperature of biodiesel. However, HC emission values were observed low in general and were diminished with increased engine load thanks to more complete combustion in the cylinder chamber at higher loads.

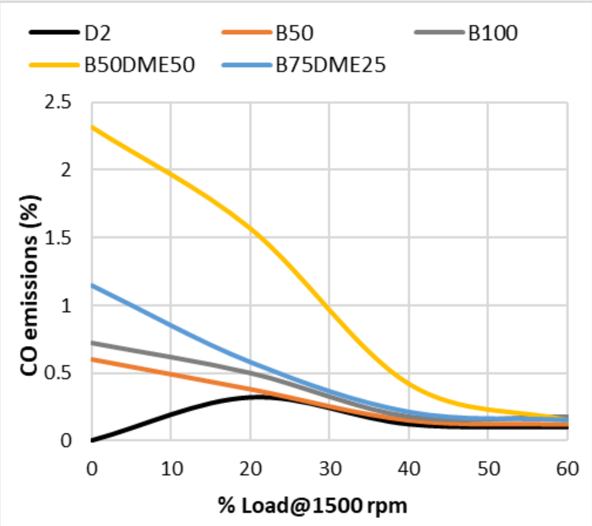

Figure 17. CO emissions with engine load.

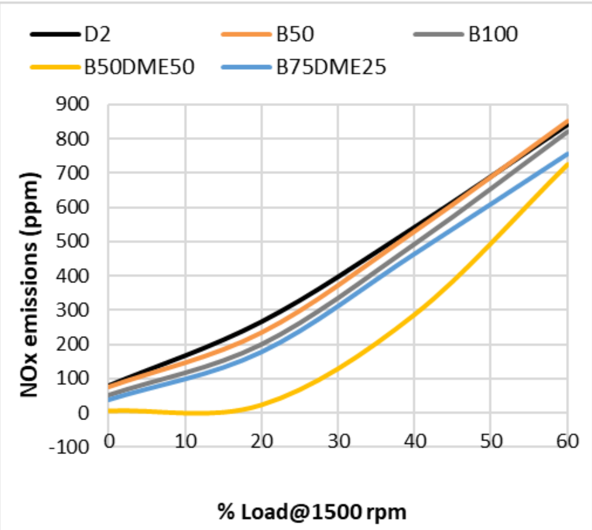

Figure 18. NOx emissions with engine load.

4. Conclusions

The experimental study aimed to analyze the effects of a high proportion of DME combined with safflower biodiesel on the combustion,

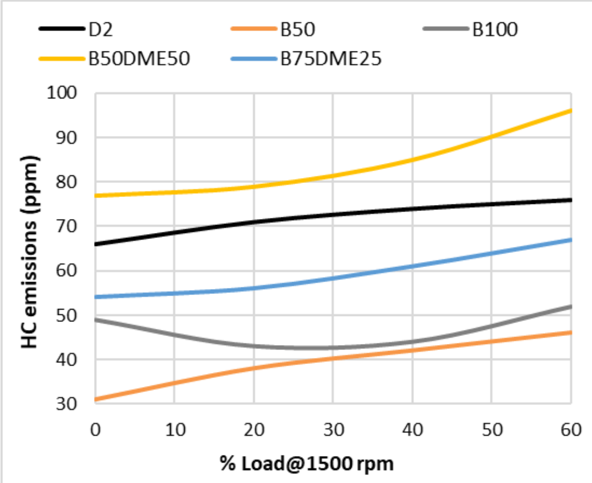

Figure 19. HC emissions with engine load.

performance, and emission characteristics of a diesel engine. The engine loads were ranged from the idle to 60% of 18 kW and the engine speed was 1500 rpm. The safflower biodiesel was obtained using transesterification. The DME was blended with biodiesel at two different ratios and the blend fuels are named as B50DME50 (which is composed of 50% biodiesel and 50% DME in volume) and B75DME25 (which is composed of 75% biodiesel and 25% DME in volume). Apart from these DME-blended test fuels, the neat safflower biodiesel, diesel fuel and diesel-biodiesel blend (%50 in vol. for each fuel) were conducted as a comparison parameter. In the literature, DME has been reported to exhibit similar behavior when used alongside biodiesel, which is consistent with our findings in this study. For instance, Hou et al. [30] used a blend of DME and biodiesel fuels in their experimental study, and the combustion characteristics of the test fuels were found to be similar to this study.

The results of the study are summarized below.

1. DME addition to biodiesel with high percentages resulted in irregularities in cylinder pressure in comparison to diesel fuel. However, cylinder pressure of DME-included blends with low percentage was increased at low load operation. the cylinder pressure was sharply decreased as increasing the DME proportion in the blend.
2. Additionally, the DME blended fuel with a high percentage exhibited a longer ignition delay and consequently led to delayed combustion. However, it also demonstrated a shorter combustion duration in comparison to

diesel fuel.

3. Overall, the HRR for DME-blended fuels was occurred higher than diesel fuel. whereas the peak values of the HRR for high proportion of DME-included blends at idle, 20% and 40% engine load were the highest, the highest value was observed for high proportion of DME with biodiesel at 60% engine load. There was an irregularity on the HRR when the engine fueled for the blend of DME addition with high ratios.

4. In general, the mean gas temperature of DME-included blends showed higher values, and the high-temperature phase was delayed during the premixed combustion stage for these blends.

5. 5. The lowest brake specific fuel consumption value was observed for standard diesel fuel, while the addition of DME resulted in increased fuel consumption due to its lower calorific value in comparison to standard diesel and biodiesel fuels. However, the mass fuel consumption results were consistent with the brake specific fuel consumption value.

6. Thermal efficiency for the experiment fuels is in similar values with diesel fuel. Besides, at 60% load operation, the highest thermal efficiency value was recorded for DME blended fuel with high percentage. In the light of this result, it can be concluded that high proportion of DME with biodiesel increases the efficiency at medium and high loads.

With high percentage of DME addition to biodiesel, CO emissions was increased whereas NO_x emission was diminished as compared to diesel fuel. However, it had no significant impact on O_2 and CO_2 emissions. HC emissions were increased for high ratio of DME blend while reduced for low ratio of DME blend.

CRediT authorship contribution statement

Yahya ÇELEBİ: Interpretation of experiments, manuscript writing/editing, journal correspondence.
Hüseyin AYDIN: Supervision, Experimental design, Analysis of experiments.
Hüsna TOPKAYA: Literature review, Experimental design, graphical design.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

5. References

1. Y. Wang, F. Xiao, Y. Zhao, D. Li, X. Lei, "Study on cycle-by-cycle variations in a diesel engine with dimethyl ether as port premixing fuel", Applied Energy, 143, 58–70, 2015.
2. B. Ashok, K. Nanthagopal, S. Darla, O.H. Chyuan, A. Ramesh, A. Jacob, G. Sahil, S. Thiyagarajan, V.E. Geo, "Comparative assessment of hexanol and decanol as oxygenated additives with calophyllum inophyllum biodiesel", Energy, 173, 494–510, 2019.
3. N. Yilmaz, A. Atmanli, F.M. Vigil, "Quaternary blends of diesel, biodiesel, higher alcohols and vegetable oil in a compression ignition engine", Fuel, 212, 462–469, 2018.
4. W. Ying, L. Genbao, Z. Wei, Z. Longbao, "Study on the application of DME/diesel blends in a diesel engine", Fuel Processing Technology, 89, 12, 1272–1280, 2008.
5. C.V.K. de Oliveira, R.F. Santos, J.A.C. Siqueira, R.A. Bariccatti, N.B.G. Lenz, G.S. Cruz, L.K. Tokura, F.F. Klajn, "Chemical characterization of oil and biodiesel from four safflower genotypes", Industrial Crops and Products, 123, 192–196, 2018.
6. A.S. Kumari, C.H. Penchalayya, A.V.S.R. Raju, "Performance evaluation of diesel engine with safflower oil", Journal of Engineering Studies and Research, 19, 2, 63, 2013.
7. B. Kayode, A. Hart, "An overview of transesterification methods for producing biodiesel from waste vegetable oils", Biofuels, 10, 3, 419–437, 2019.
8. B.N. Kale, S.D. Patle, "State of art review of algal biodiesel and its blends influence on performance and emission characteristics of compression ignition engine", Cleaner Engineering and Technology, 7, 100431, 2022.
9. K.S. Mehra, J. Pal, V. Goel, "A comprehensive review on the atomization and spray characteristics of renewable biofuels", Sustainable Energy Technologies and Assessments, 56, 103106, 2023.

10. K. Im-orb, A. Arpornwichanop, “Comparative techno-economic assessment of bio-methanol and bio-DME production from oil palm residue”, Energy Conversion and Management, 258, 115511, 2022.
11. A. Tripathi, A.K. Agarwal, “DME as a Green Fuel for Transport Sector BT - Renewable Fuels for Sustainable Mobility”, in: P.C. Shukla, G. Belgiorno, G. Di Blasio, A.K. Agarwal (Eds.), Springer Nature Singapore, Singapore, 35–77, 2023.
12. J. Huang, Z. Liu, M. Li, Y. Sun, “Study on deflagration process of LPG/DME blended combustible gas cloud in open space”, Journal of Loss Prevention in the Process Industries, 76, 104732, 2022.
13. Q. Zhang, X. Qian, R. Li, G. Zhou, Y. Sun, Y. Ma, Y. Kong, “Explosion characteristics and chemical kinetics of blended LPG/DME clean fuel based on pyrolysis and oxidation mechanism model”, Fuel, 320, 123896, 2022.
14. K. Theinnoi, P. Suksompong, W. Temwutthikun, “Engine Performance of Dual Fuel Operation with In-cylinder Injected Diesel Fuels and In-Port Injected DME”, Energy Procedia, 142, 461–467, 2017.
15. H.G. Roh, D. Lee, C.S. Lee, “Impact of DME-biodiesel, diesel-biodiesel and diesel fuels on the combustion and emission reduction characteristics of a CI engine according to pilot and single injection strategies”, Journal of the Energy Institute, 88, 4, 376–385, 2015.
16. X. LI, X. Fang, L. LAO, L. XU, L. Qian, “On-line mixing and emission characteristics of diesel engine with DME injected into fuel pipeline”, Journal of Thermal Science, 21, 1, 627–638, 2017.
17. U. Rashid, F. Anwar, “Production of Biodiesel through Base-Catalyzed Transesterification of Safflower Oil Using an Optimized Protocol”, Energy Fuels, 22, 2, 1306–1312, 2008.
18. N. Corr, Febris “Data Logging Software”, http://www.nel.com.tr/EN,5773/febris---internal-combustion-engine-analysis-testing-sy-.html, 2015.
19. J.B. Heywood, “Internal combustion engine fundamentals”, Mcgraw-hill, 1988.
20. A. I. El-Seesy, H. Hassan, S. Ookawara, “Influence of adding multiwalled carbon nanotubes to waste cooking oil biodiesel on the performance and emission characteristics of a diesel engine: an experimental investigation”, International Journal of Green Energy, 16, 12, 901-916, 2019.
21. J. L. S. Fagundez, D. Golke, M. E. S. Martins, N. P. G. Salau, “An investigation on performance and combustion characteristics of pure n-butanol and a blend of n-butanol/ethanol as fuels in a spark ignition engine”, Energy, 176, 521-530, 2019.
22. Z. Gong, L. Feng, Z. Wang, “Experimental and numerical study of the effect of injection strategy and intake valve lift on super-knock and engine performance in a boosted GDI engine”, Fuel, 249, 309-325, 2019.
23. S. Erdoğan, M. K. Balki, C. Sayın, “Combustion Analysis of Biodiesel Derived from Bone Marrow in a Diesel Generator at Low Loads”, International Journal of Automotive Technology, 8, 2, 76-82, 2019.
24. P. A. Lakshminarayanan, Y. V Aghav, “Modelling diesel combustion”, Springer Science & Business Media, 2010.
25. G.P. Merker, C. Schwarz, R. Teichmann, “Combustion engines development: mixture formation, combustion, emissions and simulation”, Springer Science & Business Media, 2011.
26. A.K. Agarwal, D.K. Srivastava, A. Dhar, R.K. Maurya, P.C. Shukla, A.P. Singh, “Effect of fuel injection timing and pressure on combustion, emissions and performance characteristics of a single cylinder diesel engine”, Fuel, 111, 374–383, 2013.
27. A. Bonnick, “A practical approach to motor vehicle engineering and maintenance”, Routledge, 2011.
28. M.A. Ghadikolaei, C.S. Cheung, K.-F. Yung, “Study of combustion, performance and emissions of diesel engine fueled with diesel/biodiesel/alcohol blends having the same oxygen concentration”, Energy, 157, 258–269, 2018.
29. Z.-W. Liu, F.-S. Li, W. Wang, B. Wang, “Impact of different levels of biodiesel oxidation on its emission characteristics”,

Journal of the Energy Institute, 92, 4, 861–870, 2019.
30. J. Hou, Z. Wang, S. Xi, S. Li, X. Xu, "Comparative Analysis of Combustion Behaviors and Emission Characteristics of Diesel Engines Fueled with Biodiesel or Biodiesel Blends", ACS Omega, 7, 37, 33461–33469, 2022.