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Research Article

An Investigation into The Utilization of a Biodiesel Fuel Blend Supplemented with $Mn(NO_3)_2$ Additives in a CI Engine

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ABSTRACT

As it is known, due to the fact that petrol has a limited reserve, the search for renewable energy has an important place in all world states (by researchers). In this perspective, it was aimed to investigate the effect of a manganese standard solution for the improvement of combustion and other properties of biodiesel fuel. The experimental fuels had been created as follows: DF (diesel fuel), B25 (a blend of 25% biodiesel and 75% DF), and Mn100B25 (a blend of 25% biodiesel, 75% DF, and 100 ppm of $Mn(NO_3)_2$ additive). During the examination of the experimental fuels, the Mn100B25 fuel exhibited a decrease in density, viscosity, cetane index, and flash point compared to the B25 fuel. However, there was a slight improvement in the calorific value of the Mn100B25 fuel. The combustion and emission parameters were empirically investigated in a compression ignition (CI) engine operating at various load conditions and constant engine speeds. The analysis of the experimental data revealed that the Mn100B25 fuel exhibited the highest values for cylinder gas pressure, average gas pressure, and net heat release at the 6 bar bmep parameter. During analyzing the emission values, it emerged that the HC emissions of Mn100B25 fuel types exhibited 14.28% lower values compared to DF fuel under the 4 bar bmep conditions. At 4 bar bmep and 6 bar bmep, the CO emission values for DF and Mn100B25 fuels were the same; however, the emission value for B25 fuel was lower than that of the other two fuel types. As a result, it was observed that positive results were obtained by adding a mixture of biodiesel and manganese standard solution to the biodiesel fuel blend at a certain rate. As a result, it was observed that biodiesel and manganese standard solution blend can be used as an alternative fuel by adding to diesel fuel at certain ratios.

1. INTRODUCTION

Energy is the most important factor that human beings need to meet their needs. Due to the ever-increasing world energy demand, industrialization and rapid population growth, the need for energy is increasing day by day and the growing energy demand deficit is growing [1]. Various studies have been carried out to investigate the feasibility of using cleaner [2-4] and renewable fuel alternatives to reduce the unfavorable impact of engine exhaust emissions on the environment. While coal, oil and natural gas were mostly used as fossil resources in the past, today more renewable and transformable energy resources such as wind, solar, hydraulic, biomass etc. are produced and consumed. In addition, biodiesel, which is one of the renewable energy sources [5-6], has advantages such as the fact that it can be used without making any changes in the structure of the diesel engine, its cetane number is high, its flash point is low, it is safer to transport and store compared to diesel fuel, and it reduces exhaust emission values [7-8]. Apart from its advantages, the disadvantages of biodiesel fuel compared to diesel fuel in terms of its thermal value, viscosity, cold flow property and freezing point have led researchers to develop it with various nanoparticles [9-10]. Although hybrid and electric vehicles are being studied intensively in the coming years, the need for an alternative renewable energy source to diesel fuel is indispensable for heavy vehicles with diesel engines that need power and torque requirements [11]. Keskin et al. reported [12] that methyl esters were produced from fatty acids and the resin acids were reacted with NiO and MnO_2 at certain ratios for the production of metallic fuel additives in order to improve the values that may occur in diesel fuel. To prepare each metallic fuel additive test fuels, a mixture of 60% biodiesel and 40% diesel fuel was made and 8 μmol/l and 12 μmol/l of additives were added. The metallic additives added to biodiesel fuel improved the pour point and viscosity values and reduced CO emissions by 64.28% and smoke opacity by 30.91% in the exhaust emission gases of biodiesel fuels. It was observed that NOx emissions were generally low in biodiesel fuel. Gürü et al. Used [13] organic compounds of Mg, Ca, Cu and Mn as fuel additives. In the experiments, manganese-containing fuel additive has a better effect on diesel fuel compared to other metallic additives. While 54 μmol Mn/l additive, which was determined as the rate to be used, decreased the freezing temperature of diesel fuel by 12.4 ºC, manganese additive used at the same rate increased the cetane number from 46.22 to 48.24. O_2 and CO emissions decreased by 0.2% and 14%, respectively.

In the literature research, the use of biodiesel obtained from waste frying oil in diesel engines needs to be improved due to deterioration in performance and combustion parameters compared to diesel fuel. Therefore, in this study, the manganese standard solution additive ($Mn(NO_3)_2$) was added to biodiesel and diesel fuel blends, and the resulting blends were tested in a CI engine to investigate the changes in combustion and emission parameters as well as the chemical and physical properties of the blended fuels.

2. MATERIALS AND METHODS

2.1. *The test equipment and methodology*

Experimental studies were carried out in the workshop of Batman University Automotive Engineering Department. Biodiesel was produced from waste frying oil by transesterification method [14]. B25 and Mn100B25 fuel blends were obtained with biodiesel fuel produced by standard methods. For combustion parameters and emission values, cylinder gas pressure, net heat release, pressure increase rate, average gas temperature, cumulative heat release and NOx, CO, CO_2, HC emission values of DF, B25 and Mn100B25 fuels were tested in the experimental engine setup shown in Figure 1 and compared graphically in results and discussion section.

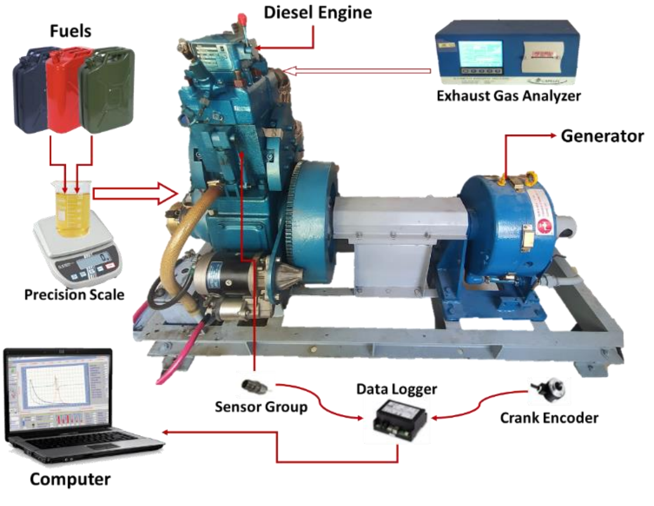

Figure 1. Schematic view of the experimental engine

The technical specifications of the diesel engine used for the determination of combustion and emission values are given in TABLE I. The combustion values of the test fuels in the diesel research engine were taken at 2 bar bmep, 4 bar bmep and 6 bar bmep parameters and under the same experimental conditions.

TABLE I. THE TECHNICAL SPECIFICATIONS OF THE TEST CI ENGINE

Engine Brand and Type	Kirloskar TV1
Bore / Stroke	87 / 110 mm
Compression ratio	17.5:1
Total displacement	0.66 liter
Connecting rod length	234 mm
Brake power	5.2 kW @ 1500 rpm

In this study, ICEngineSoft_9.0 computer program was used for combustion data. ICEngineSoft_9.0 application simultaneously transfers the data received from the engine to the computer. For the emission values in the experimental studies NOx, CO, CO_2 and HC exhaust emission values of three different fuels were measured by testing DF, B25 and Mn100B25 fuel blends at 2 bar bmep, 4 bar bmep and 6 bar bmep parameters with CAPELEC brand CAP 3200 model exhaust gas device. Technical specifications of the diesel emission device are shown in TABLE II.

TABLE II. SENSITIVITY AND LIMITS OF MEASUREMENT

Parameter	limits of measurement	Precision
Engine speed	0-12000 rpm	±0.1%
Pressure sensor	0-200 bar	±0.5%
NO_X	0-10000 ppm	±1 ppm
CO_2	0-21.0%	±0.1%
CO	0-10%	±0.001%
HC	0-20000 ppm	±1 ppm

2.1. *Test Fuels and Manganese Additives*

Mn compounds in solid form on earth are found in more than 300 minerals and the most commercially used compound is manganese dioxide (MnO_2). Manganese dioxide is used between 78-85% in the battery industry and 74-84% in the chemical industry. The density value of the additive used is 1.014 gr/cm^3, which is slightly higher than the density value of diesel and biodiesel. In the literature studies, it has been observed that Mn-based additive acts as a combustion enhancer, increases the cetane number and accordingly reduces the freezing point. In addition, the manganese additive improved the disadvantages of biodiesel fuel such as high viscosity and density and low heating value. Commercially available Sıgma-Aldrıch brand sodium hydroxide and decanol brand 99% purity methyl alcohol were used. For biodiesel production, 0.5% sodium hydroxide (NaOH) catalyst and 20% methyl alcohol (CH_3OH) were used in 1 liter of waste frying oil [14]. For fuel analysis, B100, B25 and Mn100B25 fuels were analyzed by TÜBİTAK Marmara Research Center (MAM) and viscosity, density, flash point, freezing point, cetane index and lower heating value parameters were analyzed separately for each fuel in accordance with the standards and the results are given in TABLE III.

TABLE III. PHYSICAL AND CHEMICAL PROPERTIES OF THE TEST FUELS USED IN THE EXPERIMENTS

Parametreler	DF	Biodiesel	B25	Mn100B25	Analysis method
Viscosity (mm^2/s, at 40°C)	2.895	5.292	3.344	3.291	ASTM D 445
Density (kg/m^3, at 15°C)	832	890.8	848.6	846.4	ASTM D 4052
Flash point (°C)	---	165.5	70.5	68.5	ASTM D 93
Cetane Number	52.78	53.7	53.6	53.3	EN ISO 4264
LHV (kj/kg)	43850	39.34	43.67	43.83	ASTM D 240

3. RESULTS AND DISCUSSIONS

3.1. Cylinder Gas Pressure and Net Heat Release

The variations of CGP with respect to °CA at constant engine speed at 1500 rpm for 2 bar bmep, 4 bar bmep and 6 bar bmep parameters of three different loads types used for test fuels are given in Fig. 2. When the 6 bar bmep parameter, which has the highest °CA, is examined, it is found that the highest CGP increase values are Mn100B25, B25, DF fuels and their values are 74.62 °CA, 73.28 °CA, 72.78 °CA bar, respectively.

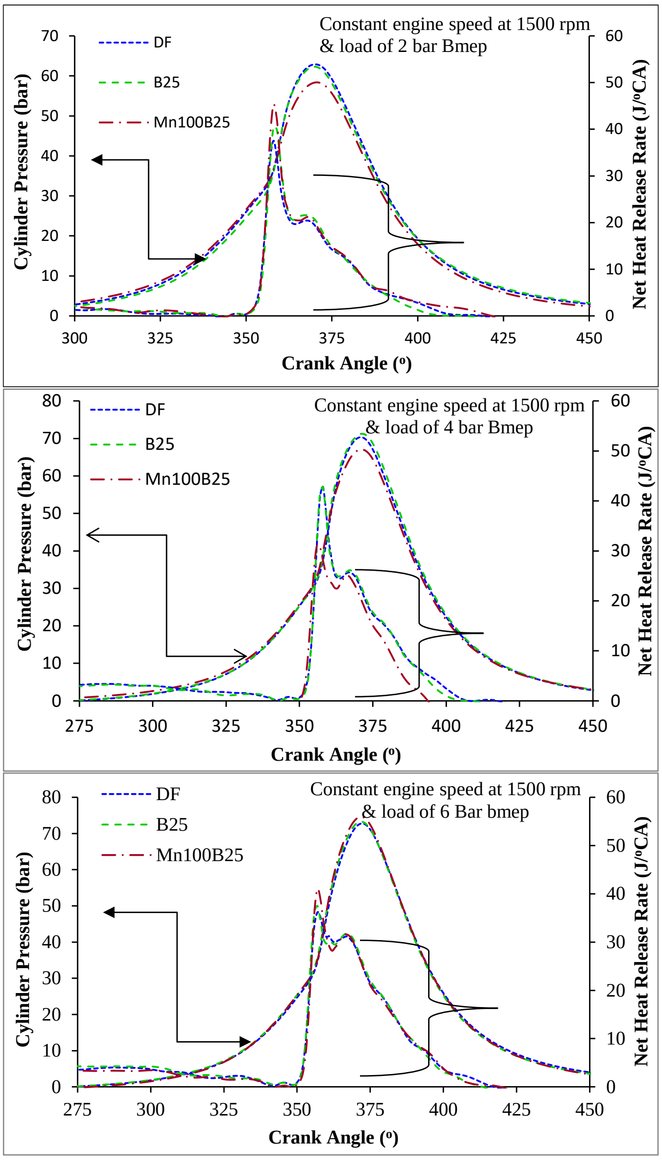

Figure 2. Cylinder gas pressure and net heat release rate curves under varying loads

The difference in CGP between Mn100B25 and DF values is 2.46%. When all the figures are analyzed, it is observed that as the engine parameter is increased, the fuel ratio sent to the cylinder will increase and the CGP will also increase. At 6 bar bmep, the CGP of Mn100B25 fuel are higher than diesel fuel, which is thought to be due to the fuel mixture ratio and the increase in the thermal value of the manganese additive.

The variations of the net HRR of the test fuels at 2 bar bmep, 4 bar bmep and 6 bar bmep parameters at constant 1500 rpm in terms of J/° with respect to °CA are given in in Fig. 3. When the 6 bar bmep parameter, which has the highest °CA, is examined, it is seen that Mn100B25, B25 and DF fuels have the highest HRR values at 357 J/° and their values are 41.05 J/°, 37.5 J/° and 36.19 J/°, respectively. The difference in HRR between Mn100B25 and DF fuel values is 11.83%. The high value in Mn100B25 fuel is due to the high amount of fuel burned per cycle due to the increase in the parameter amount [15]. Since the manganese additive added to the Mn100B25 fuel increases the calorific value of the fuel, the HRR was high at 6 bar bmep parameter.

3.2. Pressure Increase Rate and Mean Gas Temperature

The variations of the MGT of the test fuels with respect to the °CA at 2 bar bmep, 4 bar bmep and 6 bar bmep parameters and at constant 1500 rpm are given in Fig. 3. When the 6 bar bmep parameter is examined, it is seen that the highest values of the MGT at 380 K are Mn100B25, DF and B25 fuels and their values are 1624.07 K, 1600.48 K and 1588.75 K, respectively. The difference between the highest Mn100B25 fuel and DF fuel, which has the closest values, is 1.45%. Biodiesel fuel has a lower heating value than diesel fuel. The addition of manganese additive to Mn100B25 fuel increased its calorific value and increased the MGT. In addition, the decrease in density value was effective in increasing the MGT by increasing the flame intensity [16]. Changes in the rate of pressure rise (RPR) increase according to crankshaft angle (bar/°) at low, medium and high loads and at constant 1500 rpm for test fuels are given in Figure 4. When the figures are examined, it is observed that as the engine parameter is increased, the amount of fuel sent to the cylinder will increase and therefore the cylinder pressure increase rates increase. The highest-pressure increase rates were observed for B25 fuel at 2 bar bmep, DF fuel at 4 bar bmep and Mn100B25 fuel at 6 bar bmep. The sudden pressure increase of B25 fuel at 2 bar bmep depends on the cetane number of the fuel, the temperature and pressure of the air taken into the cylinder due to the long ignition delay. At 6 bar bmep, as the engine parameter increases, it can be said that a more controlled combustion occurs as a result of the decrease in the rate of pressure increase between the fuels and the shortening of the ignition delay time [17].

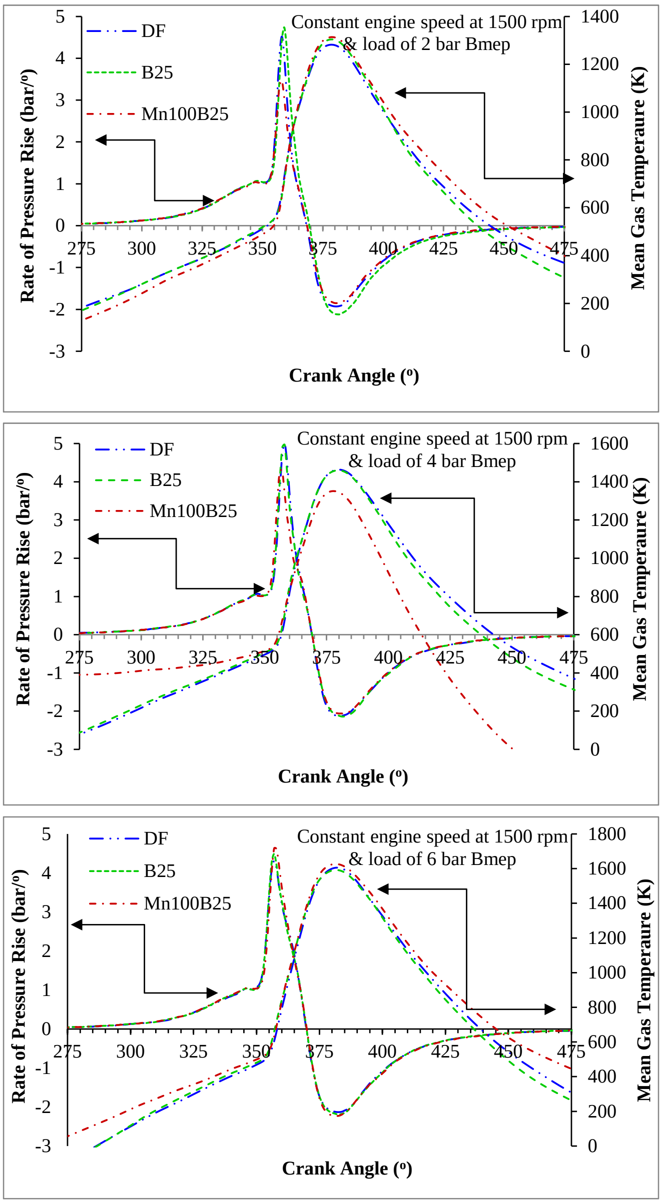

Figure 3. The mean gas temperature curves and rate of pressure rise curves under varying loads

3.3. Cumulative Heat Release

The cumulative heat release (CHR) changes for the test fuels at constant 1500 rpm and different engine parameters at low, medium and high loads, with respect to ºCA are given in Figure 4. Once the figures are examined, the CHR increased with the increase in the engine parameter, but the difference between the heat release values decreased gradually. Mn100B25 at 2 bar bmep, DF fuel has the highest cumulative heat release at 4 bar bmep and 6 bar bmep. The high CHR value of B25 and Mn100B25 fuel values can be said to be the high oxygen content in biodiesel fuel and the effect of manganese additive on cetane number [18]. It is thought that the high values CHR in the low load parameters are due to the high amount of oxygen in the biodiesel fuel, the Mn additive used and the effect on the cetane number. The high cumulative heat release value of B25 and Mn100B25 fuel values can be attributed to the high oxygen content in biodiesel fuel and the effect of manganese additive on cetane number [18].

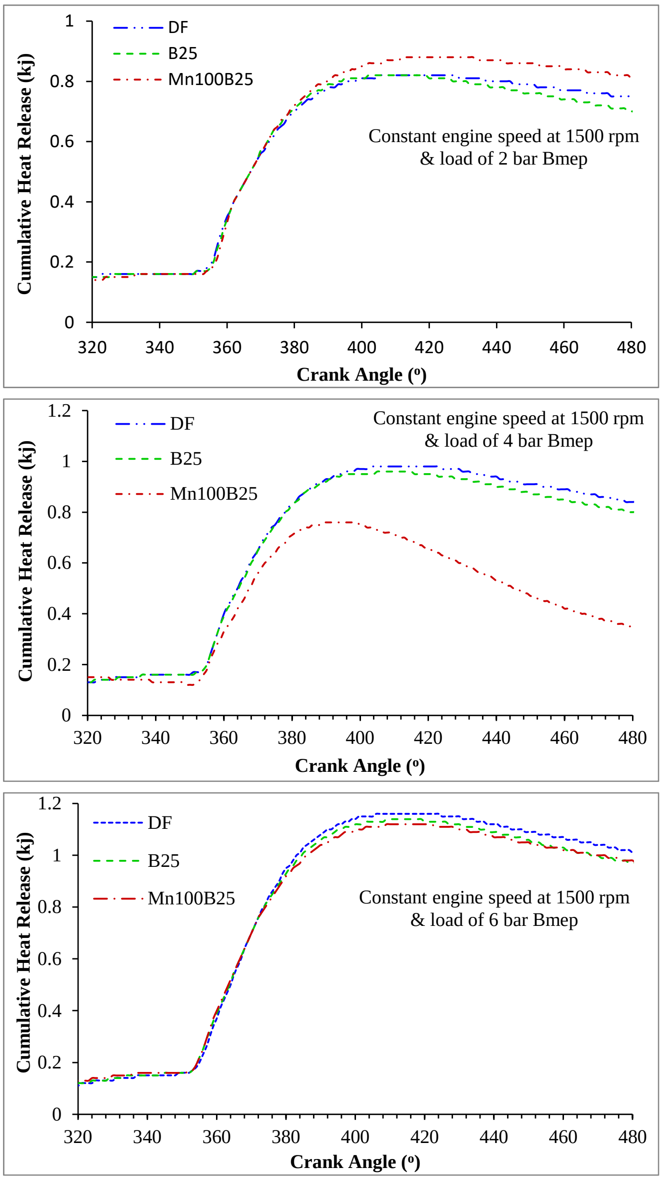

Figure 4. The cumulative heat release curves under varying loads

3.4. NOx Emission

At temperatures above 1600 ºC reached in in-cylinder combustion, nitrogen oxides are formed by the reaction of nitrogen in the air with oxygen, provided that there is sufficient time. In the case of a lean mixture, nitrogen oxide emissions will decrease as the internal temperature of the cylinder will decrease with the amount of gas reacting. In addition, nitrogen oxides can cause lung diseases, respiratory infections and damage to vegetation [16]. The NOx emission values of different fuel types at different engine parameters are shown graphically in Figure 5. When all fuel types are examined, the emission values, which are at minimum levels at low loads, increase in NOx emission values with gradual increase in engine parameters. According to the 2 bmep parameters, Mn100B25 emission value has the highest NOx emission value with 161 ppm and 144 ppm, Mn100B25 emission value has 141 ppm, DF emission value has the lowest NOx emission value with 133 ppm. The fact that diesel fuel emits less emissions compared to biodiesel fuel blended fuels, the increase in fuel consumption due to the increase in the value of the bmep parameter and the increase in the in-cylinder temperature with expanding combustion increased NOx emissions.

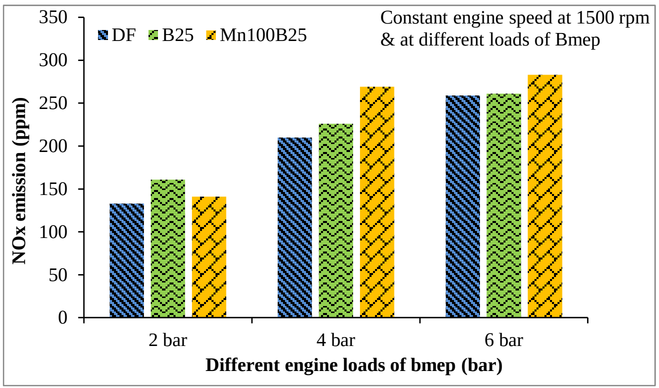

Figure 5. The variation of NOx emissions under varying loads for test fuels

3.5. CO Emission

The presence of CO emissions in combustion products is due to the lack of sufficient oxygen in the environment. If the amount of air in the air-fuel mixture is low, the amount of O_2 in the combustion reaction will be insufficient, and not all of the fuel carbon will be converted into CO_2 and remain as CO [19]. The CO emission values of different fuel types at different engine parameters (idle, low, medium and high) are shown graphically in Fig. 6. When all fuel types are analyzed, while CO emission values of all fuels are equal in the idle parameter, DF and B25 fuel values remain equal in the low parameter, while there is a slight increase in the Mn100B25 value. In the medium and high parameters, the CO emission values of DF and Mn100B25 fuels were equal to each other, while the emission value of B25 fuel remained below the two fuel types. It can be said that the oxygen content in biodiesel fuel is effective in reducing CO emission gases [20-22].

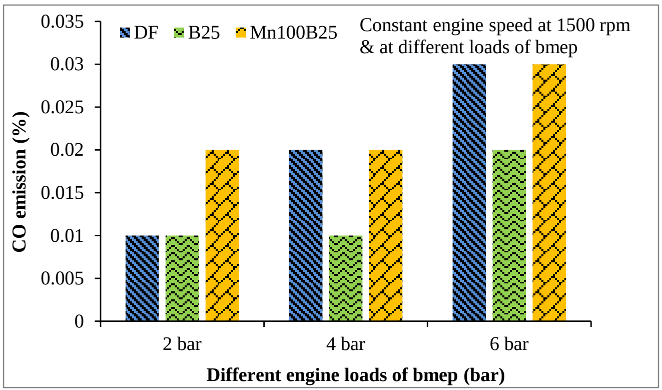

Figure 6. The variation of CO emissions under varying loads for test fuels

3.6. CO_2 Emission

Carbon dioxide is the combustion product of fuels containing carbon molecules in their structure, which combines with oxygen and combusts completely in the combustion chamber [16]. The CO_2 emission values of different fuel types at different engine parameters are shown graphically in Fig. 7. When all fuel types are examined, while the CO_2 emission values of all fuels are equal at idle parameter, an increase in all CO_2 emission values is observed due to the increase in engine parameters. At high load, B25 and Mn100B25 fuel emission values were equal values while DF emission value remained at 8.33% lower levels. With the increased amount of parameters, the emission values increased in direct proportion to the load due to the conversion of more CO emissions into CO_2 emissions with improvements in combustion with more air intake into the combustion chamber.

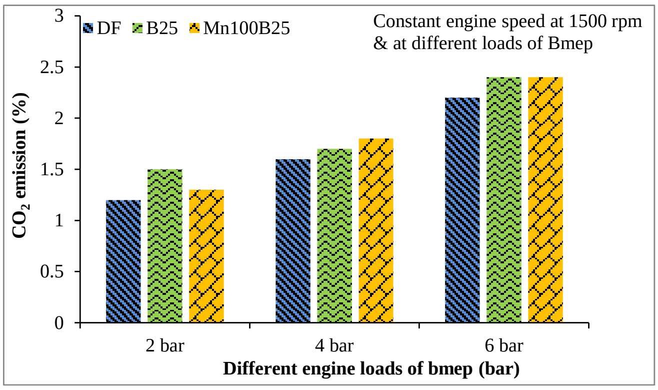

Figure 7. The variation of CO_2 emissions under varying loads for test fuels

3.7. HC emission

The presence of HC emissions in the exhaust gases is due to incomplete combustion of the fuel. It is a situation where the combustion reaction slows down due to the air-fuel mixture ratios being too rich or too lean and the combustion cannot be completed [19]. The HC emission values of different fuel types at different engine parameters (low, medium and high) are shown graphically in Fig. 8. When all fuel types are analyzed, it is seen that the in-cylinder temperature does not occur sufficiently with the increase of the parameter and accordingly the combustion efficiency does not increase sufficiently, which increases the HC emissions [23]. At medium and high fuel parameters, B25 and Mn100B25 fuel emission values are lower than DF fuel and B25 fuel has the lowest emission values, which depends on the amount of oxygen in biodiesel fuel and diesel-biodiesel fuel blend ratios [24].

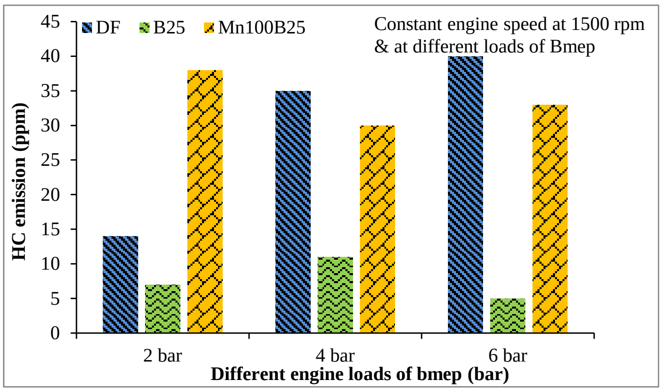

Figure 8. The variation of HC emissions under varying loads for test fuels

4. CONCLUSION

Due to the dwindling oil reserves in the world, the search for renewable fuels for internal combustion engines has led to a growing interest in biodiesel. In order to improve the chemical and physical properties such as calorific value, viscosity, and freezing point, which are among the disadvantages of biodiesel fuel, it has prompted researchers to use various additives. In this study, biodiesel fuel blend was blended with nanoparticles, and after physical and chemical analysis, combustion parameters and emission values were tested in a diesel research engine. In the experimental study with Mn100B25, B25, and DF test fuels, the following results were generally determined.

- The additive decreased the viscosity, flash point, cetane number and density of Mn100B25 fuel. It slightly increased the freezing point and calorific value.
- When the cylinder gas pressures of three different fuels are compared, the highest cylinder gas pressure was observed in Mn100B25 fuel at 6 bar bmep, which has the highest crankshaft angle, and the difference in cylinder gas pressure between Mn100B25 and DF fuels is 2.46%.
- Crankshaft angles were close to each other and the highest average gas temperature at 6 bar bmep was found for Mn100B25 fuel. The difference in cylinder gas pressure between Mn100B25 and DF fuels is 1.45%. The high average gas temperature in Mn100B25 fuel is thought to be due to density and calorific value.
- The highest net heat release was determined with Mn100B25 fuel at 6 bmep. The difference in net heat release between Mn100B25 and DF fuel values is 11.83%. The manganese additive added to Mn100B25 fuel was found to increase the calorific value of the fuel.
- It is thought that the high values at idle and low parameters in cumulative heat release, the high amount of oxygen in biodiesel fuel and the additive used have an effect on the cetane number.
- An increase in NOx emission values was also observed with the increase in bmep value. At 2 bar and 6 bar bmep parameters, NOx emission values increased the least from 33 to 259 ppm, respectively.
- The fact that diesel fuel emits less emissions than biodiesel fuel blended fuels can be said to be due to the in-cylinder temperature and the oxygen content in the biodiesel content.

As a result of the studies, manganese standard solution additive [$Mn(NO_3)_2$] added to biodiesel-diesel fuel blends obtained from waste vegetable oil improved the important chemical and physical properties of the blended fuels and the combustion parameters were generally parallel to the diesel fuel curves. It was determined that biodiesel-diesel fuel blends with $Mn(NO_3)_2$ additive can be used in diesel engines without any modification.

Abbreviations

CGP	Cylinder gas pressure, bar
CHR	Cumulative heat release
CI	Compression ignition
Mn100B25	25%(in vol.) biodiesel, 75% DF (in vol.) and 100 ppm $M(NO_3)_2$
HC	Hydrocarbon
HRR	Heat release rate, J/°
MGT	Mean gas temperature, K
DF	Diesel fuel
°CA	Crank angle degree

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BIOGRAPHIES

Tarhan TAN was born in 1985 in Diyarbakır/Turkey. I received my primary, secondary and high school education in Mersin/Turkey. I graduated from Dicle University Batman Faculty of Education Automotive Teaching Department in 2009. I graduated from Batman University Institute of Science and Engineering Automotive Engineering in 2022. I have been working as a civil servant in a public institution since 2012.

Selman Aydın was born in Batman, Turkey. Between 2000 and 2004, he graduated from the Dicle University Technical Education Faculty Automotive Teaching B.Sc. program. In 2008, he started his M.Sc. degree at Fırat University Institute of Science and Technology, Department of Mechanical Education/Automotive. In 2010, he graduated with an M.Sc. degree. In 2010, he started his Ph.D. at Marmara University Institute of Science and Technology, Department of Mechanical Education. In 2014, he graduated with a Ph.D. Between 2012 and 2015, he worked as a lecturer at Hakkari University, Department of Mechanical Engineering/Automotive. In 2015, he began working as an assistant professor in the Batman University Faculty of Technology's Department of Automotive Engineering. In 2020, he was named an associate professor in automotive engineering. Batman University Vocational High School of Technical Sciences appointed him as an associate professor in 2021. He is currently an associate professor in the same unit. Major research interests are internal combustion engines, engine dynamics, alternative fuels, fuel cells, and automotive engineering. He has published more than 50 papers in international and national journals and conferences.