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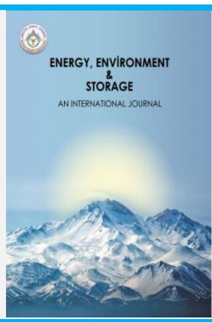

Experimental Investigation of the Effects of Biodiesel/Methanol Mixtures on Diesel Fuel on Engine Performance and Emission Values in a Diesel Engine

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ABSTRACT. In internal combustion engines, operating conditions, engine design and fuel properties are closely related to efficiency. The alternative fuel used in diesel engines is expected to improve performance and emission values. Biodiesel is widely used to improve the fuel properties of alcohol and diesel. In this study, the effects of diesel, diesel-methanol, diesel-biodiesel, diesel-biodiesel-methanol mixtures are examined. Engine performance and exhaust emission tests were carried out on a three-cylinder, four-stroke diesel engine at a constant speed of 1500 rpm and five different loads: no load, 25%, 50%, 75% and 90%. Since constant speed and torque values could not be obtained in the no-load condition (T0) in the studies, the values at T0 were not used in the comparisons. As experimental data, thermal efficiency, CO, HC, CO2, NO emission values, in-cylinder pressure values and heat release rate values were examined. In experimental studies, the effects of adding different amounts of biodiesel and methanol on engine performance and emission values were compared with diesel. As a result of the comparison, positive results were obtained in the performance and gas emission values of alternative fuels compared to 100% diesel. In addition, fuel mixtures with biodiesel addition have better performance results than fuel mixtures with methanol addition.

Keywords: Energy, exergy, internal combustion engine, methanol fuel

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Nomenclature

100D	%100 Diesel
10B90D	%10 Biodiesel %90 Diesel
20B90D	%20 Biodiesel %80 Diesel
10M10B80D	%10 Methanol %10 Biodiesel %80 Diesel
10M10B80D	%10 Methanol %90 Diesel
CA	Crank Angle

1. INTRODUCTION

Today, constantly developing and growing main sectors such as industrialization, production and transportation mostly use fossil fuels as energy sources. Fossil fuels used as energy sources cause environmental and air pollution. In addition to its negative features such as environmental and air pollution, fossil fuel resources are also decreasing. Alternative fuel studies have gained importance due to the decrease in fossil fuels and the damage caused by exhaust gases to the environment [1-2]. While the studies reduce the harmful effects of exhaust gases, efficiency and performance are required to be acceptable. Many studies have been carried out to increase efficiency and reduce gas emissions in diesel engines. Some of these studies include the method of adding different additives to diesel used as fuel in diesel engines. [3-4]. The common goal of

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experiments using alternative fuels is to reduce the use of fossil fuels and to develop environmentally friendly alternative fuel types that can operate at equivalent or higher performance and efficiency than fossil fuels. There are studies in the literature in which biodiesel [5-7] and alcohol [8-10] are mixed as additives to diesel fuel in diesel engines, or biodiesel-alcohol [11-13] is mixed with diesel together. As a result, the fuel to be used as an alternative must be within acceptable limits in terms of both performance and environment. One of the most important factors affecting combustion in diesel engines is the properties of the fuel to be used [14-16]. In this study, 10% biodiesel, 20% biodiesel, 10% methanol and 10% biodiesel-10% methanol mixtures were added to diesel fuel. Properties of the fuel to be used in a diesel engine; It depends on properties such as cetane number, volatility, latent evaporation temperature, viscosity, surface tension of the fuel, and specific temperature of the fuel [17]. It has basic advantages such as being able to be used in diesel engines without the need for modification and having physicochemical properties like diesel [18-19]. In addition, it is frequently used in alternative fuel research due to its important features such as easy accessibility and producibility from many sources. There are studies using biodiesels obtained from different sources such as soybean [20], frying oil [21], waste oil [22], cottonseed [23], palm oil [24], animal [25] and vegetable [26] oils.

Another additive used in the study is methanol. The simplest component of the alcohol group is methanol. While methanol can be obtained from fossil-based fuels, it can also be obtained from sources such as biomass, wood and solid waste [27]. Therefore, methanol is an economical fuel. The fuel mixture obtained by adding methanol to diesel fuel can improve engine performance and emissions. For this reason, many researchers have carried out studies on the use of methanol as an alternative fuel in internal combustion engines. While methanol (CH3OH) is a pure substance, diesel fuel has a hydrocarbon structure. Fuel properties vary depending on the proportion of this hydrocarbon. The specific energy of methanol is lower than diesel. For this reason, methanol fuel mixtures have higher fuel consumption than diesel to reach the same power and torque values. Methanol is easy to produce and can be widely used as an alternative fuel because it is natural and less harmful to the environment. There is no need for any changes in the engine structure to use methanol as fuel in internal combustion engines [28]. Too much oxygen content. The lower combustion temperature causes the heat loss in the cylinder to decrease and therefore the thermal efficiency to increase. A lower flame temperature improves combustion and reduces NOx and CO [27-28].

Roy et al. [29] in the study, engine performance and emission values at high idle in a diesel engine with a biodiesel-diesel blend and a canola oil-diesel blend were compared. The fuels are mixed with diesel between 2-20%. As a result of the study, a decrease was observed in CO and HC emissions compared to pure diesel. Biodiesel-diesel and canola oil-diesel blends have higher fuel conversion efficiency than diesel. Cheung et al. [30] in their article, the engine performance and emission values of a low sulfur diesel-biodiesel mixture in a 4-cylinder engine at 1800 rpm were investigated experimentally. In the study, brake-specific fuel consumption and brake thermal efficiency increased. While HC and CO emissions decreased, NO emissions increased. Büyükkaya et al. [31] experimentally investigated the engine performance, emission and combustion of the mixture obtained by mixing the biodiesel obtained from pure rapeseed oil with diesel at 5%, 20% and 70% ratios. As a result of the experimental study, the use of biodiesel provided lower smoke opacity (60%) than diesel. He observed that the brake-specific fuel consumption (BSFC) increased by up to 11%. Utku et al. [32] in this study, the use of methyl ester obtained from waste frying oil as fuel was experimentally investigated. A turbocharged, four-cylinder, direct-injection diesel engine was used in the tests. Its results were compared with diesel fuel. As a result of the comparison, the specific fuel consumption is almost the same. In addition, emissions such as CO and CO have decreased. Asokan et al. [33] in this article, engine performance and emission parameters of linseed oil biodiesel were analyzed. Fuel mix compared to diesel. The resulting B20 has a BTE of 33.05%, which is higher at higher loads than diesel (33.43%). A significant reduction in emissions (CO, HC, NO, and smoke) was observed for linseed oil biodiesel blends compared to diesel fuel throughout the test. Yılmaz [28] in this study, biodiesel (45-40%), methanol (10-20%) and ethanol (10-20%) were added to diesel fuel at different rates and engine performance emission values were compared. Fuels created with biodiesel-alcohol-diesel additions have higher brake-specific fuel consumption compared to diesel. As the percentage of alcohol used in the mixtures increased, CO and HC emissions increased, while NO emission values decreased. Yasin et al. [34] in this study, engine performance and emission values of fuel mixtures obtained by adding 20% biodiesel 5%, and 10% methanol to diesel were compared with diesel. As a result of the tests, biodiesel-methanol-diesel mixtures increased brake-specific fuel consumption compared to diesel. As the amount of methanol in the mixture decreased, the NO emission value decreased and the CO emission value increased. Sayın et al. [35] in their experimental research, mixed methanol (5%, 10%, 15%) with diesel fuel in different proportions. The effect of the obtained fuel mixture on engine performance and emissions in a diesel engine was investigated. The experiments were carried out at 20 Nm engine load at 2200 rpm and three different injection pressures and timings. As a result of the experiments, it was observed that BSFC and BSEC increased in methanol-added fuels. He stated that this is due to the lower energy content of methanol. In addition, as the amount of methanol increased, BTE decreased. While fuels with methanol added decreased CO emission values, they increased NO emission values.

Qui et al. [41] in the study titled Performance and combustion characteristics of biodiesel–diesel–methanol blend fuelled engine. In his studies, he examined the effects of biodiesel and methanol-added diesel mixture on engine performance, gas emission data and combustion performance. 50% diesel and 50% biodiesel were used as base fuel. Experiments were carried out by adding 5% and 10% methanol to the resulting fuel. Experiments were carried out at different engine loads. As a result of the study, it was concluded that fuels with 1500 rpm methanol added at low engine power burned later than the base fuel. It has been stated that this delay time decreases as the engine load increases. When the cylinder pressure is compared, the cylinder pressure of methanol added fuels is higher than the base fuel. It was also stated that the fuel mixture using methanol contributes to the reduction of harmful gas emissions.

When the literature studies are examined, there are many articles using methanol and biodiesel mixtures as additives to diesel fuel. However, the number of studies comparing biodiesel and methanol mixtures together is less. This study, conducted at different torque values, will contribute to the literature in this context.

2. MATERIALS AND METHODS

2.1 The Experimental Setup

The experiments of the study were conducted at Erciyes University Engines Laboratory. The experiments are carried out three-cylinder, water-cooled, four-stroke diesel engine. The experimental setup also includes a hydraulic dynamometer, dynamometer load cell, encoder to measure engine speed, exhaust emission device for combustion gas emissions and smoke measurement, precision electronic scale to measure fuel consumption, piezoelectric pressure sensor, and temperature sensor measuring the temperature of the exhaust gases. Figure 1 and Table 1 show the experimental test system and the specifications of the diesel engine where the experiments are performed respectively.

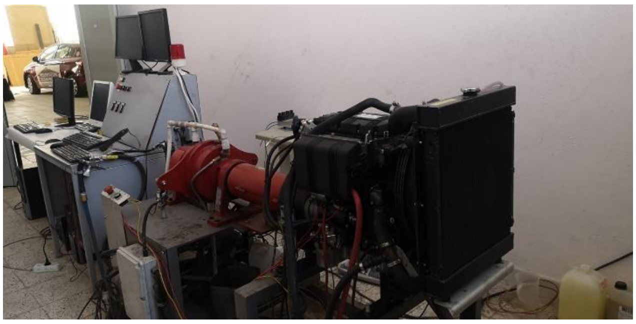

Fig. 1. Test Device

Table 1 Diesel Engine Specifications [36]

DİESEL ENGİNE	TECHNICAL SPECIFICATIONS
Cylinder number	3
Maximum speed (rpm)	3600
Maximum torque (Nm)	67
Compression ratio	22.8:1
Maximum power(kW)	19.5
Bore x Stroke (mm – mm)	75-77.6
Total cylinder volume (cm3)	1028

Table 2. Pressure Sensor Specifications [36]

Pressure Sensor	PCB113B22
Measurement Range	34475 KPa
Maximum Pressure	103425 KPa
Temperature Range	−73 to + 135 °C
Non-Linearity	≤1.0% FS
Sensitivity	0.145 mV/kPa
Low-Frequency Response	(−5%) 0.001 Hz
Resonant Frequency	>=500 kHz
Sensing Element	Quartz
Ranges	0–5000 psi
Accuracies	±1% of actual reading

The hydraulic dynamometer uses the NF150 model dynamometer, which can measure 0-6500 rpm engine speed and 0-450 Nm torque. As a hydraulic load cell, the CAS SBA 200L load cell is used and thus the effective engine torque is measured. Bosch BEA60 emission device has been used to measure the excess air ratio, hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO2), nitrogen monoxide (NOx), and oxygen (O2) [37].

Table 3. Mixture of Fuels Used in Experiments

Alternative Fuels Used in Experiments	Diesel Mixing Ratio (%)	Biodiesel Mixing Ratio (%)
100D	100	-
10B90D	90	10
20B90D	80	20
10M90D	90	-
10M10B80D	80	10

2.2 Heat Release Rate Calculation

In internal combustion engine applications, heat release rate figures show where the heat appears, the duration of the heat, whether there is burning at different points, and how much heat must be given for pressure changes in the cylinder [36]. The heat release rate is calculated according to the first law of thermodynamics using the equation:

$$\frac{dQ_n}{d\theta} = \frac{\gamma}{\gamma-1} p \frac{dV}{d\theta} + \frac{1}{\gamma-1} V \frac{dp}{d\theta} \quad (1)$$

In this formula, θ is the crank angle, γ (γ=Cp/Cv) is the specific heat ratio of the fuel/air mixture, and dQn/dθ is the net heat release [36].

3. Results and Discussion

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3.1 Thermal Efficiency

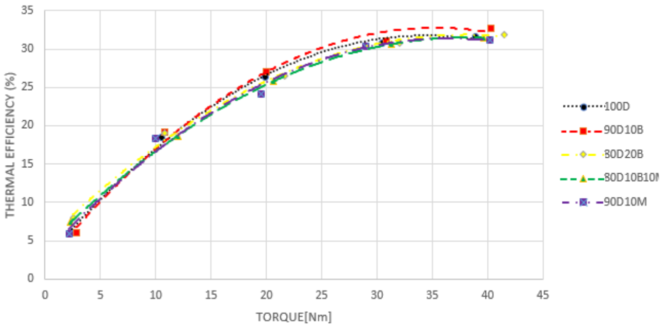

Fig.2. Thermal Efficiency Graph of Diesel, Biodiesel, Methanol Mixtures

The thermal efficiency graph of five different fuel mixtures is shown in Figure 2. According to the data obtained in the experiment, the highest thermal efficiency values were obtained with the use of 10% biodiesel in fuel mixtures. Biodiesel improves combustion in the cylinder due to its higher oxygen content and better C/O ratio compared to diesel [38]. Biodiesel Production and Engine]. The use of 20% biodiesel increased the thermal efficiency compared to diesel fuel, but it provided a lower increase than the use of 10% biodiesel. When the literature was searched, it was concluded that the use of 10% biodiesel has better results than the use of 20% biodiesel. As a result of the experiments we have done, the fact that 10% biodiesel gives better results than the use of 20% biodiesel overlaps with each other when compared with the literature. When the literature studies are examined, it is stated that better engine performance is obtained in the use of 10% biodiesel in some studies, while the use of 20%-50% in some studies gives better performance. The parameters that affect the performance most in the engine are compression ratio, injection advance, and air-fuel ratio. Air fuel ratio is the ratio of the amount of air to the amount of fuel. In order for combustion to occur, a certain amount of air and fuel must be present together in the combustion chamber. In order to obtain good performance data, all the fuel must be burned in the combustion chamber. The air-fuel ratio determines the quality of combustion and closely affects engine efficiency. In addition, the amount of oxygen in the biodiesel fuel improves combustion. There must be enough oxygen in the combustion chamber to burn all the fuel. Otherwise, unburned fuel will be expelled from the exhaust. This will both reduce engine performance and increase harmful emission gases released into the environment. Therefore, the amount of oxygen contained in additives such as biodiesel and methanol used in fuel mixtures will closely affect the efficiency. Each of these factors can be different in different engines, such as the injection advance, the shape of the combustion chamber, and the fuel-air mixture ratio. The viscosity value of the biodiesel fuel used in the study is higher than the diesel fuel. The higher the viscosity, the more energy the fuel needs to break down and evaporate. This is a factor limiting the increase in biodiesel rate. The high thermal efficiency of the %10 biodiesel mixture has a lower viscosity and increases the volatility compared to the %20 biodiesel mixture. This enhances the fuel atomization leading to improved air-fuel mixing [39]. At low compression ratios, a 10% biodiesel-added fuel mixture with lower viscosity yields better results than a 20% biodiesel fuel mixture with higher viscosity and a 10% biodiesel-added mixture. Therefore, the thermal efficiency for %20 biodiesel mixtures is lower than %10 biodiesel.[40] These results are consistent with the studies of ref 16 and 24. The use of 10% biodiesel increased the thermal efficiency by 2.6% in total at five different loads. The use of 20% biodiesel resulted in an improvement of 1.03%. The highest thermal efficiency in all fuel types was obtained at the maximum load of 40 Nm torque.

3.2 Gas Emission Values

In diesel engines, CO emission occurs due to an insufficient amount of oxygen in the combustion chamber and incomplete combustion. The increase in CO emissions is not a desirable situation for the emission parameters of diesel engines. The CO2 emission value is affected by the amount of oxygen contained in the fuel used in the engine, the air-fuel mixture ratio, the excess air factor and the turbulence in the combustion chamber. Increasing the CO2 emission value in engines is a desired result CO2 emission value increases as a result of good combustion in engines. NOX emission occurs due to the reaction of nitrogen in the air with oxygen at high temperatures resulting from combustion in engines. The higher the temperature in the cylinder, the higher the NOX emission. Different torque values have been obtained at 0% torque and a constant torque value could not be obtained. Therefore, test results at 0% load were not used when making comparisons.

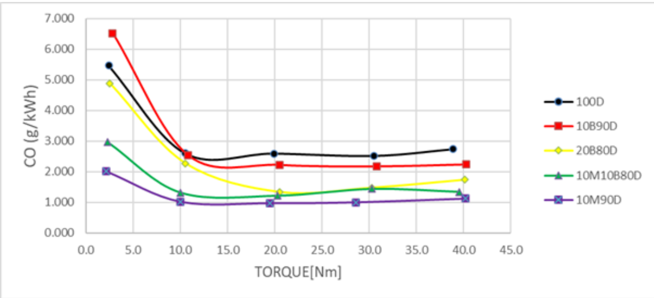

Fig. 3. CO Emission Graph of Diesel, Biodiesel, Methanol Mixtures

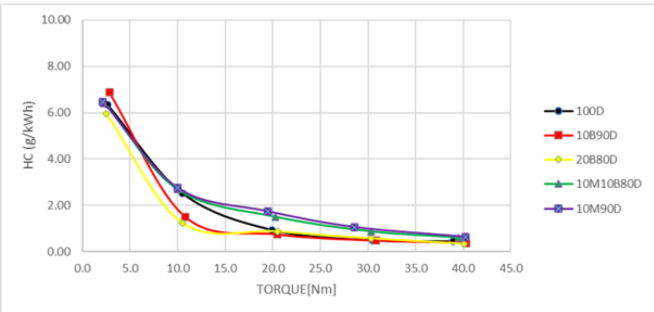

Fig. 4. HC Emission Graph of Diesel, Biodiesel, Methanol Mixtures

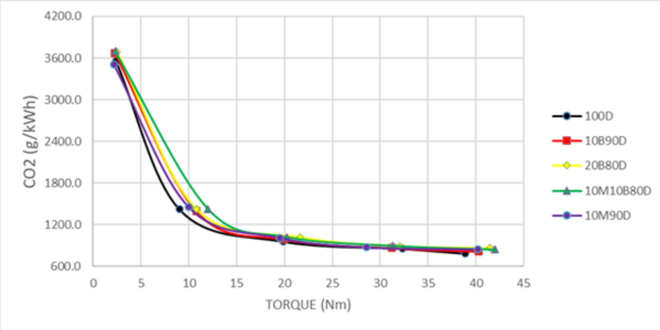

Fig. 5. CO_2 Emission Graph of Diesel, Biodiesel, Methanol Mixtures

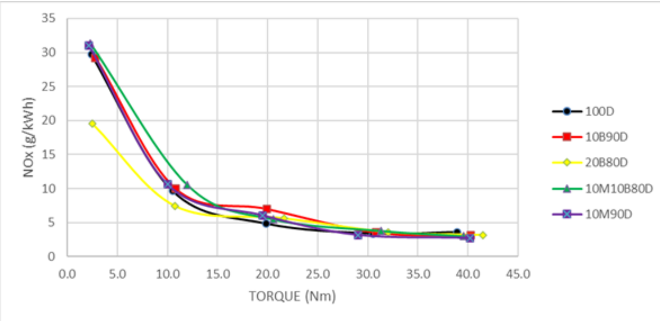

Fig. 6. NO_X Emission Graph of Diesel, Biodiesel, Methanol Mixtures

Figure 3 shows the CO emission graph of diesel biodiesel methanol blends. CO emission values vary between 6,525 g/kWh and 0,972 g/kWh. CO emission occurs due to incomplete combustion in the cylinder. Compared to 100D fuel, CO emission seems to decrease with the addition of biodiesel and methanol. In full load condition, 10B90D, 20B80D, 10M10B80D, and 10M90D fuels decreased their CO emission value by 17.92%, 36.60%, 50.92% and 59.00%, respectively, compared to 100D fuel. It has been observed that the high number of C atoms and oxygen density in the structure of biodiesel reduce the CO emission value. Methanol created a better air-fuel mixture during combustion due to the excess oxygen and low carbon in their structure compared with diesel and reduced the CO emission value.

Figure 4 shows the HC emission graph of diesel, biodiesel, and methanol blends. HC emission values decrease as the load value increases. Compared to pure diesel at full load, HC emission decreased respectively by 15.17% and 22.72% in 10B90D and 20B90D blends and increased respectively by 38.63% and 45.45% in 10M10B80D and 10M90D blends. Although HC emission decreases with the addition of biodiesel to diesel, HC emission increases when methanol is added. Since biodiesel makes the combustion more ideal, HC emission decreases, while HC emission increases due to the low cetane numbers of methanol. Adding 20% biodiesel resulted in a greater reduction in HC emissions than adding 10%. Figure 5 shows the CO2 emission graph of the mixtures obtained using diesel, biodiesel, and methanol. Effects such as the air excess coefficient, the turbulence occurring in the combustion chamber and the chemical properties of the fuel vary the amount of CO2. In general, higher CO2 emissions mean better combustion. When the figure is examined, CO2 emissions increase in all fuel mixtures compared to diesel fuel in full load conditions. This is because methanol and biodiesel contain more oxygen in their structures compared to diesel. A high CO2 emission value at full load has been obtained in the 90D10M mixture. The lowest CO2 emission value at full load was obtained in pure diesel fuel. CO2 and CO emissions are inversely proportional to each other. In a good combustion, CO2 emission increases while CO emission value decreases.

Figure 6 shows the NOx emission graph of the mixtures obtained using diesel, biodiesel, and methanol. NOx emission gas is formed by the reaction of nitrogen in the air with oxygen at high temperatures. NOx gas emission is affected by effects such as combustion reaction time, gas temperature in the cylinder and the amount of oxygen. In general, to reduce NOx emission, the temperature formed during combustion in the cylinder should be reduced. When the figure is examined, it has been observed that the methanol fuels reduce the NOx emission value compared to the normal diesel fuel. The reason for the lower NOx emission of methanol fuel blends: Methanol absorbs heat from the cylinder due to high evaporation heat and lowers the temperature in the cylinder. Thus, a lower in-cylinder temperature is achieved and less NOx emissions are produced.

3.3 In-Cylinder Pressure and Heat Release Rate

In-cylinder pressure and thermal release values help us to comment on the performance of a diesel engine. It gives information about how performance emerges, along with fuel consumption and engine efficiency. The position of the maximum pressure points and the in-cylinder pressure curve is important when interpreting engine performance. The size of the area under the in-cylinder pressure curve is related to the engine efficiency.

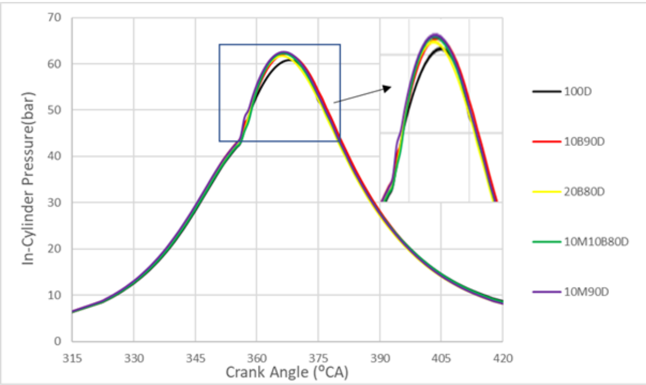

Fig. 7. In-cylinder pressure Graph of Diesel, Biodiesel, and Methanol Mixtures at T40 Load Value

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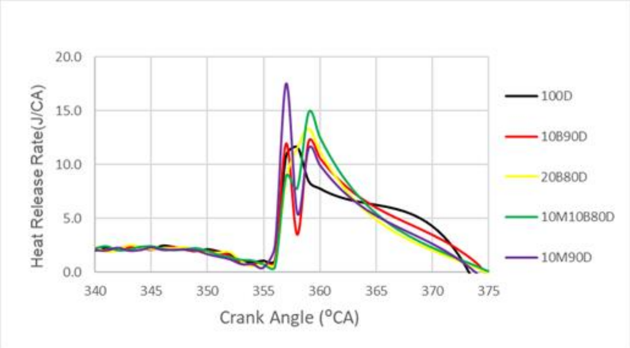

Fig. 8. Heat Release Rate Variation with Crankshaft Angle

In-cylinder pressure graph for diesel, biodiesel, and methanol blends at T40 (40 Nm torque) load value is shown in Figure 7. The change in heat release rate with the crankshaft angle is shown in Figure 8. The highest in-cylinder pressure values were obtained in the 10M90D mixture at 62.59 bar. Due to the rapid evaporation of methanol, the pressure in the methanol mixtures increased rapidly in the cylinder and then decreased. In-cylinder pressure values for 100D have 60.82 bar at 368 CA, for 10B90D 62.09 bar at 367 CA, for 20B80D 61.62 bar at 366 CA, for 10M10B80D 62.225 bar at 366 CA, and for 10M90D 62.59 bar at 367 CA. In the case of full load, the in-cylinder pressure values increased with the addition of biodiesel (10B90D, 20B80D) and methanol (10M10B80D, 10M90D) added to the diesel by volume. When the heat release rate is examined, it is seen that the heat release rate of methanol and biodiesel mixtures is larger than diesel fuel. It is thought that the heat release rate is higher than diesel because the mixtures burn faster than normal diesel fuel. When Figure 8 is examined, the heat release rate increased when biodiesel and methanol were added to pure diesel. The highest heat release rate was obtained with a mixture of 17.54 J/CA 10M90D at 357 CA. Due to the rapid evaporation of methanol, a sudden heat is generated in the cylinder when the spraying starts, but it has been observed that the temperature drops rapidly afterwards.

4. CONCLUSION

In this study, the effect of mixing biodiesel and methanol with diesel fuel on engine performance and emission values was investigated. The results of this study can be summarized as follows:

1-In the experiments where diesel methanol and biodiesel mixtures were used, the highest thermal efficiency values were obtained in the 10B90D mixture (10% biodiesel, 90% diesel) with a ratio of 32.75% at full load. When the 10B90D fuel mixture is compared to the 100D fuel mixture, the thermal efficiency increases by 3.61%. These results are consistent with references 39 and 40.

2-Since methanol has lower thermal energy than biodiesel and diesel, lower performance results were obtained compared to biodiesel and diesel.

3-The fuels obtained at the end of the mixture contributed to the improvement of harmful gas emissions compared to diesel.

4-Fuel mixtures were applied without making any changes to the engine and the results were obtained.

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