

The Influence of Diesel-Biodiesel-Alcohol Blends on the Performance and Emissions in a Diesel Engine

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Abstract

The pure biodiesel is not widely used in diesel engines due to its high viscosity leading to the fuel droplet size, poor atomization qualities and fuel penetration in the cylinder which is very vital in terms of engine performance and emissions. Therefore it is important to balance the biodiesel's high viscosity with alcohol additives and positively contribute the combustion efficiency and resulted in lower NO_x emissions. The aim of this study is to evaluate the performance and emissions of high proportion of methanol and propanol (20% by volume) in a B30 blend and conventional diesel when operating on a direct injection diesel engine. The experiments were conducted from 1200 rpm to 2600 rpm with the intervals of 200 rpm at full load conditions for seven types' blended fuels. The results revealed that lower brake power was observed with B30M15P5 and B30M17P3 test fuels. However, an increase in brake specific fuel consumption (BSFC) of 31.12% and 34.01% was determined when the engine was fueled with B30M15P5 and B30M17P3, respectively. It was concluded that NO_x emissions decreased up to 32.4% and 27.9% for B30M10P10 and B30M15P5, respectively at 2000 rpm in comparison with biodiesel.

Keywords: Combustion, engine performance, additives, diesel engine.

1. Introduction

There is an increasing interest regarding biodiesel and its additives as a fuel in order to control the emissions and to improve engine performance in compression ignition engines (CI). Biodiesel is clean, renewable and has higher combustion efficiency, no sulphur, no aromatic content, higher cetane number, higher flash point, higher biodegradability and oxygen content (10-11% by weight) which helps it to burn fully [1–8]. However, the high viscosity of biodiesel leads to the fuel droplet size, poor atomization qualities and fuel penetration in the cylinder which is very vital in terms of the combustion quality [9-10]. Some negative properties of fuels such as lowered heating value, higher viscosity, higher NOx emission, can be compensated for by blending diesel with biodiesel and/or other additives [11-13]. Biodiesel, solvent and fossil diesel blends showed that addition of an oxygen agent such as ethanol or acetone to mineral diesel can offset the biodiesel's high viscosity and positively contribute the combustion efficiency and resulted in PM emissions [14-16].

Many researchers investigated the engine performance and emission characteristics of diesel engine operating with biodiesel and its blends. Pand and Chiu [3] showed that the addition of alcohol in a diesel–biodiesel blend could improve the burning rate, decrease the preheating delay, and cut back soot particles pollution. It was stated that 5% blend of methanol reduced the density and viscosity of the fuel. However, for a higher percentage alcohol in the blended fuels, the cooling effect is determinative factor considering lower brake thermal efficiency (BTE) [7]. It was performed that alcohol–biodiesel blends with 10% and 15% alcohol concentration increased HC and CO emissions while 5% alcohol addition to biodiesel fuels decreased these emissions [8]. While there is an increase in CO and HC emissions for high concentrations of methanol and ethanol in biodiesel–alcohol blends, there is evidence of reduction of those emissions with low concentrations of methanol and ethanol. The reason for higher emissions is that ethanol has a high vaporization energy requirement, which causes incomplete combustion [8]. The fuels with varying percentages of acetone, isopropyl alcohol, and waste-edible-oil-biodiesel to conventional fossil diesel were investigated in terms of the pollutant emission characteristics by Tsai et al [17]. The fuel blends including waste-edible oil-biodiesel (B20 vol.%), acetone (1–3 vol.%), and isopropyl alcohol (1 vol.%) are encouraging alternatives to diesel fuel due to the reducing emissions of particulate matter. Accordingly, it is very substantial to detect what kind of blend is more influential in decreasing emissions and in increasing the other performance characteristics of a diesel engine. Although there is some available work in the literature regarding ethanol and methanol blended biodiesel and biodiesel–diesel fuels. However, there is a limitation about diesel-biodiesel with a high percentage of alcohol blends up to 20% which does not usually need any important engine modification. In this study, diesel-biodiesel blend is mixed with different percentage of methanol and propanol, which is another encouraging source of biological energy that may balance the degrading of using biodiesel alone. It will contribute the evaluation of making a better blend in terms of engine performance and exhaust emissions.

2. Material and Method

Sunflower oil is used as a raw material for biodiesel production. Sunflower methyl ester (SFME) was produced by the transesterification method. In this reaction, methyl alcohol and sodium hydroxide (NaOH) were used as reactant and catalyst. Transesterification reaction was conducted in a spherical glass reactor having reflux condenser, stirrer and thermometer so as to determine best production condition. Chemical structure of the transesterification process is given in Figure 1. Methanol and sodium hydroxide were blended in order to obtain sodium methoxide. After that, sodium methoxide and sunflower oil were mixed in the reactor. The mixture was heated up to 60oC and kept at this temperature for 90 minutes being stirred. After the reaction process, the crude methyl ester was held at separating cone for 8 hours. And then, crude glycerin was separated from methyl ester. Eventually, the crude methyl ester was washed by warm water until the washed water appeared clear and dried at 105 oC for 1 hour. Finally, washed and dried methyl ester was passed through a filter. At the end of the transesterification reaction 96% conversion of oil was obtained. There are seven kinds blended fuel used in the experimental study including mineral diesel (D), biodiesel (B100), B30M3P17, B30M5P15, B30M10P10, B30M15P5 and B30M17P3 by volume. The ratio of blending with mineral diesel is referred as Bxx, Mxx and Pxx where xx indicates the amount of biodiesel and alcohol in the blend (i.e. B30M5P15 blend is 30% biodiesel, 5% methanol, 15% propanol and 50% diesel).

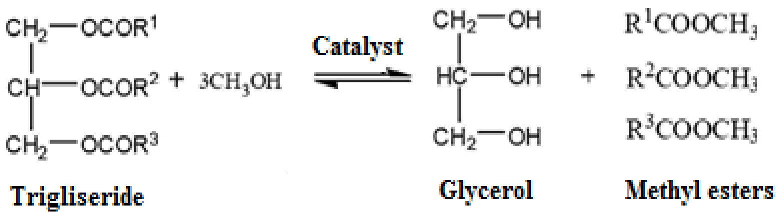

Figure 1. Chemical structure of transesterification reaction [18].

In this study, sunflower biodiesel and alcohols blends with mineral diesel were prepared to obtain fuel properties of each blend and to conducted engine performance and exhaust emissions.

2.1. Experimental procedure and specifications

Schematic representation of experimental setup is given in Figure 2. Engine performance was performed on a four cylinders, four stroke, and naturally aspirated, direct injection diesel engine. Technical properties of the diesel engine are given in Table 1. Technical specifications of hydraulic dynamometer are given in Table 2. Table 3 shows the technical properties of fuel measurement devices. Exhaust emissions were also measured with the help of Testo 350-S diesel emission analyzer and technical specifications of analyzer are given in Table 4. All tests were executed under steady state conditions. Tests were initially performed with diesel fuel to reach the base data of the engine. Each engine test was reiterated three times at a given load and the average value of measurements was taken. All tests were conducted at full-load conditions and the engine speed was varied between 1200 and 2800 rpm with the intervals of 200 rpm. After each fuel test, the engine was run for at least 30 min to consume the fuel which was remained in the fuel system from the prior test.

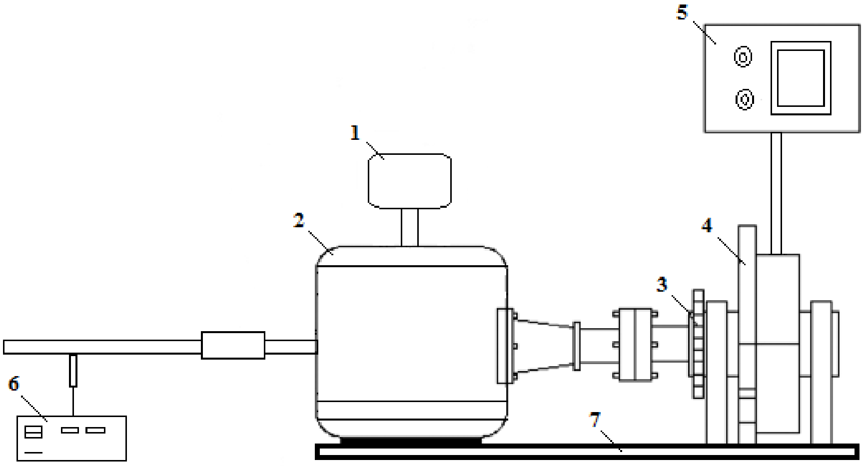

Figure 2. Experimental set-up: 1.Fuel tank; 2. Test engine; 3.Magnetic pick-up; 4. Hydraulic dynamometer; 5. Control panel; 6. Diesel emission analyzer; 7. Platform.

Table 1. Technical specifications of the diesel engine

Brand	***Mitsubishi Center***
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel
Displacement	3907 cc
Bore	104 mm
Stroke	115 mm
Power	89 kW@3200 rpm
Torque	295 Nm@1800 rpm
Oil Cooler	Water cooled
Air Cleaner	Paper element type
Weight	325 kg

Table 2. Technical specifications of the dynamometer

Brand	Netfren
Torque range	0-1700 Nm
Speed range	0-7500 rpm
Body diameter	250mm
Torque arm length	250mm
Torque	295Nm @ 1800rpm

Table 3. Technical properties of fuel measurement instruments

Property	Device	Accuracy
Cetane Number	Zeltex ZX440	3%
Lower Heating Value (LHV)	IKA-Werke C2000 Bomb Calorimeter	0.001 K
Density	Kyoto Electronics DA-130	±0.001 g/cm^3
Viscosity	TANAKA AKV-202 Auto Kinematic Viscosity	-
Flash Point	Tanaka Automated Pensky-Martens Closed Cup Flash Point Tester APM-7	-
CFPP	Tanaka AFP-102	-

Table 4. Technical Specifications of Testo 350-S Diesel Emission Analyzer

Parameter	*Unit*	*Measuring Range*	*Accuracy*
O_2	%	0-25	0.01
CO	ppm	0-10,000	1
CO_2	%	0-50	0.01
NO	ppm	0-3,000	1
H_2S	ppm	0-300	0.1
NO_2	ppm	0-500	0.1
SO_2	ppm	0-5,000	1
HC	%	0-4	0.001
Temperature	^{o}C	40-1,200	0.1
Combustion Efficiency	%	0-120	0.1

3. Result and Discussion

3.1. Fuel properties

The propanol and methanol of 99.5% pure supplied by Merck Limited was used for blending with diesel and biodiesel. The fuel properties were performed in Petroleum Research and Automotive Engineering Laboratories of the Department of Automotive Engineering at Cukurova University, Turkey. Table 5 shows the basic fuel properties of biodiesel, diesel and their alcohol blends. Alcohols used as additives in fuel blend have lesser heating value, kinematic viscosity, cetane number and density in comparison with diesel and biodiesel except for flash point. Although propanol's heating value is higher than that of methanol, it is about 27% lower than that of diesel fuel. Propanol, which has higher heating value, is an important advantage regarding the engine performance and fuel consumption. Adding oxygenated additives to the biodiesel blend reduces the density and viscosity as well as increases the oxygen content of the blend.

It clearly shows that the viscosity of B100 is higher than that of mineral diesel by 40% due to the free fatty acid (FFA) concentration in biodiesel. When alcohol is added by 20 % by means of methanol and propanol, the flash points for B30-alcohol blended fuels are higher when compared to mineral diesel. The density of SFME was found higher than that of diesel fuel. The densities of alcohols such as methanol and propanol were lower than diesel fuel. So, alcohol additive offset the adverse effect of biodiesel in terms of density. Cetane number is an important indicator determining the ignition quality of fuel. It provides prior information about the ignition delay of fuel throughout the combustion process. An increase in cetane number is due to the increase in carbon chain length. Generally, alcohol has lower cetane number in comparison with mineral diesel and biodiesel. The cetane number of methanol and propanol are 5 and 12, respectively. Free Fatty Acid of Sunflower Oil is 0.25.

Table 5. Properties of different diesel/biodiesel/alcohol blended fuels.

Fuels	*Density (20 °C) kg/m³*	*Cetane Number*	*CFPP °C*	*Heating Value MJ/kg*	*Kinematic Viscosity mm²/s (40 °C)*	*Flash Point °C*
Diesel	837	56.47	-16	45.856	2.76	79.5
EN590	820-845	Min 51	-	-	2.0-4.5	Min 55
B100	883	49	-10	36.16	4.57	>140
EN 14214	860-900	Min 51	Summer <4 Winter<1	-	3.5-5.0	Min 120
M100	792	5	-	19.8	0.59	11
P100	786	12	-	33.13	1.95	11.7
B30M3P17	838.5	52	-15	43.10	3.05	>90
B30M5P15	848	51	-14	42.49	3.04	>90
B30M10P10	842	50.6	-12	42.44	2.97	>90
B30M15P5	845	49.9	-10	41.45	2.91	>90
B30M17P3	842	45.5	-10	40.50	2.90	>90

3.2. Performance of biodiesel–diesel – alcohol blends

The variation of torque with respect to engine speed for different fuels is illustrated in Figure 3. The brake torque of diesel fuel is higher than that of other fuel blends at all engine speeds. The maximum brake torque for diesel fuel is obtained to be 287.48 Nm and the minimum brake torque is found to be 255 Nm for B30M17P3 fuel blend at 1400 rpm. Further, addition of methanol resulted in a decrease in the brake torque. At high engine speeds, the torque values showed a decrease for whole test fuels.

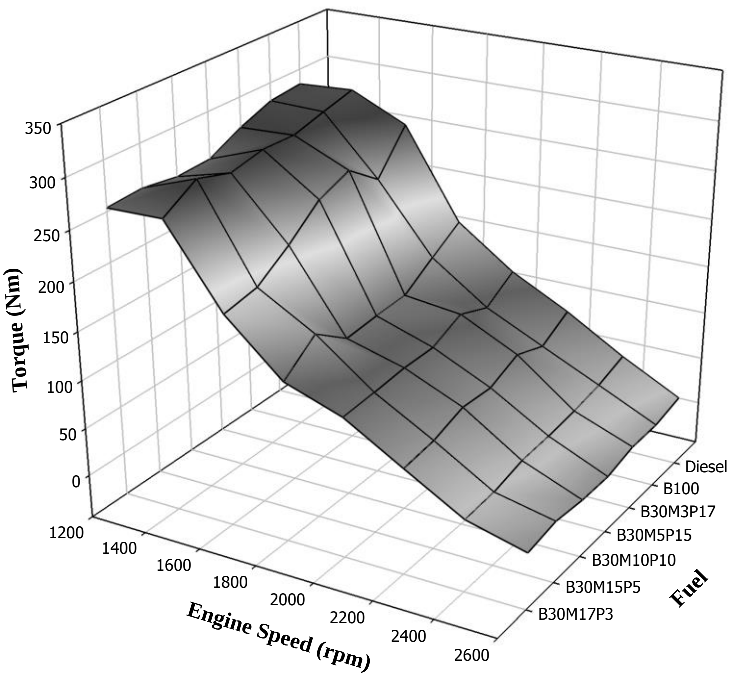

Figure 3. Variation of torque with engine speed for different fuels.

Figure 4 presents the variation of power with engine speed for different fuels. The maximum power is 61.065 kW for diesel fuel at 2400 rpm in comparison the graph of power and engine speed. The power values of diesel fuel increased by 5.38%, 4.59%, 3.22%, 13.25%, 10.2% and 11.58% in relation to biodiesel, B30M3P17, B30M5P15, B30M10P10, B30M15P5 and B30M17P3, respectively at 1400 rpm. The results for the propanol blends indicate an increasingly improving power with the increasing propanol ratio in the blend. The high viscosity of biodiesel reduced the engine torque and engine power, also the lower calorific value of biodiesel resulted in the increase in specific fuel consumption and decrease in combustion temperature. This reduction in the brake power and torque values can be attributed for incomplete combustion of fuels caused the lower cetane number when compared to the diesel fuel.

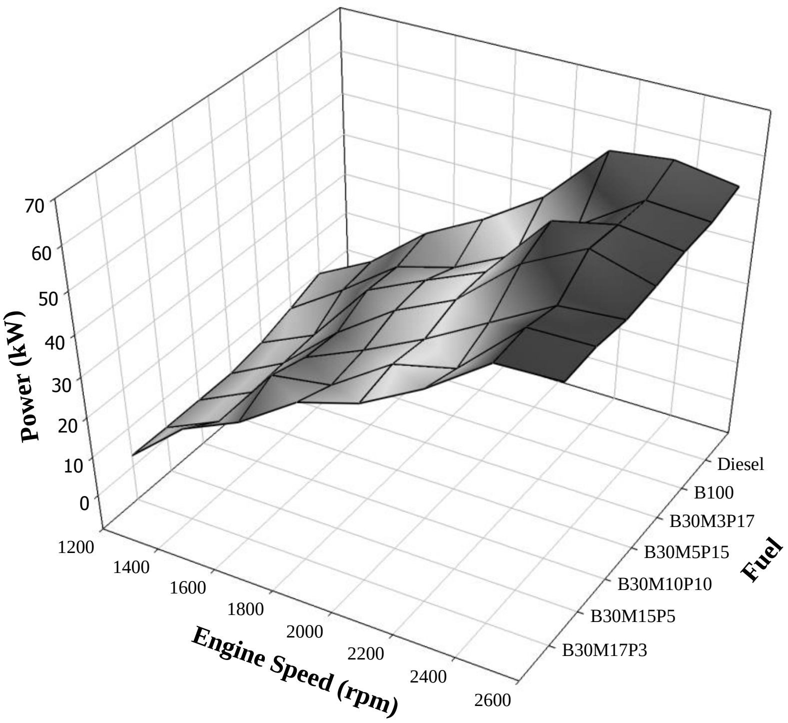

Figure 4. Variation of power with engine speed for different fuels

Specific fuel consumption is described as the consumption per unit of power in a unit of time and has important parameter of engine. The variation of BSFC versus engine speed is presented in Figure 5.
The minimum BSFC value was obtained for diesel fuel at 2000 rpm. As shown in Figure 5, the minimum BSFC values were found to be 127.70 g/kWh with mineral diesel, 140.59 g/kWh with biodiesel, 159.55 g/kWh with B30M3P17, 161.09 g/kWh with B30M5P15, 163.54 g/kWh with B30M10P10, 167.45 g/kWh with B30M15P5, 171.14 g/kWh with B30M17P3 at 2000 rpm. This case is due to heating value per unit mass of the methanol, which is considerably lower than that of the propanol. It was also observed that the highest BSFC values were obtained for B30M17P3 fuel at all engine speeds. The BSFC values showed a considerable increase after 2000 engine speed for all fuel blends.

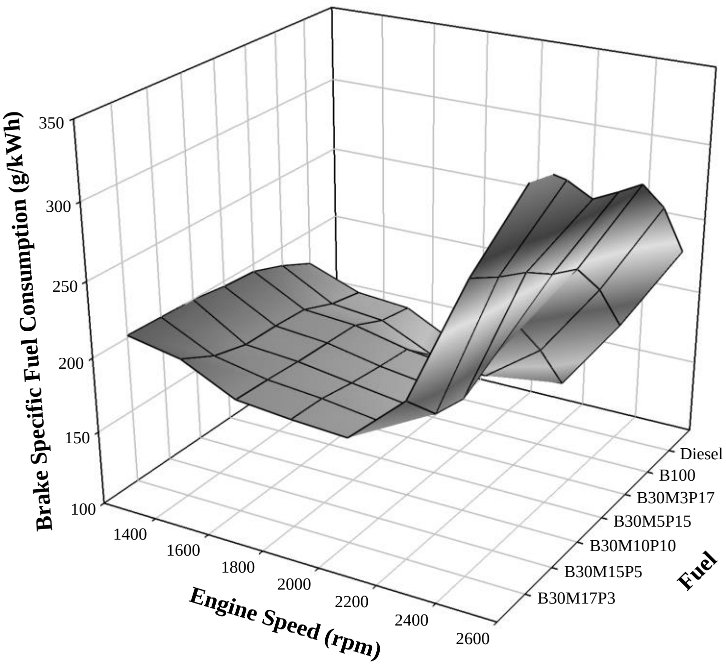

Figure 5. Variation of brake specific fuel consumption with engine speed for different fuels.

3.3. Emission Characteristics

CO is a toxic combustion product causing incomplete combustion of hydrocarbons. Effects of engine speed on CO emissions for different fuels are given in Figure 6.

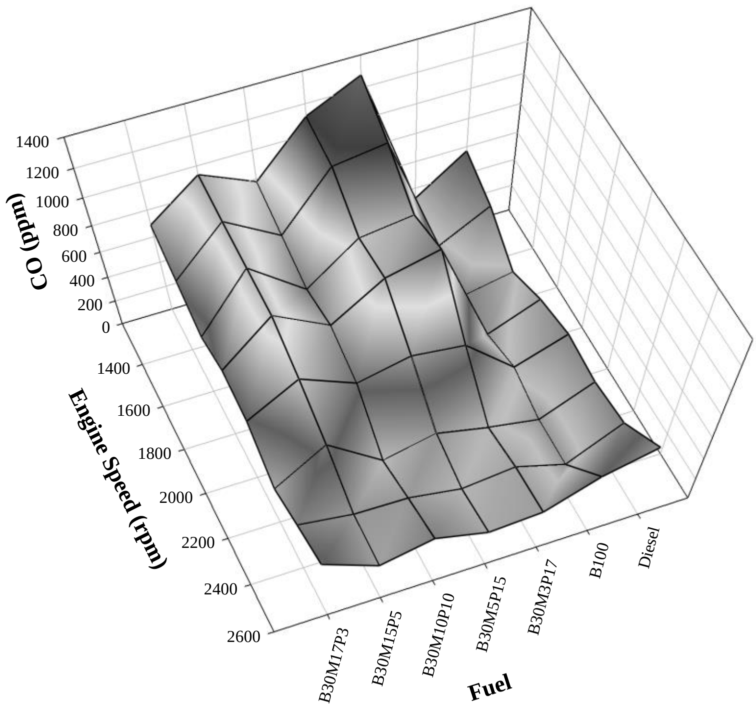

Figure 6. Effects of engine speed on CO emissions for different fuels.

For all fuel blends, it is revealed that the CO emissions reached the highest value at 1200 engine speed, and slowly decreased to 2200 engine speed and tend an increase again from this point to higher engine speeds. Biodiesel is an oxygenated fuel and contribute reducing CO emissions due to more complete combustion. CO emissions of biodiesel are the minimum, as expected. However, the presence of higher percentage of propanol as an additive in blend exhibited a significant increase in CO emissions.
There is a drastically increase by 128.5 % with B30M3P17 and by 100% with B30M5P15 when compared with biodiesel. It was concluded that the higher alcohol concentration, especially propanol in the fuel blends contributed to the higher CO emissions. This is parallel with the study performed by Lei Zhu et al [19].
The most important factor that causes NO_x formation is the peak combustion temperature. The NO_x formation is noticeably dependent on fuel types, in-cylinder temperature, and the oxygen concentration and residence time for the reactions to occur. Oxygenated additives are also considered for minimizing the ignition temperature of biodiesel fuels. The comparison of NO_x values with engine speed is shown in Figure 7.

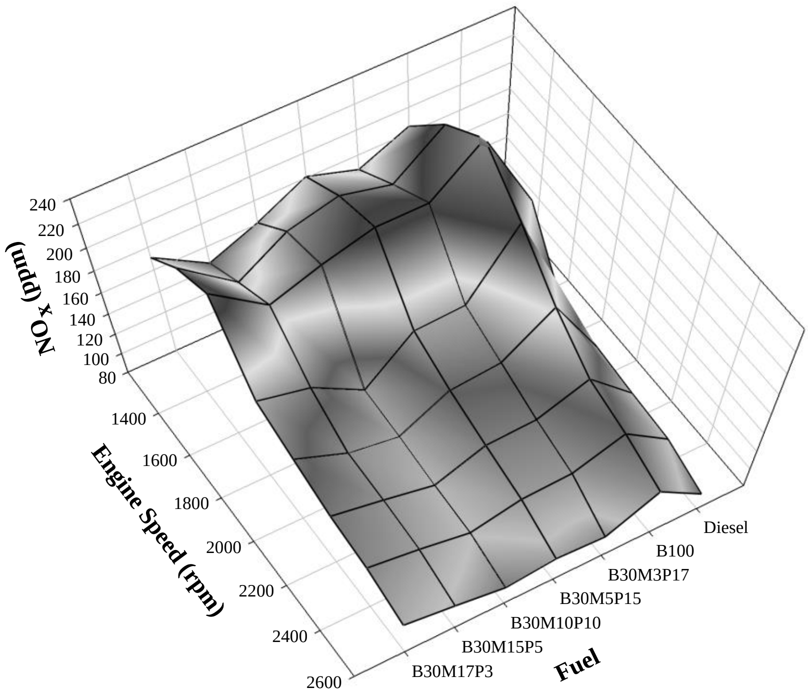

Figure 7. Effects of engine speed on NO_x emissions for different fuels.

NO_x emissions are the minimum for diesel fuel and are the maximum for biodiesel since injected fuel droplets of biodiesel is larger than mineral diesel, the combustion efficiency and maximum combustion temperatures of the biodiesel were lower and hence NO_x emissions were less. It is understood that NO_x emissions values of diesel-biodiesel and alcohol blends remains in between NO_x emission values obtained from diesel fuel and biodiesel. It is found that the NO_x emissions reached the highest value at 1600 engine speed, and slowly reduced corresponding with the higher engine speed for all test fuels. It was shown that among the addition of two alcohols, higher percentage addition of methanol resulted in better NO_x emissions than that of propanol at lower engine speeds which is agreement with the study conducted by Yılmaz [8].

5. Conclusions

In this study, Alcohols (methanol and propanol) as additives to biodiesel – diesel blends were studied in terms of performance and emission characteristics in a diesel engine operating on seven fuel blends. The main conclusions of this study can be given as follows;

- Brake specific fuel consumption of all alcohol blends is higher than that of diesel and biodiesel due to the lower heating value.
- High percentage of propanol in blend is more effective than that of methanol blends in terms of

BSFC and power.

- NO_x emissions values of diesel-biodiesel and alcohol blends remains in between NO_x emission values obtained from diesel fuel and biodiesel. When the methanol ratio increases in the blend, the cooling effect of methanol is more effective and results in a decrease in NO_x emission.
- CO emissions of biodiesel-diesel-methanol and biodiesel-diesel-propanol blends are higher corresponding with the same engine speed when compared with diesel and biodiesel.

If the goal is to balance the adverse effect of diesel-biodiesel NO_x emissions, it would be better choice to use high percentage of alcohol additives.

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