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Performance and Emission Characteristics of Diesel Engine Operating on Biodiesel and Biodiesel Blended with Methanol and Propanol

SafakYildizhan
Department of Automotive Engineering, Cukurova University,
01330, Adana, Turkey
E-mail: yildizhans@cu.edu.tr

Abdulkadir Yasar
Department of Mechanical Engineering, Cukurova University, Ceyhan Engineering Faculty
01330, Adana, Turkey
E-mail: ayasar@cu.edu.tr

Abstract
In this study, fuel properties, performance and emission characteristics of sunflower biodiesel and its blends with diesel fuel and alcohols has been evaluated. Blend ratios used in this study were diesel-biodiesel-methanol (50-30-20% by volume) and diesel-biodiesel-propanol (50-30-20% by volume). Experiments showed that alcohol blends improved the NO_x emissions increased as 45.44%, 16.75% and 10.09% in relation to conventional diesel for B100, B30M20 and B30P20, respectively which indicates alcohol blends improved the NOx emissions but increased the CO emissions at the rate of 106,1% and 38,88%, respectively. Consequently, propanol is more effective as additive than methanol and might be a feasible additive for biodiesel improvement in terms of contributing to NO_x emissions.

Keywords: Biodiesel, Diesel, Methanol, Propanol, Emission

1. Introduction

Nowadays, many countries are substituting their conventional energy sources with renewable and sustainable ones in some extent [1]. Biodiesel, renewable clean bio-energy, can be produced from extracted from Jatropha curcas, Sunflower, Vernicia fordii, Rape flower, and Soybean, and even waste-edible-oil which is reacted with alcohol to form esters (biodiesel) and glycerol [2-3]. Studies of biodiesel as an alternative fuel for diesel engine generators show that it has higher cetane number than diesel fuel, has no aromatics, almost no sulfur, and contains10–11% oxygen by weight. These characteristics of the fuel reduce the emissions of carbon monoxide (CO), hydro- carbon(HC), and particulate matter(PM) in the exhaust gas compared to diesel fuel, and lower the biotoxicity of emitted PM [4]. With the increasing demand on renewable energy sources different blends of biodiesels and different additives has a potential to be a new source for compression ignition engines. Researchers are looking for some additives that can improve the fuel properties and performance characteristics. Alcohols are getting attention as additives or direct use in some cases. Adding alcohols to biodiesel–diesel blends increase CO and unburned HC emissions while reducing NO_x emissions. Studies of "biodieselhol", a blend of biodiesel, solvent, and fossil diesel, show that adding an oxygen agent such as ethanol, methanol or propanol to pure petroleum diesel can balance the high viscosity of biodiesel and improve engine fuel combustion efficiency and reduce PM emissions [5]. Methanol and propanol have lower calorific value and cetane number in comparison with diesel fuel. Low calorific value of methanol and propanol result in an increase in specific fuel consumption and low cetane number reduces the cetane level of the biodiesel-diesel-alcohol blends [6].

Alcohols as additives to biodiesel–diesel blends were investigated in terms of performance and emission characteristics in diesel engines by the authors [7]. It was reported that the use of alcohol blends up to 20% does not usually require any important modification [1]. It has been shown that alcohol–biodiesel blends with 10% and 15% alcohol concentration increase HC and CO emissions while 5% alcohol addition to biodiesel fuels decrease these emissions [8]. Yilmaz and Vigil [9] showed that biodiesel–ethanol and biodiesel–methanol blends reduce NO_x and PM emissions while methanol is more effective than ethanol to reduce those emissions.

Most of the researchers have used diesel alcohol blends with a small percentage of ethanol, methanol and propanol [4, 10-11]. Aim of this work is to replace diesel with maximum fraction of methanol and propanol in diesel blends with a support of biodiesel and balance the high lubricity of sunflower oil methyl ester with the low lubricity of alcohols by mixing these additives to diesel fuel and decrease the NO_x level.

2. Material and Method

The experimental study was conducted in Petroleum Research and Automotive Engineering Laboratories of the Department of Automotive Engineering at Cukurova University. Sunflower oil is used as a raw material for biodiesel production.

Sunflower (SFME) was produced via the transesterification method. In this reaction, methyl alcohol and sodium hydroxide (NaOH) were used as reactant and catalyst. The chemicals (methanol and sodium hydroxide) which were used during the experiments were purchased from Merck and methanol was purified prior to use. In order to determine best production condition, transesterification reaction was carried out in a spherical glass reactor equipped with reflux condenser, stirrer and thermometer. In the reaction, molar ratio of alcohol to oil was 6:1. The reaction were performed with following conditions, methanol 20 wt %, sodium hydroxide 0.5 wt %, temperature 60 °C, time 90 minutes. Methanol and sodium hydroxide were mixed in order to obtain sodium methoxide. Then, sodium methoxide and sunflower oil were mixed in the reactor. The mixture was heated up to 60°Cand kept at this temperature for 90 minutes by stirring. After the reaction period, the crude methyl ester was waited at separating funnel for 8 hours. And then, crude glycerin was separated from methyl ester. Finally, the crude methyl ester was washed by warm water until the washed water became clear and dried at 105 °C 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. After biodiesel being produced, alcohol blends were prepared with methanol and ethanol. Flow diagram of biodiesel production process is shown in Figure 1.

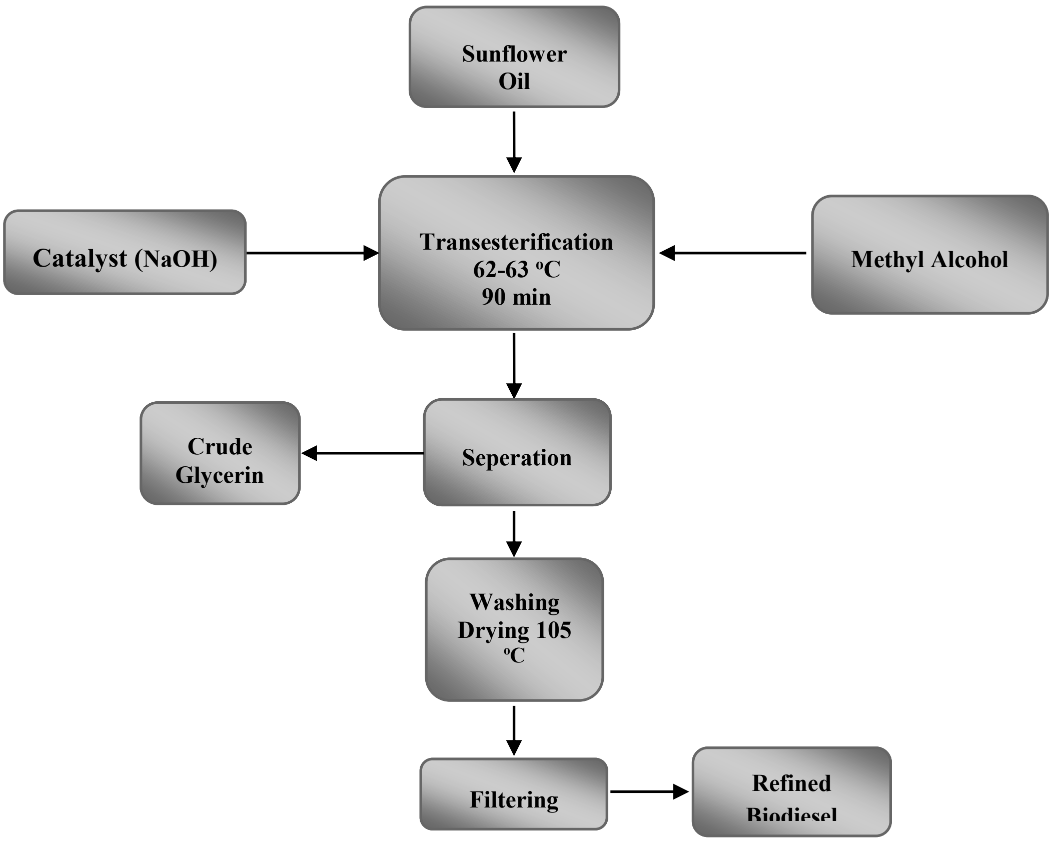

Fig.1. Flow diagram of biodiesel production process and alcohol blends preparation

In this study, two mixtures sunflower biodiesel (B) - diesel fuel (D) – alcohols methanol (M) and propanol (P) were evaluated as test fuels. These fuels are diesel-biodiesel-methanol (50-30-20% by volume) and diesel-biodiesel-propanol (50-30-20% by volume) which are called B30M20, B30P20, respectively. Test fuels were mixed on volume basis. After the preparation of test fuel blends, fuel properties of blends were measured. Also the performance and emission characteristics of these blends were evaluated in detail. Results were compared with diesel fuel and B100. Engine performance was performed on a four cylinders, four stroke, and naturally aspirated, direct injection diesel engine. All measurements were repeated three times and averages of tests were stated. Test fuels were tested between 1200 and 2600 rpm with the intervals of 200 rpm at full load condition. Schematic representation of experimental setup is given in Figure 2. Technical properties of the engine are given in Table 1.

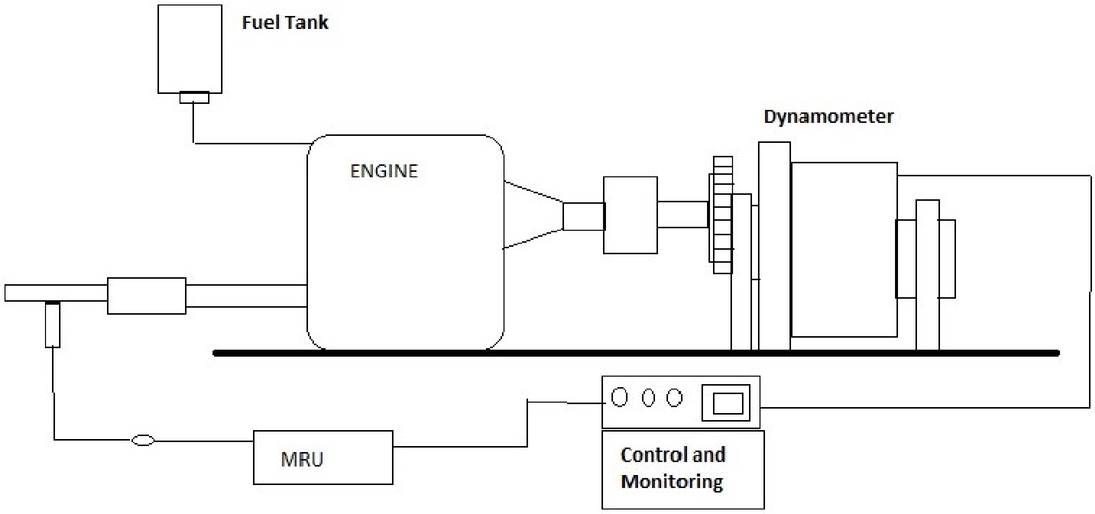

Fig. 2. A schematic representation of experimental setup

Table 1.Technical properties of the engine

Brand	Mitsibushi Center
Model	4D34-2A
Configuration	Inline 4
Type	Direct injectiondieselwithglowplug
Displacement	3907 cc
Bore	104 mm
Power	89 kW@3200 rpm
Torque	295 Nm@1800 rpm
AirCleaner	Paper element type
Weight	325 kg

Table 2.Technical specifications of hydraulic dynamometer

Brand	Netfren
TorqueRange	0-1700 Nm
SpeedRange	0-7500 rpm
Body Diameter	250 mm
Torquearmandlenght	250 mm
Torque	295 Nm @ 1800 rpm

Technical specifications of hydraulic dynamometer are shown in Table 2. Table 3 shows the fuel properties and measurement devices. Technical specifications of Testo 350-S diesel emission analyzer are also shown in Table 4.

Table 3. Fuel properties and measurement devices

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 Close 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	°C	40-1,200	0.1
CombustionEfficiency	%	0-120	0.1

3. Results and Discussion

3.1. Fuel Properties

Fuel properties of sunflower oil methyl ester and its blends with diesel fuel and alcohols were shown in Table 5. One of the most important measures of ignition characteristics of diesel and/or biodiesel fuels is the cetane number, since it directly pertains to ignition phenomena within compression ignition engines. The cetane number is the primary specification measurement used to match fuels and engines. To define kinematic viscosity, it is useful to begin with the definition of viscosity. Simply stated, viscosity, which is also called dynamic viscosity (η), is the ease with which a fluid will flow. Technically, it is the ratio of the shear stress to the shear rate for a fluid. Measure of the low temperature performance of diesel/biodiesel fuels is the pour point [12].The density of SFME was found higher than that of diesel fuel. Due to the higher density of SFME in accordance with the diesel fuel, blending with SFME was caused an increase in the density values. The density of alcohols both methanol and propanol were lower than diesel fuel.

Table 5. Fuel properties of test fuels

Fuel Properties	Diesel	EN590	B100	EN 14214	M100	P1S00	B30M20	B30P20
Density (20 °C) kg/m^3	837	820-845	883	860-900	792	786	829	824
CetaneNumber	56.47	Min 51	49	Min 51	5	12	47	53
CFPP, °C	-16	-	-10	Summer<4 Winter<1	-	-	-14	-19
Heating Value, MJ/kg	45.856	-	36.1	-	19.8	33.1	40.104	43.254
Kinematic Viscosity mm^2/s (40 °C)	2.76	2.0-4.5	4.57	3.5-5.0	0.59	1.95	2.86	3.094
Flash Point °C	79.5	Min 55	>140	Min 120	11	11.7	-	-

The heating value of a fuel indicates the internal energy of the fuel which is directly related with the indicated power obtained in the cylinders when it is burned. The heating values of SFME and diesel fuel were measured as 39048 and 45856kJ/kg, respectively. The heating value of SFME is lower than that of diesel fuel by 21,27%. Also, the heating values of pure methanol and pure propanol were lower than diesel fuel as 56,12% and 27,81%, respectively. Due to lower heating values of alcohols and biodiesel, the heating values of B30M20 and B30P20 were found to be 12,54% and 5,67%,respectively and lower than that of diesel fuel.
Generally, cetane number is an indicator of the ignition quality of a diesel fuel. If the cetane number is too high, combustion can occur before the fuel and air are properly mixed, which results incomplete combustion and smoke. If a cetane number is too low, incomplete combustion occurs [13]. The cetane number of blends having low cetane number is lower than that of diesel fuel. The temperature at which is the lowest temperature of the standardized volume of fuel can pass through a standardized filter is determined by cold filter plugging point (CFPP). Also CFPP is a significant property which is relative with pour point. Methyl ester derived from sunflower oil has a CFPP of -10 °C which is considerably low compared with other biodiesel fuels such as palm oil biodiesel, cotton seed oil biodiesel, peanut oil biodiesel. Due to low CFPP of diesel and biodiesel and depending on low properties of alcohols the cold flow properties of blends were within the standards.
Viscosity, which is a measure of resistance to flow of a liquid due to internal friction of one part of a fluid moving over another, affects the atomization of a fuel upon injection into the combustion chamber and thereby, ultimately, the formation of engine deposits. The general rule is; the higher the viscosity, the greater the tendency of the fuel to cause such problem [13]. Biodiesel's high viscosity and low volatilities cause problems in long-period engine performance tests [14]. Analysis revealed that SFME has higher viscosity value than diesel fuel (4.57 and 2.76 mm^2/s, respectively), however; the low viscosity of alcohols decreased the viscosity of the blends which complied the standards.
The flash point is the temperature at which the fuel will give off enough vapor to produce a flammable mixture [3]. This is important information for the safe transportation, storage of the fuel. The experiments showed that SFME has flash point of over 140°C which is acceptable according to European Biodiesel Standards. But, the flash point of the blends was not measured due to low boiling points of alcohols.

3.2. Performance Characteristics

The variation of torque versus engine speed is shown in Figure 3. The maximum torque with diesel fuel operation was obtained approximately 287Nm at 1400 rpm. and alcohols. The torque of biodiesel was lower than diesel fuel by 2,73% due to lower heating value of biodiesel. Methanol blend was the lowest brake torque as expected since the B30M20 blend had the lowest heating value within the experimental fuels. The brake torque value of B30M30 and B30P20 decreased by 6,17% and 5,51%, respectively in comparison with diesel fuel. As can be seen from Figure 4, maximum power was obtained for diesel fuel approximately 61 kW at 2400 rpm when compared to other fuel blends. The power values of sunflower methyl ester, B30M20 and B30P20 obtained from the experiment decreased by 5,38%, 22,48% and 20,94% compared to the conventional diesel fuel.

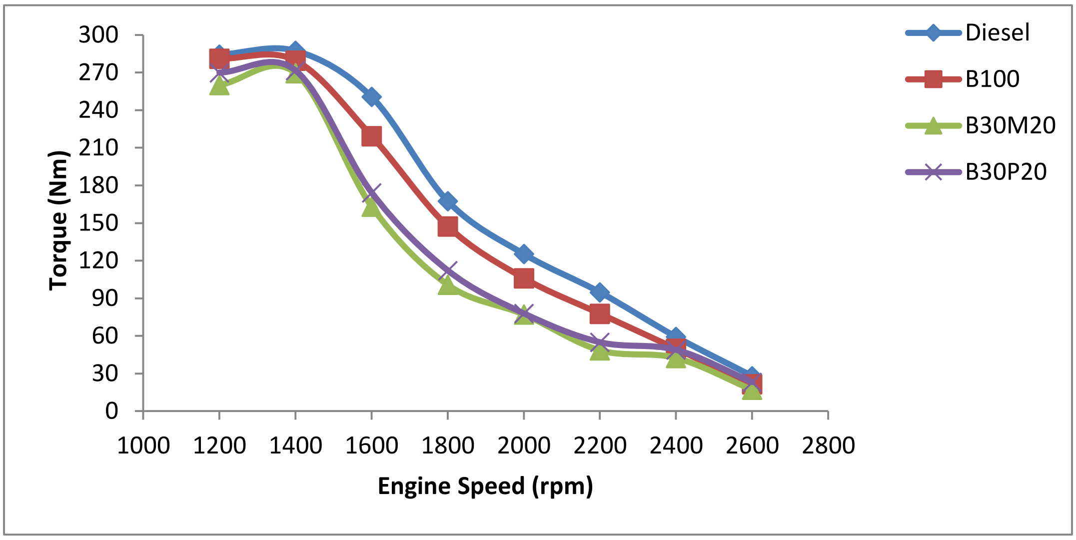

Fig.3. The variation of torque versus engine speed

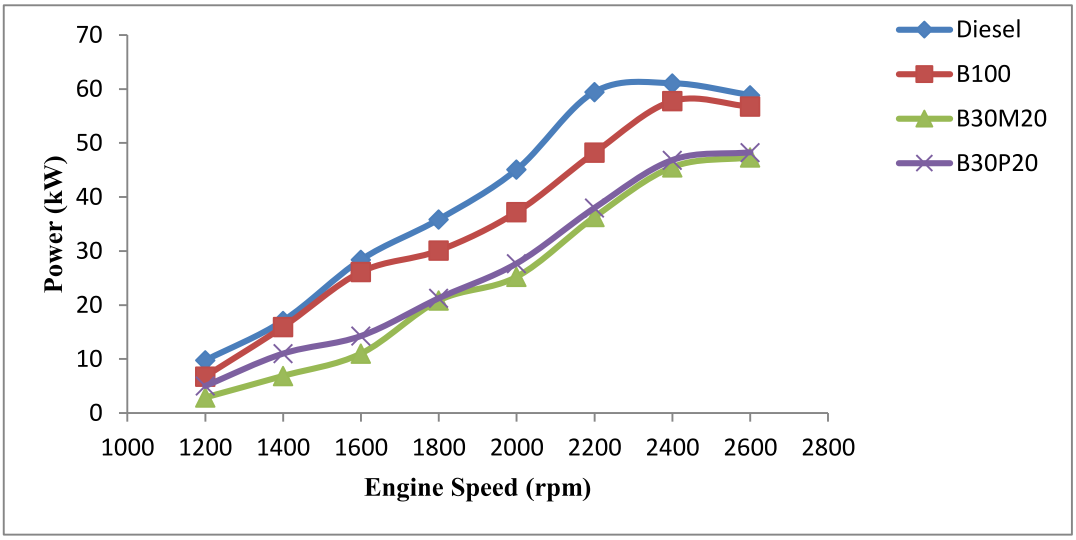

Fig.4. The variation of power versus engine speed

Specific fuel consumption is one of the important parameters of an engine and is defined as the consumption per unit of power in a unit of time. Figure 5 shows the brake specific fuel consumption (bsfc) characteristics of experimental fuels.

As shown in Fig.5, the minimum specific fuel consumption value was found to be approximately 127 g/kwh with diesel fuel at 2000 rpm due to its higher energy content. The bsfc of biodiesel, B30M20 and B30P20 blends deteriorated to be 10,09%, 21,77% and 18,83% at 2000 rpm when compared to diesel fuel, respectively. The results showed that increasing alcohol proportion in the fuel blend increased the BSFC. This behavior is attributed to heating value per unit mass of the methanol and propanol, which is noticeably lower than that of the diesel fuel. The BSFC of a diesel engine depends on the relationship among fuel density, viscosity and heating value [15].

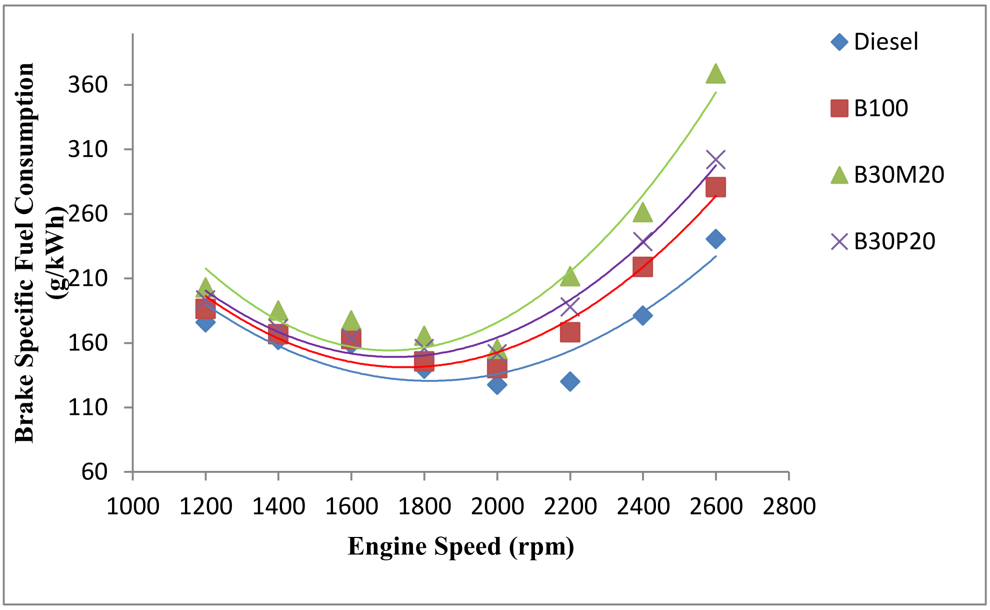

Fig.5. Variation of brake specific fuel consumption versus engine speed

3.3. Emission Characteristics

Figure 6 shows the variation of CO concentration versus engine speed. Experiments show that alcohol blends increased the CO emission, but the lowest CO emission was obtained from biodiesel. The lowest CO emissions were also at about 2200 rpm for each fuel. Biodiesel decreased CO emission as 38,14% in comparison with diesel fuel. This is due to effect of the complete combustion because of the presence of the oxygen molecules in Biodiesel. However, it was shown that CO emission increased by 106,1% and 38,88% for B30M20 and B30P20, respectively when compared to diesel fuel. The reason for higher emissions is that alcohols have a high vaporization energy requirement, which causes incomplete combustion. It is believed that the higher alcohol concentration in the blend fuels could contributes to the higher CO emissions. This is parallel to a study conducted by Lei Zhu et al. [16] and Yılmaz and Vigil [9].

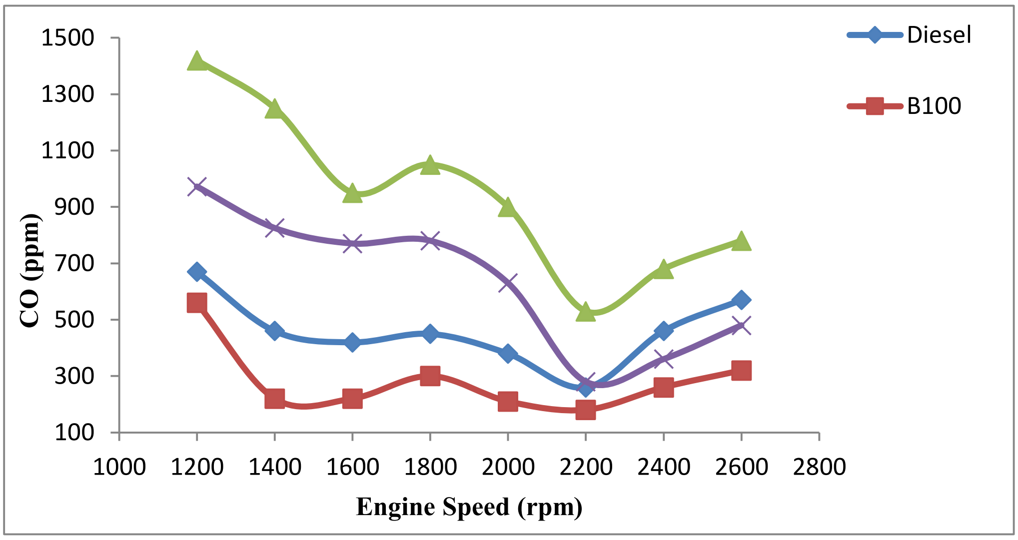

Fig.6. The variation of CO emission versus engine speed

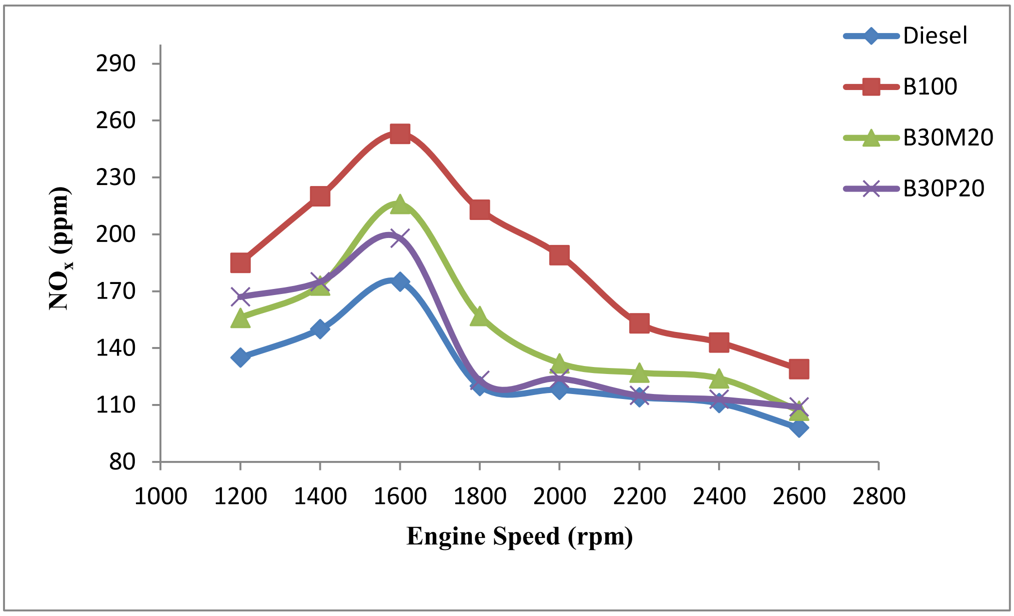

Fig.7. The variation of nitric oxide emission versus engine speed

As can be seen from the Figure 7, Of these blends, diesel fuel had the greatest reduction in NO_x emissions, which is consistent with earlier reports by the authors [10-16]. NO_x emissions of biodiesel were obtained higher than that of diesel fuel and the other blends. NO_x emissions increased as 45.44%, 16.75% and 10.09% in relation to conventional diesel for B100, B30M20 and B30P20, respectively. Alcohol additives improved the NO_x emission characteristics when compared with B100 due to its higher heat of vaporization; therefore, it reduces the peak temperature inside the combustion chamber leading to lower NO_x emissions.

4. Conclusions

In this study, the influence of methanol and propanol in 20% by volume in a B30 blend on performance and emission characteristics of a four cylinder, four stroke diesel engines have been investigated. Fuel properties of SFME, diesel fuel and alcohol blends were also determined. The following conclusions can be drawn;

- A high concentration of alcohol 20% by volume diluted in B30 blend fuel significantly reduced viscosity and density of the B30 blend fuel.
- Lower brake power was noticed when operating with B30M20 and B30P20 blend due to the lower energy content of methanol and propanol.
- Compared to the diesel fuel, all blends yielded an increase in BSFC which was roughly inversely proportional to the energy content of the blends. Especially, an increase in brake specific fuel consumption (BSFC) of 19-22% was observed when the engine was fueled with B30P20 and B30M20, respectively.
- Alcohol additives improved the NO_x emission characteristics when compared with B100. But higher carbon monoxide (CO) was observed in the blends of B30M20 and B30P20 when compared to the biodiesel and mineral diesel.
- As a result, the study indicated that propanol is more effective as additive than methanol and might be a feasible additive for biodiesel improvement in terms of balancing of the NO_x emissions.

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