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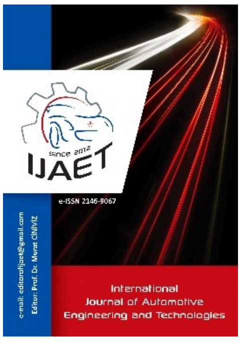

Original Research Article

Investigation of the Effects of Linseed Oil Biodiesel and Diesel Fuel Blends on Engine Performance and Exhaust Emissions

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ABSTRACT

In this study, linseed oil was obtained with the aid of screw presses and linseed oil biodiesel (B100) (linseed oil methyl ester) production was performed by transesterification method. Linseed biodiesel was blended with regular diesel fuel at different ratios as B2 (98% diesel + 2% biodiesel), B5 (95% diesel + 5% biodiesel), B20 (80% diesel + 20% biodiesel), B50 (50% diesel + 50% biodiesel). Fuel properties tests were performed on all fuels. Results revealed that engine performance values of linseed biodiesel and fuel blends were similar with the standard diesel fuel. With regard to maximum torque, while the highest value was obtained as about 59.6 Nm at 1000 rpm with diesel fuel, the value was observed as about 53.8 Nm at 1200 1/min with B100 fuels. The highest maximum power output was recorded as approximately 10.96 kW at 2100 rpm with diesel fuel and as approximately 10.23 kW at 2000 rpm with B100 fuels. With regard to minimum specific fuel consumption, while the lowest value was measured as about 231.36 g/kWh at 1000 rpm with diesel fuel, the value was measured as about 296.73 g/kWh at 1200 rpm with B100 fuels. Exhaust emissions are generally improved by the addition of linseed biodiesel to diesel fuel.

Keywords: Biodiesel, biodiesel – diesel fuel blends, linseed-flaxseed, linseed oil, transesterification

1. Introduction

The number of studies on energy has recently been increasing. Just because of depletion and environmental impacts of fossil fuels, researches on alternative energy sources have gained a great significance and acceleration. There is a significant increase in number of studies on alternative energy sources in Turkey [1].

Fossil fuels have the greatest share in primary energy sources and these sources are distributed throughout the world in an unbalanced fashion. Such a case made some countries advantageous, but made some others dependent on those advantageous ones. Such a dependence solidified even more with the increasing energy demands of dependent countries. Therefore, countries are now in search for appraisal of their own energy sources and they are trying to diversify their energy sources to reduce their dependency on foreign countries and to provide supply security [2].

Biofuels are produced from new or used vegetable oils or animal fats through chemical methods. These environment-friendly renewable liquid fuels are also called as biodiesel [3]. Biodiesel is produced from raw or refined oils of sunflower, rapeseed, soybean, safflower, maize, linseed or the other oil-seeds or from animal fats through the reaction of an alcohol (methanol or ethanol) with the aid of a catalyzer (acidic, basic or enzymatic). It is used as a renewable fuel.

Biodiesel is quite similar with petroleum diesel fuels in physical and chemical aspects. Biodiesel can either be used alone in diesel engines or blended with petroleum diesel fuels. Pure biodiesel and diesel-biodiesel blends can be used in diesel engines without any modifications or with slight modifications on engine. While pure biodiesel is entitled as B100, 20% biodiesel – 80% diesel blend is entitled as B20 [4].

In this study, it was aimed to compare the results of fuel characteristics, engine performance and exhaust emissions of linseed biodiesel mixed with diesel fuel in different ratios.

1.1. Improvement of fuel characteristics of vegetable oils

The studies about the improvement of fuel characteristics of vegetable oils initially focused on reducing oil viscosities. The different methods (heat and chemical) are used to reduce viscosity of vegetable oils [4]. The chemical methods used to reduce viscosity include dilution, micro emulsion formation, pyrolysis and transesterification. Of these methods, transesterification is the most common one. Transesterification, also called as alkalosis, is a process applied to reduce viscosity of triglycerides. The method includes esterification of vegetable oils with a monohydric alcohol (methanol, ethanol) a catalyzer (acidic, basic catalyzer and enzymes) through formation of fatty acid esters and glycerin as the primary products [5]. Although methanol, ethanol, butanol and amyl alcohols are able to be used in transesterification process, methyl alcohol is commonly used because of low costs, chemical and physical advantages [6].

1.2. Linseed

Linseed (*Linum usitatissimum*) is an annual crop with 30-100 cm plant height and blue flowers. The Latin name of the plant means “very beneficial plant”. It has been cultivated since the ancient Egyptians and used for various purposes. Seeds are 4-6 cm long, oval in shape, bright, reddish colored, unscented, tasty and oily [7].

Linseed seeds contain about 30-40% fixed oils including linoleic, linolenic and oleic acids, viscous plant juice, protein and glycoside called promarin. The linseed oil obtained from plant seeds is used in dyeing, linoleum production and nutrient industry. The pulp after oil extraction from the seeds is used as animal feed. The fibers are used in linen yarn production and textile industry [8].

Linseed contain about 6,5-10% moisture, 20-24% protein, 40-45% oil, 15-29% crude cellulose, 4,8-9% carbohydrate and 2,4-4% crude ash. Specific weight of linseed is between 0,924-0,926 g/cm^3.

Fatty acids ratio of linseed was indicated as between 30-40%. Fixed oils are largely composed of unsaturated fatty acids; linoleic acid contents are between 36-50%, linolenic acid contents are between 10-25% and oleic acid contents are between 13-30%. Saturated fatty acid contents are between 5-11% and meristic acid palmitic acid and stearic acid are the major components [9,10,11].

Table 1.1. Properties of linseed oil [12].

	Linseed oil
Refraction index	1,474-1,479
Melting point	0
Saponification value	189-194
Iodine value	175-185
Acid value	1-3
Non-saponified substance (%)	0,5-1,5

P. Karthikeyan et al., (2017), conducted an experimental study on a single-cylinder, four-stroke direct injection diesel engine with a output of 5.2 kW at 1500 rpm at various injection times 20, 23, 26 degrees BTDC for observe the performance and emission characteristics of direct injection diesel engine by using methyl esters of linseed oil and mixtures. Linseed biodiesel has better properties than petroleum diesel fuel. The results showed an increase in BTHE and a reduction in SFC compared to diesel. NOx was less in both biodiesel mixtures. The CO and HC emissions were slightly higher. They found that when injection increased, performance and emissions increased [13].

L. Narsinga Rao et al. (2017) evaluated the various performance and emission parameters like brake power (BP), brake specific fuel consumption(BSFC), Brake thermal efficiency (BTE), CO emissions, CO_2 emissions, HC emissions, NOx emissions and smoke were evaluated at different loads in a 4 stroke, single cylinder Diesel engine. These performance and emission parameters of diesel fuel were compared with B25, B50, B75 and B100. BTE for Linseed oil is lower by 34.60% compared to diesel. BSFC is higher by 54.76% compared to diesel at rated load. CO emission for Linseed oil 96% compared to diesel at rated load. The performance and emissions for 25% blend of Linseed oil is better than that of all other blends and is alternate fuel to diesel in C.I. Engine [14].

M. M. Tunio et al., (2018), produced linseed biodiesel by transesterification process and then mixed with blends of 10% (LB10), 20% (LB20) and 30% (LB30) volume of petro-diesel fuel (D100). The fuel properties of the produced biodiesel were found to comply with the ASTM standards. The specific fuel consumption (SFC) of the LB10 mixture was less than that of LB20 and LB30. The SFC of the D100 is slightly less than all the mixes. Brake Thermal Efficiency of LB30 is greater than D100 at the maximum load. It was found that the rate of heat distribution in all linseed biodiesel mixtures was less than in D100. Carbon monoxide, carbon dioxide and NOx emissions of linseed biodiesel mixtures are lower than D100. It is concluded that LB10 may be the most suitable alternative fuel for diesel engines and can be blended with petro diesel without engine modifications [15].

2. Material and Method

2.1. Test fuels

The study was carried out in six stages as follows.

- Obtaining linseed oil from linseed for methyl ester to be used as alternative fuel in diesel engine,
- Determination of physical and chemical properties of obtained linseed oil,
- Production of linseed oil methyl ester to be used as alternative fuel in diesel engine,
- Preparation of B2, B5, B20, B50 fuel mixtures,
- Determination of fuel properties of B2, B5, B20, B50, B100 and diesel fuel.
- Preparation of the engine tester and performed engine tests according to TS 1231 standard.

For biodiesel production from linseed oil, initially a screw press was used to obtain linseed oil.

Linseed oil (30 liters) was placed in an oil tank in pilot plant. From there, the oil was pumped into oil reactor. The reactor was heated until 55ºC. The temperature was kept constant throughout the reaction with a thermostat controller. A mixer was used for homogeneous oil temperature distribution in every place of the reactor.

Linseed oil was then supplemented with 6 liters methanol corresponding to 20% of oil volume and 105 gram NaOH catalyzer (as to have 3.5 g catalyzer per liter oil). The reaction was implemented in two phases. Methanol (6 liters) and NaOH catalyzer (105 gram) were dissolved in methoxide tank and send to reactor while mixing the oil. The mixture was mixed for 60 minutes. The mixture was rested for 2 hours and 2.5 liters glycerol was obtained. The raw biodiesel in reactor was sent to settling/washing tank, waited there for 15 hours to settle glycerol and to cool biodiesel. Following 15 hours, 2.5 liters more glycerol was obtained.

Biodiesel was subjected to washing with distilled water through misting. The objective of washing is to remove alcohol left in biodiesel without reacting, residual fatty acids, Na+, K+ ions, catalyzer substances and potential residual glycerol. During washing process, biodiesel temperature was 50ºC and distilled water temperature was also 50ºC and a total of 10 liters distilled water were used. Following the washing process, it was waited for 12 hours to settle the water. Settled water was then sent to waste water tank.

Heater of settling/washing tank was turned on and biodiesel was heated until the boiling point of water (100ºC). Water vapor was then discharged from the settling/washing tank through a vacuum pump. Biodiesel was dried at 100ºC for 2 hours. Linseed biodiesel was filtered through fuel filter connected to biodiesel tank. In this way, biodiesel was produced from linseed oil. Resultant biodiesel was blended with diesel fuel to get B2, B5, B20 and B50 blends.

Linseed oil, methyl ester of linseed oil (B100), blends of B50, B20, B5, B2 and diesel fuel were analyzed at Biodiesel Laboratory of Agricultural Faculty at Selçuk University. Analysis results are provided in Table 2.1. Following the transesterification of linseed oil methyl esters, fuel characteristics of B2, B5, B20, B50 and B100 blends were compared in accordance with TS EN 14214 for B100 and with TS 3082 EN 590 for blends and color characteristics were compared in accordance with ASTM standards. It was observed that density, viscosity, flash point, water content, copper strip corrosion and color analyses were all within limit values.

Table 2.1. Analysis results for linseed oil, B100, B50, B20, B5, B2 and diesel fuels

	Diesel	B100	B50	B20	B5	B2	Crude Linseed Oil
Density 15 °C (g/cm³)	0.826	0.897	0.861	0.840	0.839	0.831	0.933
Kinematic Viscosity 40 °C (mm²/s)	2.822	4.274	3.3	3.024	2.877	2.851	26.922
Flash Point (°C)	60	148	78	72	67	66	>200
Water Content (mg/kg)	8.793	489.42	238.14	85.40	40.68	31.13	522.37
pH	6	5.5	5.6	5.7	5.8	5.9	6.5
Color test (ASTM)	<0.5	1.1	0.8	0.6	0.5	0.5	2.2
Calorie Value (MJ/kg)	47.5	39.56	42.27	46.66	47.26	47.39	41.018
Cloud Point (°C)	-12	-4	-6	-8	-10	-11	-
Pour Point (°C)	-28	-12	-16	-19	-22	-24	-
Cold Filter Plugging Point (°C)	-20	-2	-9	-12	-13	-13	-
Copper Strip Corrosion	1a	1a	1a	1a	1a	1a	1a

2.2. Test apparatus and experimental setup

Diesel engine and hydraulic dynamometer given to specifications in Table 2.2 was used in the tests. Mobydic – 5000 model gas analyzer given to technical properties in Table 2.3. was used for exhaust gas measurements.

The experiments were performed in experimental setup shown schematically in Figure 2.1. The tests for all test fuels were performed with 100 rpm intervals between 1000-2200 rpm by changing engine load when the engine was in full gas position.

Table 2.2. The specifications of test engine and hydraulic dynamometer

Super Star Engine	Units	Value
Working principle	---	4 stroke, direct injection
Cylinder Bore	mm	108
Stroke	mm	100
Cylinder Number	---	1
Cylinder Volume	l	0.92
Compression Ratio	---	17:1
Maximum Power	HP	15 (2100 min^{-1})
Maximum Torque	Nm	60 (1100 min^{-1})
Maximum Speed	min^{-1}	2600
Cooling System	---	Water Cooling
Injection Advance	kg/cm^2	175
Injection Advance	degree	28-35 ^{0} (Crank Shaft angle)
Technical specifications of hydraulic dynamometer		
Maximum torque	Nm	1700
Maximum speed	Rpm	7500

Table 2.3. The specifications of exhaust gas analyzer

Measuring Range	Unit	Value
CO	%Vol	0 – 10
CO_2	%Vol	0 – 20
HC	ppm Vol	0 - 20000
O_2	%Vol	0 – 21
NO_x	ppm	0 – 500
SO_2	ppm	0 – 500
Lambda (λ)	---	0 - 5

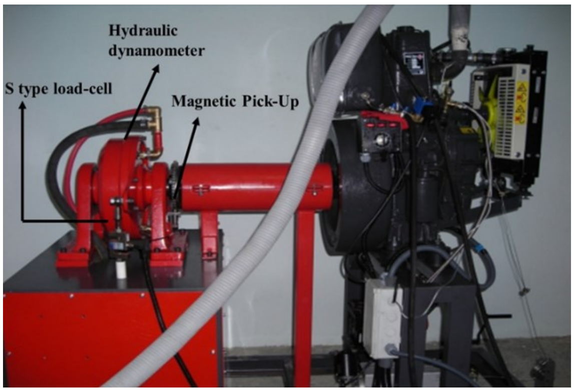

Figure 2.1 Engine and hydraulic dynamometer used in experiments

3. Results and Discussion

3.1. Comparison of engine torque values

Effective torque values received from flywheel with the use of different fuel blends were compared in Figure 3.1. Among the fuels, the greatest torque value was obtained from 1000 rpm engine speed in B2 fuels, from 1100 rpm in B5 fuels, 1400 rpm in B20 fuels and 1200 rpm in B50 and B100 fuels. When the pure biodiesel was compared with biodiesel blends, it was observed that torque value obtained from fuel blends decreased as compared to diesel fuel. Such a decrease average was about 2.28% in B2 fuels, 5.21% in B5 fuels, 7.00% in B20 fuels, 8.00% in B50 fuels and 9.51% in B100 fuels. As it can be seen from the Figure 3.1, the decrease ratio in engine torque values increased with increasing biodiesel ratios in fuel blends.

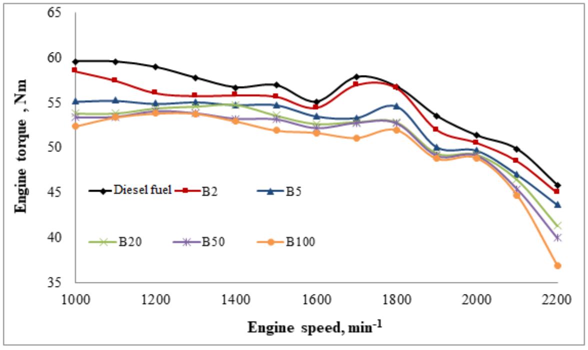

Figure 3.1. Engine torque value for diesel, B2, B5, B20, B50 and B100 fuels

The major important causes of decrease at engine torque with using biodiesel can explain with its lower calorific value compared to diesel fuel. Engine torque decreased by rising of biodiesel rate in blends owing to a decrease in heat energy in cylinder at burn-end due to decline of lower heating value. Furthermore, high density and viscosity of biodiesel caused bad spray characteristics such as higher droplet diameter, less amount fuel injected etc. Therefore, combustion worsen, and torque is decreased [16, 17].

3.2. Comparison of effective power changes

The effects of biodiesel on engine power calculated based on torque values are presented in Figure 3.2. According to test values of fuel blends, the greatest power value was achieved at 2100 rpm in diesel fuel, at 1800 rpm in B2 fuels and at 2000 rpm in B5, B20, B50 and B100 fuels. In general, engine power values decreased with the use of biodiesel. As compared to diesel fuel, such a decrease was measured as 2.21% in B2 fuels, 0.3% in B5 fuels, 1.54% in B20 fuels, 1.00% in B50 fuels and 1.21% in B100 fuels.
The decrease ratios in engine power increased with increasing engine speeds and biodiesel ratios.
The major cause of decrease in effective power with rise of biodiesel ratio within blends is their lower calorific value. Besides, biodiesel's bad flow properties effected combustion negatively [18, 19].

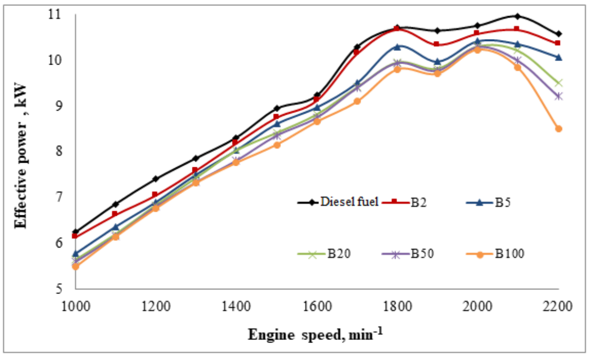

Figure 3.2. Effective power values for diesel, B2, B5, B20, B50 and B100 fuels

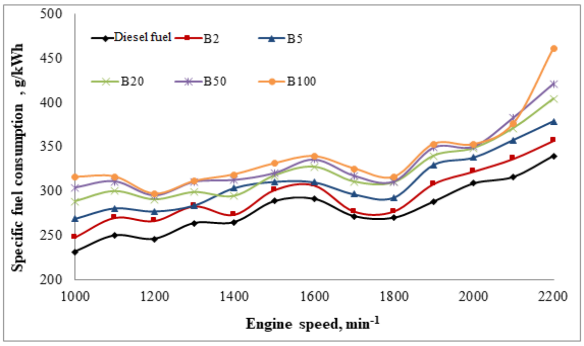

Figure 3.3. Specific fuel consumption values for diesel, B2, B5, B20, B50 and B100 fuels

3.3. Comparison of specific fuel consumption values

The amount of fuel consumed per unit power output is expressed as specific fuel consumption. The effects of biodiesel on specific fuel consumptions are presented in Figure 3.3. According to tests carried on all fuels, the lowest specific fuel consumption was obtained from 1000 rpm in diesel, B2, B5 and B20 fuels and from 1200 rpm in B50 and B100 fuels. In general, specific fuel consumptions increased with the use of biodiesel. As compared to diesel fuel, such an increase was measured as 5.5% in B2 fuels, 11.00% in B5 fuels, 16.00% in B20 fuels, 19.1% in B50 fuels and 21.63% in B100 fuels. As reported by P. Karthikeyan et al (2017) and L. Narsinga Rao et al. (2017) increasing specific fuel consumption values were observed with increasing biodiesel ratios in blends.

Biodiesel increased specific fuel consumption due to bad combustion performance quality as well as its lower calorific value [20,21].

3.4. Comparison of exhaust gas temperature values

The effects of biodiesel on comparison of exhaust gas temperature are presented in Figure 3.4. According to tests carried on all fuels, the highest comparison of exhaust gas temperature was obtained from 1900 rpm in for diesel fuel and all blends. In general, comparison of exhaust gas temperature increased with the use of biodiesel. As compared to diesel fuel, such an increase was measured as 4.3% in B2 fuels, 6.29% in B5 fuels, 10.26% in B20 fuels, 13.85% in B50 fuels and 16.65% in B100 fuels. The oxygen in biodiesel is caused almost full combustion. Therefore, combustion efficiency is improved owing to oxygen. Exhaust gas temperature increased due to shorten of combustion duration and the better combustion [22, 23].

3.5. Comparison of CO emission values

The effects of biodiesel on comparison of CO emission values are presented in Figure 3.5. In general, comparison of CO emission values decreased with the use of biodiesel. As compared to diesel fuel, such a decrease was measured as 3.9% in B2 fuels, 6.86% in B5 fuels, 18.33% in B20 fuels, 30.65% in B50 fuels and 58.34% in B100 fuels. Decreasing comparison of CO emission values were observed with increasing biodiesel ratios in blends. Similar results were also reported by P. Karthikeyan et al. (2017) and M. M. Tunio et al (2018). Biodiesel has lower stoichiometric air/fuel ratio. Therefore, it needs lower oxygen for burning. The oxygen in biodiesel caused that C atoms found enough O atoms and they formed CO_2. Hence, CO emission values of biodiesel and its blends decreased due to oxygen contents compare to diesel fuel [24,25].

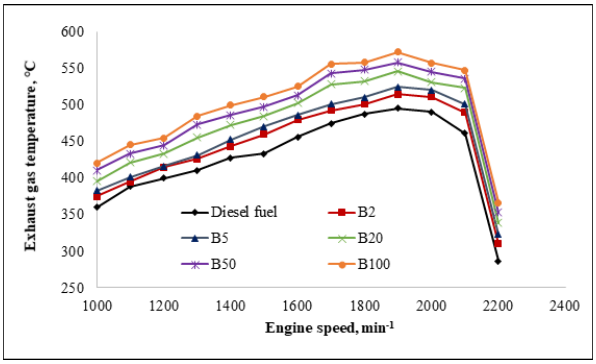

Figure 3.4. Exhaust gas temperature values for diesel, B2, B5, B20, B50 and B100 fuels

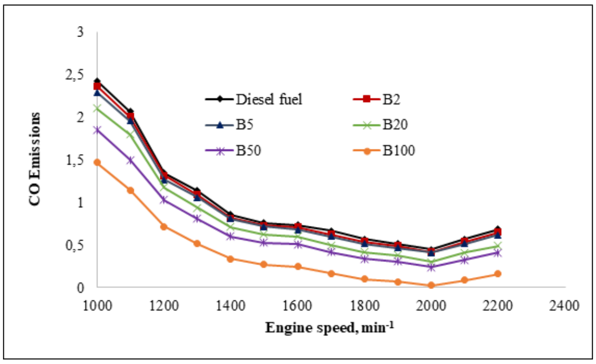

Figure 3.5. Comparison of CO emission values for diesel, B2, B5, B20, B50 and B100 fuels

3.6. Comparison of CO_2 emission values

The effects of biodiesel on comparison of CO_2 emission values are presented in Figure 3.5. In general, comparison of CO_2 emission values increased with the use of biodiesel. Similar results were obtained in the study of M. M. Tunio et al (2018). As compared to diesel fuel, such an increase was measured as 7.50% in B2 fuels, 23.30% in B5 fuels, 44.71% in B20 fuels, 53.89% in B50 fuels and 68.04% in B100 fuels. Increase of CO_2 emission values by use biodiesel can explain that its C atoms amount higher than that diesel fuel [26, 27].

3.7. Comparison of HC emission values

The effects of biodiesel on comparison of HC emission values are presented in Figure 3.7. In general, comparison of HC emission values decreased with the use of biodiesel. Karthikeyan P. et al. (2017), reported that due to the less oxygen content in the biodiesel mixes, slow burning occurred and thus they released less hydrocarbons. As compared to diesel fuel, such a decrease was measured as 6.55% in B2 fuels, 16.99% in B5 fuels, 25.99% in B20 fuels, 41.55% in B50 fuels and 58.11% in B100 fuels. Increase of exhaust gas temperature due to biodiesel's oxygen contents caused decrease of HC emission. Besides, HC emissions decreased due to earlier combustion of biodiesel [28,29].

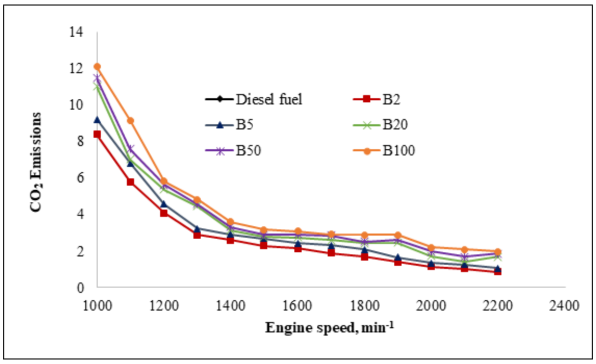

Figure 3.6. Comparison of CO_2 emission values for diesel, B2, B5, B20, B50 and B100 fuels

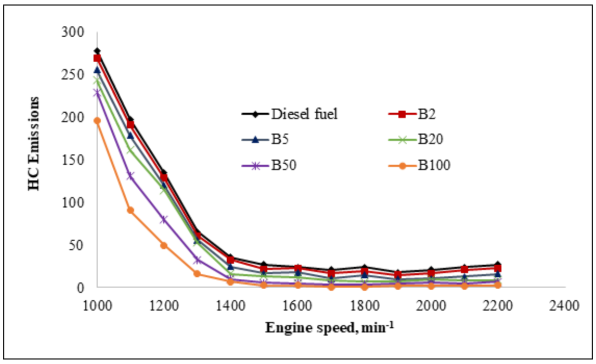

Figure 3.7. Comparison of HC emission values for diesel, B2, B5, B20, B50 and B100 fuels

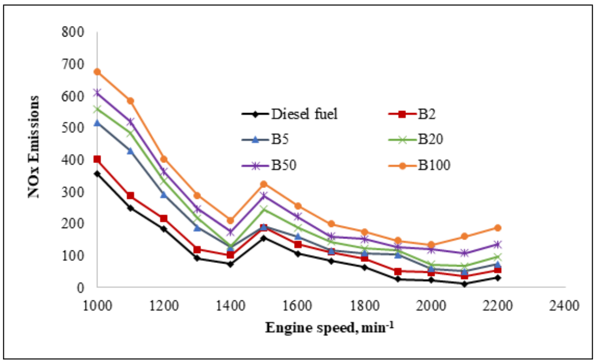

Figure 3.8. Comparison of NOx emission values for diesel, B2, B5, B20, B50 and B100 fuels

3.8. Comparison of NOx emission values

The effects of biodiesel on comparison of NOx emission values are presented in Figure 3.8. In general, comparison of NOx emission values increased with the use of biodiesel. Karthikeyan P. et al. (2017), reported that NOx emissions were lower for all biodiesel mixtures compared to pure diesel. As compared to diesel fuel, such a rise was measured as 26.2 % in B2 fuels, 65.2 % in B5 fuels, 90.2 % in B20 fuels, 120.9 % in B50 fuels and 156.7 % in B100 fuels.

NOx emissions increased due to raising exhaust gas temperature with using biodiesel. Because, N and O atoms react at high temperature. Besides, oxygen content of biodiesel provided more O atoms for N atoms [16,29].

4. Conclusions

The fuel properties were all within limit values for all fuels. The performance values achieved by using biodiesel and biodiesel blends in diesel engines were quite close to the values obtained from standard diesel fuels. The linseed biodiesel had similar physical characteristics with the standard diesel fuel.

For linseed oil, total fatty acid content was 10.79%, total effective unsaturated fatty acid content was 20.34% and total polyunsaturated fatty acid content was 68.87%.

Test results revealed that maximum power output was 10.96 kW with regular diesel fuel, the value was 10.67 kW with B2, 10.41 kW with B5, 10.3 kW with B20, 10.28 kW with B50 and 10.22 kW with B100. While the specific fuel consumption was about 231.36 g/kWh for regular diesel fuel, the value was 247.51 g/kWh for B2, 268.77 g/kWh for B5, 288.28 g/kWh for B20, 294.88 g/kWh for B50 and 296.73 g/kWh for B100.

Exhaust gas temperature, CO_2 and NOx emissions are observed to be higher for linseed biodiesel fuels compared to diesel. Linseed biodiesel mixture fuels have lower HC and CO emissions than diesel. As result, this study is show that with linseed biodiesel adding to diesel fuel, exhaust emissions was generally improved.

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