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Analysis of the Performance and Emission Characteristics of Biokerosene with 2-Ethylhexyl Nitrate Additive

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Abstract: The increase in population and living standards has sparked to mobility of people. Therefore, mobility of the people who enhanced welfare causes a raising in travel activities. Such a demand growth results in the accumulation of the energy requirement. In parallel, leads to developing greenhouse gas (GHG) reduction strategies. To decrease the GHG in the aviation sector comes into prominence nowadays. Emissions from the aircrafts that using as the transportation medium are related to the fuel characteristics. In this sense, growing attention of using biokerosene instead of the fossil based kerosene is encountered in some air carriers. In this study, biodiesel produced via transesterification manner and obtained from waste frying oil was blended with fossil based kerosene in volumetrically (B60K40: 60% waste frying oil methyl ester and 40% fossil based kerosene). Then, 1000 ppm, 2000 ppm, 3000 ppm and 4000 ppm amount of 2-Ethylhexyl nitrate (2-EHN) cetane improver have been added to the biokerosene mixture of B60K40. These fuels have been scrutinized emission and engine parameters in 4 cylinder, 4 stroke, turbocharged, direct injection compression ignition (CI) engine with the volume of 3.908 liters and 17/1 compression ratio at full load at 1400, 1600, 1800, 2000, 2200, 2400 and 2600 rpm. In consequence of the present study, biokerosene fuel (B60K40) with additive 2-EHN improves the emissions.

Keywords: Biokerosene, Emissions, Kerosene, Performance, 2-EHN

Introduction

The interest in alternative fuels have been increasing with the effect of environmental awareness and oil scarcity. Biodiesel, which is used as an alternative to petrol based diesel fuel, is derived from vegetable oils or animal fats as a fuel consisting of monoalkylesters of long-chain fatty acids (Cıldır & Canakcı, 2006). Transesterification, which is the most spread method of biodiesel generating methods, is also called alcoholysis, is the process of formation of fatty esters and glycerine by the reaction of triglyceride molecule with alcohol and base (Arslan & AlibaS, 2015). In terms of sustainability, the use of fatty acid methyl esters as biodiesel by blending with diesel fuel is a very common method, while the use of fatty acid methyl esters as biokerosene by blending with fossil-based kerosene fuel is not widespread. On the other hand, studies on the use of bio kerosene fuel are increasing. Kerosene i.e. white oil includes paraffin and naphtha, is obtained from crude oil distillation. Researchers from oil importing countries more particularly have studied about performance and emissions of blending kerosene-vegetable oils and kerosene-diesel fuels, because of the kerosene has lower price than gasoline and diesel fuels (Ekaab et al., 2019). Kerosene not only improves ignition characteristics at low temperatures, but also improves cold starting. Thanks to the low viscosity of kerosene, the injection duration is longer than diesel fuel, and it completes the combustion by improving atomization and injection (Gad et al., 2020). Bayindir et al., (2017) reported a decrease in NOx and CO emissions, while an increase in HC emissions, by using canola biodiesel and kerosene in B80&K20 and B80&K10&D10 fuel mixtures. They also stated that

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by adding kerosene or kerosene diesel fuel to biodiesel to reduce the density of biodiesel and similar properties to diesel fuel can be obtained (Bayındır et al., 2017).

Aydın et al., (2010) explained that, in terms of environmental pollution, biodiesel-kerosene mixture can be used as an alternative because its emissions are lower than fossil-based diesel and biodiesel-diesel mixtures. By adding kerosene to biodiesel fuel, engine power increased slightly and specific fuel consumption decreased compared to biodiesel-diesel mixtures, they explained that BK20 fuel has similar properties with fossil-based diesel fuel and that the low viscosity and high calorific value of kerosene, and the high cetane number and thermal efficiency of the mixture cause the increase in effective pressure and power of this fuel (Aydın et al., 2010). Aydın, (2016) determined that, among S90&K10, S75&K25 and S50&K50 safflower biodiesel and kerosene mixtures, the highest Pmax value and maximum heat release rate, the lowest specific fuel consumption and exhaust temperature were obtained with S50&K50 mixtures. In addition to this, as the kerosene ratio increases, NOx emissions decrease and there was a slight increase in CO and HC emissions compared to diesel fuel (Aydın, 2016). Roy et al., (2014), have investigated biodiesel–diesel and biodiesel–diesel-additive blends of 0, 5, 10, 20, 50 and 100 volume percent, and kerosene–biodiesel blends of 0, 5, 10, 20, 50 and 100 volume percent, and specific fuel consumption have increased in biodiesel–diesel and biodiesel–diesel-additive mixtures by increasing biodiesel ratio. With regard to emissions, they stated that CO emissions decreased with biodiesel-diesel and biodiesel-diesel additive blends at low and medium loads. As the biodiesel amount increases in biodiesel-diesel and biodiesel-diesel mixtures HC emissions decrease, but in kerosene-biodiesel mixtures, HC emissions only reduce under heavy loads. With the increment of biodiesel ratio in biodiesel-diesel and biodiesel-diesel additive mixtures, NOx emissions increase at medium loads, while in kerosene-biodiesel mixtures have lower NOx emissions at all loads (Roy et al., 2014).

Fuel additives are chemical compounds used to improve fuel properties, if less than <1% is added in refineries, they are called refinery (functional) additives, while if they are added in more than 1%, they are called blending components (Uyaroglu & Unaldı, 2021a). Ali et al., (2016) indicated that DTBP and EHN cetane improvers reduce NOx emission by 4% in B20 mixtures (Ali et al., 2016). Imdadul et al., (2016) NO emissions tend to decrease as the EHN ratio increases. They found that the addition of EHN increased the HC emissions while reducing the smoke emissions (Imdadul et al., 2016). Atmanlı, (2016) determined that the EHN cetane improver Diesel n-butanol mixture decreased the specific fuel consumption and NOx emissions by 1.07%, while increasing the CO and HC emissions by 15.7% and 11.10%, respectively. With the addition of EHN to the diesel fuel 1-pentanol mixture, NOx emissions decreased by 2.23%, HC emissions decreased by 17.25%, and CO emissions increased by 10.49% (Atmanlı, 2016). İleri, (2016) conducted the engine performance and emissions at 0%, 25%, 60%, 98% and 100% engine loads at 2200 rpm with the addition of 500, 1000 and 2000 ppm EHN to 70% diesel fuel, 10% sunflower oil and 20% n butanol or 1-pentanol mixtures. Thanks to the adding EHN to D70S20B10 and D70S20P10 fuels reduced NOx emissions by 2.28%-5.26% and 0.26-2.90%, respectively, while increasing CO emissions by 11.85-23.46% and 7.16%-23.41%, respectively. It was stated that while the addition of EHN to D70S20B10 fuel increased HC emission a little, the addition of EHN to D70S20P10 fuel reduced HC emission by 28.23%, 21.63% and 17.70% compared to D70S20P10 (İleri, 2016). Zhang et al., (2013) the addition of EHN slightly increases NOx emissions and significantly reduces THC emissions. The addition of EHN has little effect on CO emissions, but offers a better match between combustion noise and soot emissions (Zhang et al., 2013). Hess et al., (2004) determined that the addition of 1000 ppm 2-EHN reduced NOx emissions by 4.5% (Hess et al., 2004).

In this study, B60K40 mixture, that optimum biodiesel-kerosene mixture obtained previous work (Uyaroglu & Unaldı, 2021b), was added 1000 ppm, 2000 ppm, 3000 ppm ve 4000 ppm of EHN (Ethylhexyl Nitrate). These fuels (B60K40/1000, B60K40/2000, B60K40/3000, B60K40/4000) are tested under full engine load with 1400, 1600, 1800, 2000, 2200, 2400 and 2600 engine speeds in terms of the performance and emission characteristics.

Method

Methyl ester production and test fuel specification

In the transesterification reaction, 0.45% NaOH and 6:1 alcohol/oil molar ratio MeOH were used. The reaction took place for 60 minutes and at 60 °C. After the transesterification reaction is finished, ester was left to rest for 6-8 hours to separate the glycerin and then esters were washed with hot distilled water (85 °C) several times till the water and ester became clear. At the end of the washing process, it was dried at 120 °C for 30 minutes. Various properties of fuels that used in the tests were shown at Table 1.

Table 1. Fuel properties

Fuels	Kinematic viscosity (40 °C mm^2/s)	Density @15 °C (g/cm^3)	Lower Heating Value (kJ/kg)
B100	5.17	0.8831	37953
Diesel	3.02	0.8342	43524
Kerosene	1.42	0.7898	44407
B60K40	3.08	0.8464	40388
B60K40-3000	3.09	0.8479	40346

The engine and test devices specifications

Engine tests were conducted at full load in a brand of Tumosan 4-cylinder, 4-stroke, compression ratio 17/1, 3.908 liters turbocharged direct injection compression ignition (CI) engine at full load and at 1400, 1600, 1800, 2000, 2200, 2400 and 2600 rpm. The technical specifications of the Tumosan brand engine are shown in Table 2.

Table 2. Engine specification

Technical specification	Engine specification
Number of cylinder	4
Diameter of cylinder	104 mm
Stroke	115 mm
Total cylinder volume	3908 cm^3
Compression ratio	17:1
Maximum torque	295 Nm (at 1600 1/min)
Maximum power	62.5 kW (at 2500 1/min)
Maximum speed	2700 1/min
Cooling system	Water cooled
Injection advance	18 (CA°)
Injection pressure	230 Bar
Fuel pump	Bosch - Distributor Type

Table 3 has shown the specifications of the hydraulic dynamometer used in the tests.

Table 3. Engine dynamometer specification

Technical specification	Dynamometer specification
Max. Brake power	160 (HP)
Max. Brake moment	750 (Nm)
Max. speed	6000 (min^{-1})
Water amount	2.4 (m^3)
Direction of rotation	One direction
Engine Mounting Flange	Double

Table 4 consists of the features of the devices used for emission measurements.

Table 4. Emission devices

Emission	Measuring range	Precision
CO (% volume)	0-10	0.01
CO_2 (%volume)	0-20	0.01
HC (ppm)	0-2000	1
O_2 (%volume)	0-21	0.01
NOx (ppm)	0-5000	1
Lambda	0.5-2	0.001
k	0-20	1/m

Table 5 indicates the flowmeter specifications while Table 6 indicates the flowmeter indicator specifications.

Table 5. Flowmeter specifications

Flowmeter	Specifications
Measuring range (min^{-1})	0.005-1.5
Maximum pressure (bar)	100
Body, gear and shaft	AISI316
Precision	±%0.5
Output	NPN, signal output
Operating voltage (VDC)	5-24

Table 6. Flowmeter indicator

Flowmeter indicator	Specifications
Indicator	2x6 digit
Outputs (Vac)	2 relay output 8A@250
Supply voltage (Vac)	220

Engine performance characteristics calculation method

Effective power is calculated by the effective motor torque (Me) value and the motor speed (n) at which this torque is obtained. Equation 1 used to calculate the effective power (Pe) is shown below.

$$P_e = \frac{M_e.n}{9549.3} \text{ (kW)} \quad (1)$$

Effective specific fuel consumption (be) determines the amount of fuel spent (m_y) over an hour to obtain unit power (P_e), and calculated with equation 2.

$$b_e = \frac{\dot{m}_y.3600}{P_e} \text{ (gr/kWh)} \quad (2)$$

The thermal efficiency (η_{th}) of the engine represents the conversion rate of the fuel energy taken into the cylinder to power. H_u represents lower heating value. The thermal efficiency is calculated using Equation 3.

$$\eta_{th} = \frac{P_e \times 3600}{m_y \times H_u} \times 100 \quad (3)$$

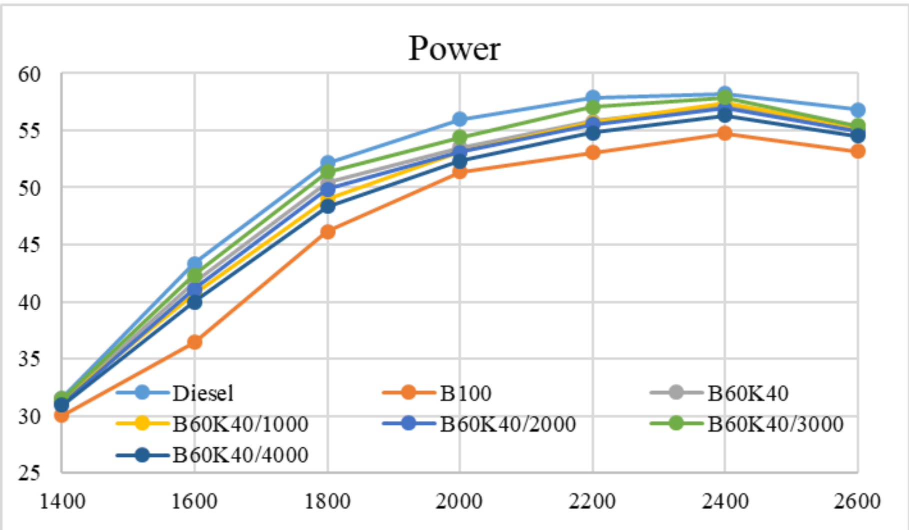

Figure 1. Engine power

Results and Discussion

Engine speed and power changes of the test fuels have shown at Figure 1. While the highest engine power was reached with diesel fuel at 58.2495 kW at 2400 rpm, the lowest engine power was reached with B100 fuel at 30.031 kW at 1400 rpm. This situation can be explained from the low calorific value of biodiesel In Figure 2, the torque changes with the speed of the test fuels are shown. Diesel fuel gives the highest torque value, and the B60K40/3000 fuel mixture has the highest torque value after diesel fuel. The highest torque value was realized with diesel fuel at 276.58 Nm at 1800 rpm, and the lowest torque value was realized with B100 fuel at 2600 rpm with 195.27 Nm. The fact that the torque values are lower than diesel is due to the high viscosity and lower heating value compared to diesel (Aksoy et al., 2018).

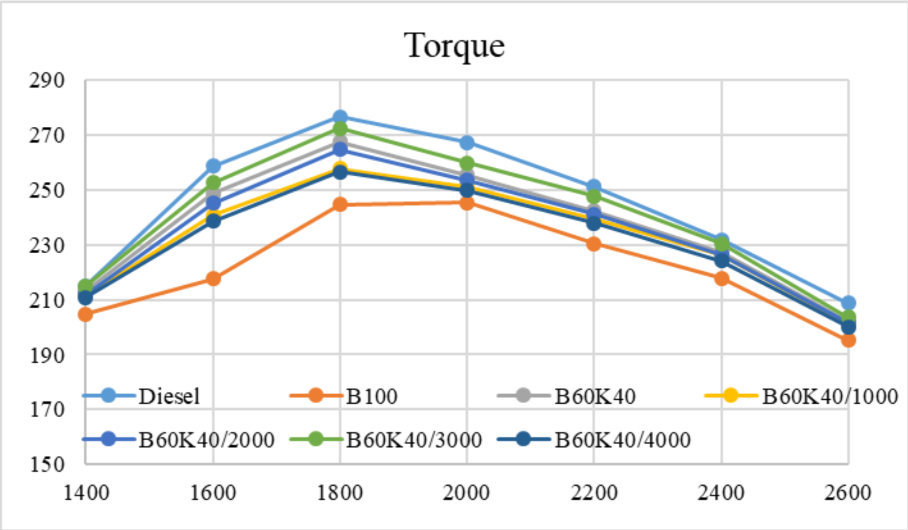

Figure 2. Engine Torque

The variation of brake specific fuel consumption (BFSC) according to engine speed is shown in Figure 3. Looking at the figure, it is seen that the lowest values are obtained with standard diesel fuel, while the highest values are obtained with B100, that is, 100% biodiesel fuel. It is known that the heating value causes this difference.

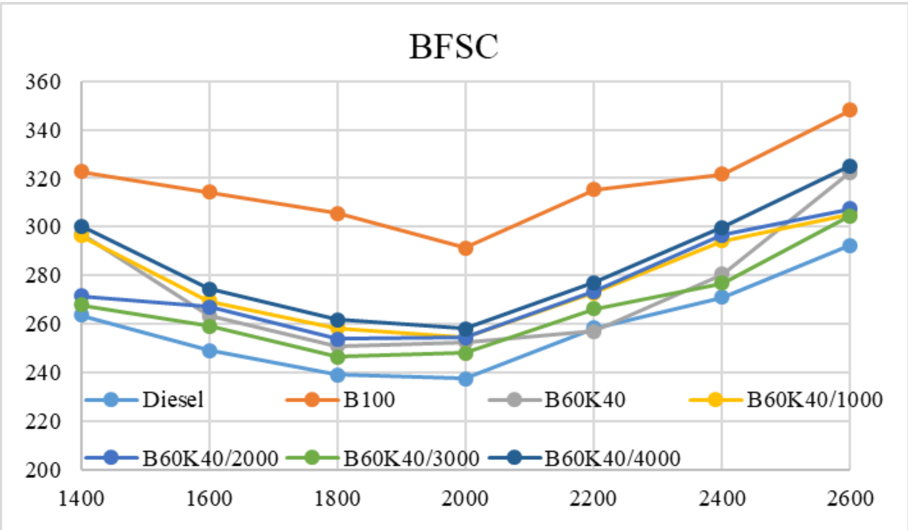

Figure 3. Brake specific fuel consumption

The relationship between thermal efficiency and engine speed is given in Figure 4. While the highest thermal efficiency was 36% with B60K40/3000 with 60% biodiesel-40% kerosene and 3000 ppm 2-EHN additive added, the lowest thermal efficiency was realized in B100 fuel with approximately 27%.

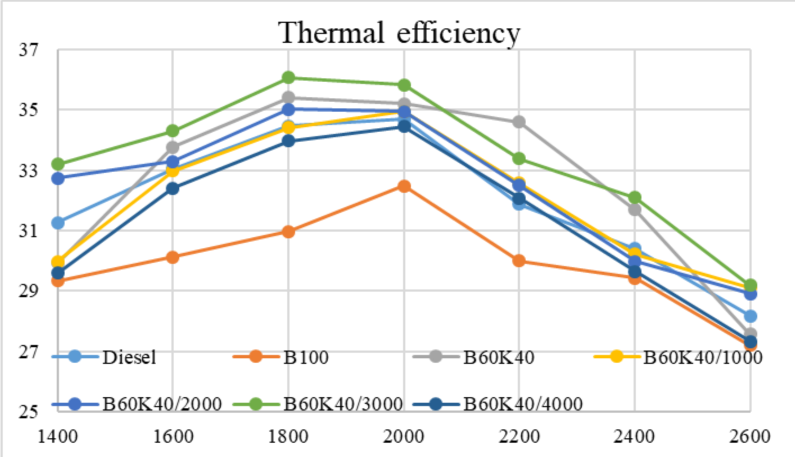

Figure 4. Thermal efficiency

Figure 5 shows the variation between exhaust gas temperature (EGT) and engine speed. While the highest exhaust gas temperature was measured at 470 °C and 2600 rpm in B100 fuel, the lowest value was measured at 370 °C at 1400 rpm in standard diesel fuel.

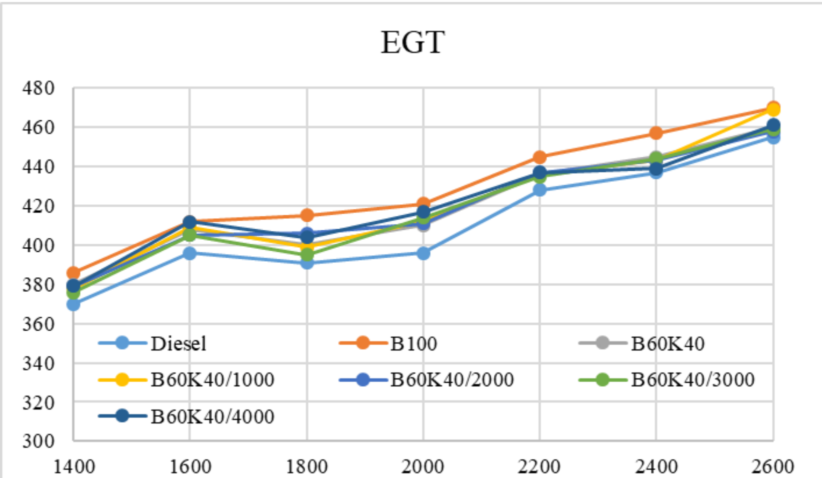

Figure 5. Exhaust gas temperature

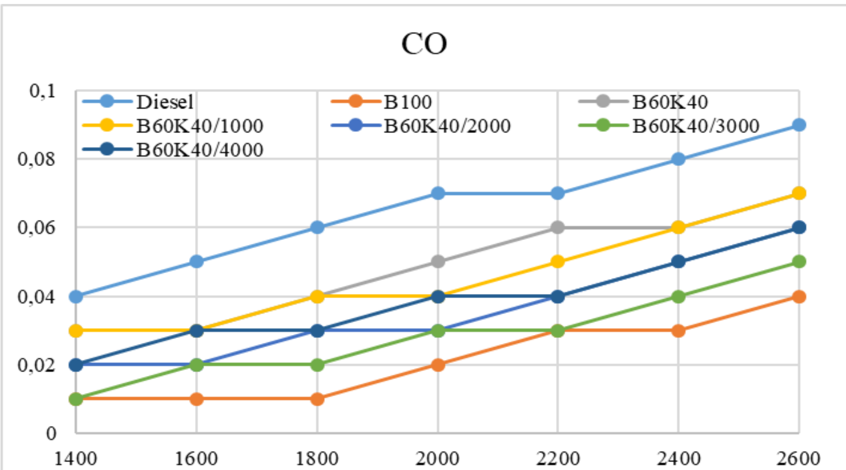

Figure 6. CO emissions

The variation of carbon monoxide (CO) emission depending on engine speed is given in Figure 6. The CO emission values of diesel fuel were higher than the other test fuels at the engine speeds indicated in the graph. Carbon monoxide is formed from incomplete combustion caused by insufficient oxygen (Sugozu, 2016). Owing to the oxygen content of biodiesel, CO emissions are less. The changing of hydrocarbon (HC) emissions at various engine speeds is shown in Figure 7. It is seen in the graph that the amount of HC emission of standard diesel fuel at various engine speeds is higher than that of other test fuels. Oxygen content in biodiesel is effective in reducing HC emissions.

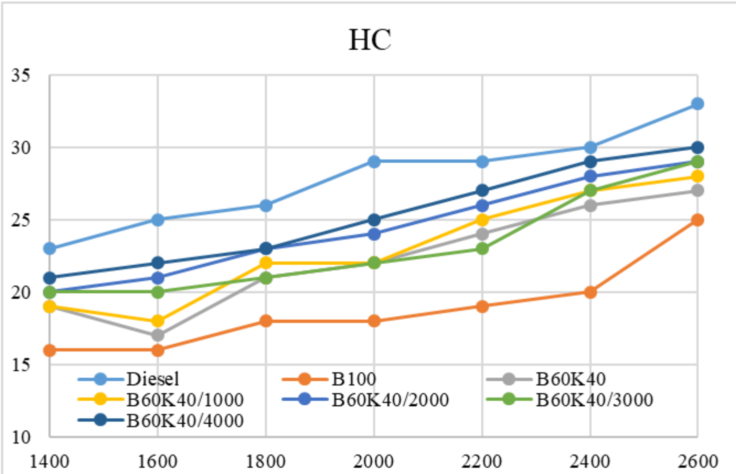

Figure 7. HC emissions

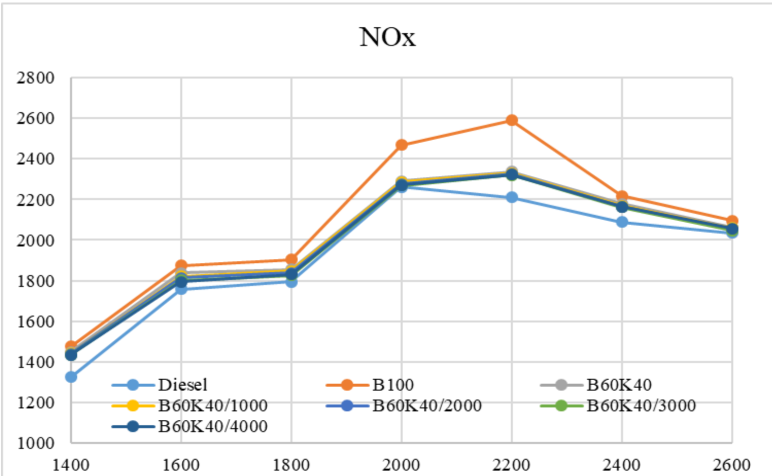

Figure 8. NO_x emissions

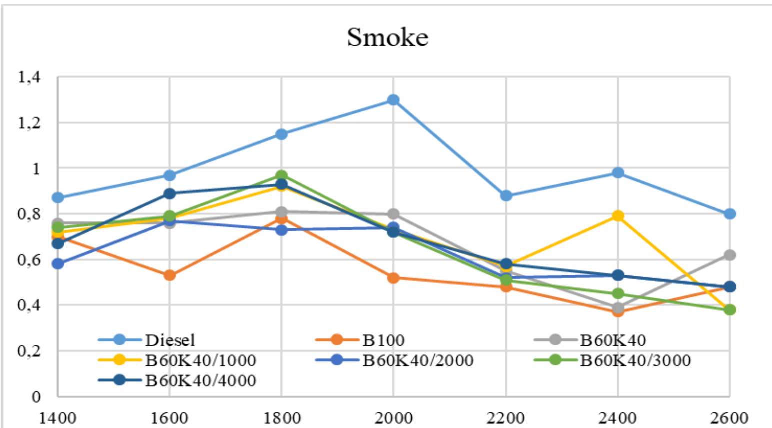

Figure 9. Smoke emissions

Figure 8 shows the nitrogen oxides (NOx) emission changes of the test fuels depending on the engine speed. The highest NOx emission values were determined in B100 fuel, and the lowest NOx emission values were determined in standard diesel fuel. By means of the N and O atoms reacting at elevated temperatures, NOx emission is emanated (Ors, 2020). According to Sathiyamoorthi et al. (2018), biodiesel blends with 2-EHN additives reduce NOx emissions by emitting less heat as they reduce the in-cylinder temperature

(Sathiyamoorthi et al., 2018). Ciniviz et al., (2017) 2-EHN reduces NOx emissions by increasing the cetane number (Ciniviz et al., 2017).

The changes in smoke emission were determined as in figure 9. While the highest soot emission value was seen in standard diesel fuel, the lowest value was observed in B100 fuel. The fact that biodiesel contains more oxygen improves oxidation reactions and prevents soot formation. According to Calam (2020), soot emissions are the result of thermal decomposition of long-chain hydrocarbons in regions where oxygen is scarce for combustion, and the oxygen content of biodiesel is effective in reducing soot emissions (Calam 2020).

Conclusion

In a Tumosan brand direct injection compression ignition (CI), 4-cylinder, 4-stroke, turbocharged engine with a compression ratio of 17/1, with an engine capacity of 3.908 liters, at full load at 1400, 1600, 1800, 2000, 2200, 2400 and 2600 rpm. 2-EHN that is a cetane improver, was added to B60K40 biodiesel-kerosene mixture at rates of 1000 ppm, 2000 ppm, 3000 ppm and 4000 ppm. Among these test fuels, the mixture with B60K40 and 3000 ppm 2-EHN; in terms of specific fuel consumption, engine power, engine torque and thermal efficiency, it showed values close to diesel fuel, and it was observed that it had lower emission values than diesel fuel in terms of emissions. In this respect, it is thought that it is possible to use B60K40-3000 ppm 2-EHN fuel mixture as an alternative fuel in diesel engines.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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