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PERFORMANCE AND EMISSION CHARACTERISTICS OF SESAME BIODIESEL BLENDS IN DIESEL ENGINE

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KEYWORDS

Sesamum indicum L., oil, energy, fuel, biodiesel.

ABSTRACT

Sesame (*Sesamum indicum* L.) oilseed needs to be studied in relation to the production of biodiesel and its application as an alternative to the soybean biodiesel used in Brazil. The aim of this study was to evaluate biodiesel blends (B0, B5, B10, B20, B40, B80, and B100) of sesame in the performance and emissions of engines. A few studies of sesame biodiesel in engines were found in the literature imparts novelty to the current study. The fuels were tested in a 5-kVA generator engine at loads ranging from 1000 to 6000 W. The results of the analysis showed that the increase in the sesame biodiesel blend caused a reduction in the specific fuel consumption (SFC), carbon monoxide (CO) emissions, and an increase in nitrogen oxide (NOx) emissions. The SFC of sesame biodiesel (B100) was 11% higher than that of diesel (B0). CO emissions increased 39% for diesel (B0) compared to sesame biodiesel (B100). However, B20 showed lower SFC than diesel and lower gas emissions than B80 and B100 blends. Therefore, sesame biodiesel, especially up to B20, is a viable alternative for the partial replacement of conventional diesel. Sesame biodiesel should be considered as a promising candidate for alternative fuels.

INTRODUCTION

The demand for energy and growing consumption of oil with increases in crude oil prices have led to economic growth worldwide (Atmanli et al., 2015; Leite et al., 2019). The growing energy demand is still highly dependent on fossil fuels, which produce gas emissions that influence global climate change, putting life on the planet and the perpetuation of species at risk (Atmanli et al., 2016; Saravanan et al., 2020; Yilmaz et al., 2022).

Experts and policymakers have been working to reduce the dependence on oil, increase fuel economy, and reduce emissions (Yilmaz et al., 2022). Although alternatives to electric mobility and hydrogen technology are increasingly being studied, transformations for vehicles still seem to be long term (Işik, 2021). Reducing emissions from fossil fuels is a major step in the fight against global warming (Odibi et al., 2019; Yesilyurt et al., 2020). This has led to research on obtain alternative fuels from renewable and ecologically correct sources, such as biodiesel (Odibi et al., 2019; Yesilyurt et al., 2020).

Biodiesel is renewable and has become a promising fuel for diesel combustion engines (Yilmaz et al., 2018). Hence, its use has become popular in recent years. It consists of methyl and ethyl esters of fatty acids (triglycerides), derived from vegetable oils such as jatropha, soy, canola, sunflower, cotton, and animal fats (Leite et al., 2019; Bassegio & Zanotto, 2020). Biodiesel is obtained by transesterification, and triglycerides react with a short-chain alcohol in the presence of a catalyst (Yesilyurt & Cesur, 2020). This fuel is non-toxic and biodegradable, with less exhaust gas emissions and a lower sulfur content. It still has the advantages of a low flash point, low volatility, low content of aromatic compounds, high lubricity, and 10 to 12% oxygen by weight (Noor et al., 2018).

Soybean constitutes most of the raw material that feeds the Brazilian biodiesel production chain, as approximately 70% of Brazilian biodiesel is produced from soy. Currently, soy has the advantage of meeting the domestic demand for biodiesel and has the most

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competitive price compared to other raw materials (César et al., 2019). However, regarding oil production per hectare, soybean is not the most attractive option for biodiesel production, considering the oil content of the seed compared to those of other oilseeds (Gongora et al., 2022). Thus, other unconventional oilseeds, such as sesame (*Sesamum indicum* L.), may be promising alternatives to increase the diversity of raw materials used for biodiesel production.

Sesame is one of the most cultivated crops in Asia and Africa (Chun et al., 2021). The oil is used in various applications in the food, chemical, cosmetic, phytotherapeutic, and pharmaceutical industries, and can also be used for the production of biodiesel. Sesame oil has oxidative stability when compared to most vegetable oils because of its fatty acid composition and the presence of natural antioxidants (Ghosh et al., 2019). In addition, sesame oil has a high degree of unsaturation (up to 85%) and thus has good cold flow properties and can be the most suitable option for blending with all other feedstock oils (Mujtaba et al., 2020). Arruda et al. (2016) verified that sesame oil showed itself a good option for production of biodiesel in the northeast of Brazil and physic-chemical properties evaluated for the biodiesel samples were in accordance with Brazilian legislation.

It is suggested in the literature that up to 20% biodiesel (B20) is the most acceptable blend ratio in alternative fuel blends (Atmanli et al., 2016; Yilmaz et al., 2022). Few studies have studied various blends of sesame biodiesel in engines to prove this theory and this imparts novelty to the current study. The aim of this study was to evaluate the performance and emissions of engines according to sesame biodiesel blends and engine load.

MATERIAL AND METHODS

Location

The experiments were conducted at the Sustainable Technologies Laboratory, State University of Western Paraná (UNIOESTE, Cascavel, PR, Brazil).

Production of methyl esters

Biodiesel was obtained via a transesterification reaction with potassium hydroxide (KOH) as the catalyst (1% of oil weight) and methanol as the alcohol (25% of oil volume). First, methanol and potassium were vigorously mixed for 10–20 min. Next, the formed potassium methoxide was mixed with oil in a round-bottom flask, stirred continuously using a magnetic stirrer, and maintained at a temperature of 60 °C. After the reaction, the flask content was transferred into a separatory funnel and left for 24 h to separate into two layers. After separation, the biodiesel was washed with warm distilled water. Finally, the biodiesel was placed in a forced-air circulation oven to remove the excess water content (Leite et al., 2019).

Biodiesel–diesel blend

The blends of sesame biodiesel and diesel considered were B5 (5% biodiesel), B10 (10% biodiesel), B20 (20% biodiesel), B40 (40% biodiesel), and B80 (80% biodiesel). The mandatory biodiesel–diesel blend in Brazilian is at least B10, and the goal for 2023 is to reach B30. Pure diesel oil (no biodiesel present) was used.

Biodiesel characteristics

The physical and chemical characterization of biodiesel (B100) and diesel (B0) were determined according to the Standard Test Method for Determination (ASTM) (Table 1)

TABLE 1. Physical and chemical characterization of biodiesel and diesel.

Variables	Color	Especific mass (kg m^{-3})	Flash point (ºC)	Karl Fischer water (ppm)	Freezing point (ºC)	Viscosity cSt (40 ºC)
Biodiesel	Yellow	883.2	186.1	976.88	–4.0	4.26
Diesel	Yellow	833.8	58.0	48.94	–9.0	2.44
Method	Visual	ASTM D 4052	ASTM D 93	ASTM D 6304	ASTM D 97	ASTM D 445
Specification limit	Yellow	820 – 853	> 38	< 200	–	1.5 – 6.0
Variables	Ester (%)	Total aromatics (%)	Olefins (%)	Benzene (%)	Toluene (%)	Glycerol (%)
Biodiesel	29.5	1.0	28.2	0.02	13.28	5.60
Diesel	0.0	4.1	3.6	0.06	1.82	0.00
Method	Infrared	Infrared	Infrared	Infrared	Infrared	Infrared
Specification limit	–	–	–	–	–	–

Engine tests

In this study, a BD-8500 E3 diesel cycle generator driven by a 13.0 hp engine was used, coupled to a generator with 7.5 kVA/6.0 kW of nominal power, with an output voltage of 240 V three-phase (Figure 1). To record data, an Eaton programmable logic controller (XV-102-D6-70TWR) equipped with a human-machine interface with a remote terminal unit (XN-GWBR-CANopen Marl Eaton) was used. In addition, a multifunctional meter for monitoring electrical parameters (DPM-C520 brand Delta) and a weighing indicator with a load cell (3107C, Alfa) were used. To connect the equipment, industrial network protocols (Modbus-RS485 and CAN-open) were used, presenting real-time information on the process in a supervisory system to monitor, present, record, and store the precepts of the generation system. The load used consisted of a bank of 15 finned resistors, each with a nominal dissipation of 1500 W/220V and, thus, a total power of 6 kW.

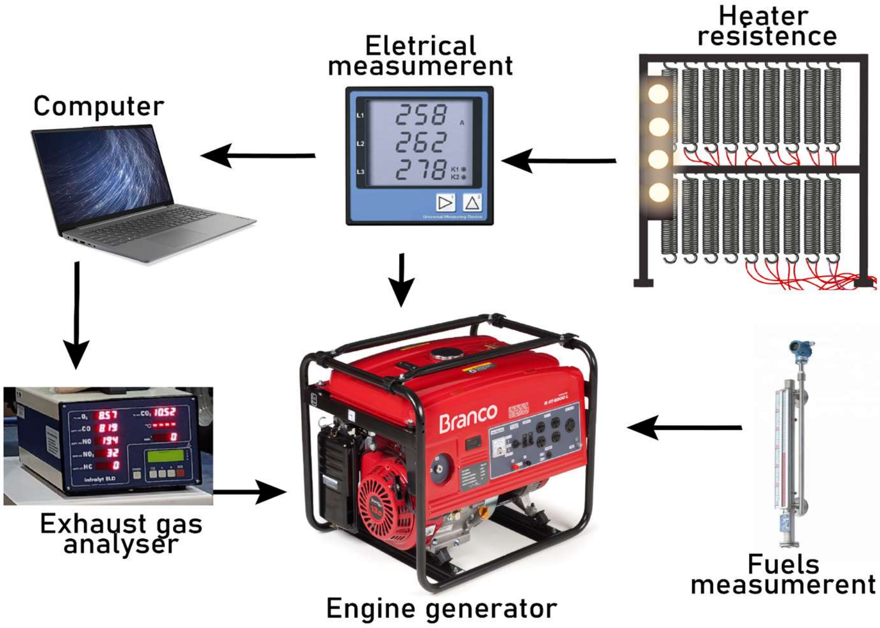

FIGURE 1. Schematic diagram of the system used with a diesel/generator cycle engine, resistive loads and biofuel.

The specific fuel consumption (SFC) was calculated using [eq. (1)].

$$SFC = (mi - mf) / Pe \times t \tag{1}$$

Where:

SFC is the specific fuel consumption in g kW^{-1} h^{-1};

mi is the fuel mass at the start of the test in g;

mf is the mass of the fuel at the end of the test in g;

Pe is the motor power in kW;

t is the consumption time in operating hours of the generator engine.

The main engine exhaust gases, carbon dioxide (CO_2), carbon monoxide (CO), and nitrogen oxide (NOx) were measured using a gas analyzer (SAXON, Infralyt ELD).

RESULTS AND DISCUSSION

The SFC of sesame biodiesel was higher than that of diesel (Figure 2). The use of biodiesel mixtures increased the amount of fuel required to obtain the same amount of brake power from the engine because an increase in the biodiesel content reduced the heating value. Therefore, it was expected that fuel with a higher biodiesel content in the blend would have a higher SFC compared to other blends (Yesilyurt et al., 2020). Özener et al. (2014) reported an increase in SFC between 9% soybean biodiesel (B100) and D100. According to Mofijur et al. (2013), the SFC of biodiesel and its blends is higher than that of diesel alone.

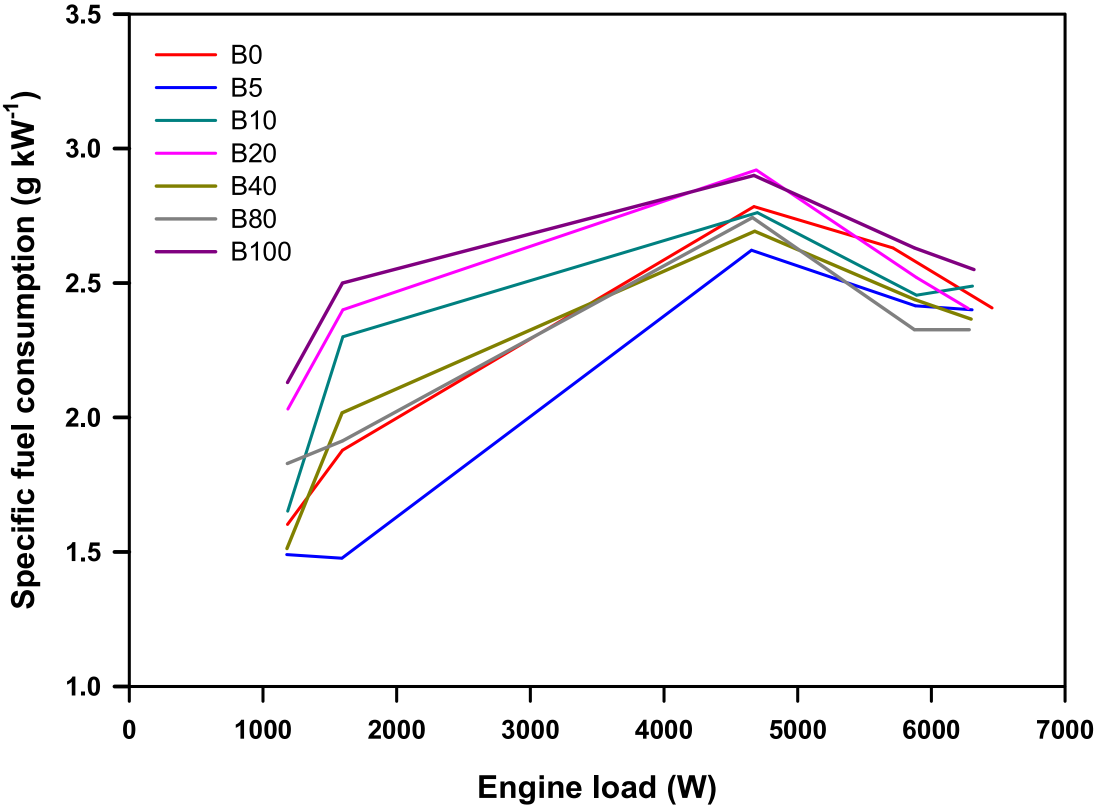

FIGURE 2. Specific fuel consumption (SFC) according to engine load and sesame biodiesel blends.

The higher SFC of pure sesame biodiesel (B100) can be attributed to the lower calorific value of biodiesel compared to that of diesel (B0). Therefore, it was expected that the biodiesel in the blend would have a higher SFC than diesel (Figure 2). According to Ilkılıç et al. (2011), the SFC of biodiesel increases with an increase in the safflower biodiesel content. The authors reported that the main reason for this increase was the lower calorific value of the biodiesel included in the mixture. As the lower calorific value of biodiesel is lower than that of diesel fuel, more fuel is injected from the fuel pump to reach a power equal to that generated by the diesel fuel, leading to an increase in the SFC (Simsek, 2020). Neat sesame biodiesel has high viscosity and density, which affects the atomization of the spray, leading to slower heat release and an increase in energy consumption, as the fuel required to produce the same power is greater (Thiyagarajan et al., 2020). In this sense, according to Atmanli & Yilmaz (2020), the addition of higher alcohol to biodiesel is one of the methods to reduce density and viscosity and improve the general properties of fuel mixtures. Yesilyurt et al. (2020) attributed the higher SFC to the lower heating value, higher viscosity, and higher density of biodiesel compared with those of diesel. The SFC decreased with increasing load for all fuels. This may be due to an increase in the energy production and the subsequent increase in the temperature inside the cylinder.

CO emissions increased for pure diesel (B0) compared to sesame B100 (Figure 3). Simsek & Uslu (2020a) observed that, at loads of 3000 W, the highest CO emission was achieved with D100, whereas the lowest CO emission value was achieved with B100. The oxygen present in biodiesel improves the burning of carbon molecules, leading to a more complete combustion (Aydın, 2020). At higher engine loads and the resulting higher combustion temperatures, the use of biodiesel results in a more efficient performance, while generating less CO emissions (Kivevele et al., 2011). The emission of CO from exhaust represents a loss of chemical energy during combustion owing to the incomplete burning of diesel fuel (Kalam et al., 2003; Deheri et al., 2020). In diesel engines, a high cetane number is a parameter that improves combustion. With the use of high-cetane fuels, the incomplete combustion rate decreases and the overall degree of combustion increases (Simsek & Uslu, 2020b; Selvan et al., 2021).

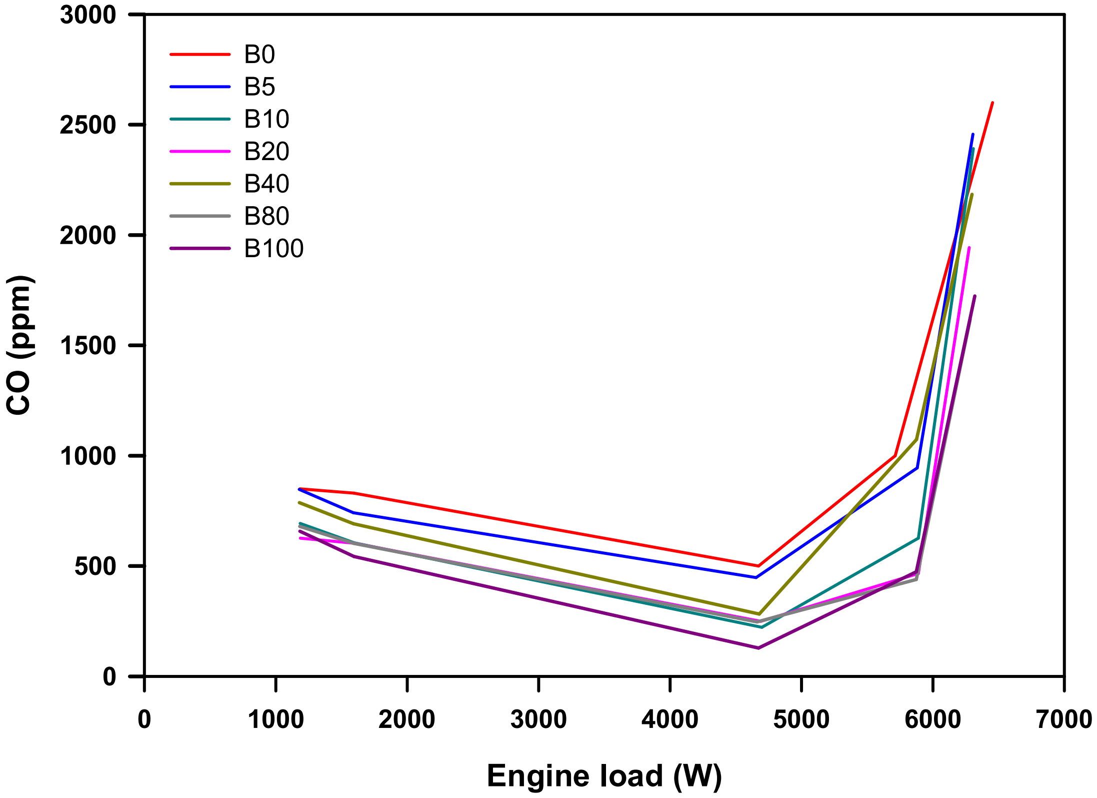

FIGURE 3. CO according to engine load and sesame biodiesel blends.

The CO_2 emissions from the combustion of sesame biodiesel were higher than those from the combustion of diesel oil (Figure 4). Sesame biodiesel releases more CO_2 than conventional diesel fuel because of the presence of oxygen in biodiesel. CO_2 emissions during the burning of hydrocarbon fuels is a sign of complete combustion (Yesilyurt et al., 2020). The CO_2 and CO emission formation mechanisms are opposite to each other. Therefore, under the same conditions, CO_2 emissions should increase while CO emissions decrease (Simsek & Uslu, 2020a). As shown in Figure 5, the amount of CO_2 increased with the engine load. The increase in CO_2 emissions with increasing load is due to an increase in the mass of biodiesel (Aydin & Bayindir, 2010). A decrease in CO_2 emissions is important in relation to global warming. Most researchers have recognized that the CO_2 emissions of biodiesel or biodiesel–diesel blends are greater than those of diesel fuels (Celebi & Aydın, 2018; Yesilyurt et al., 2020). However, CO_2 emissions generated by the use of biodiesel are offset by photosynthesis in the oil plants used for biodiesel production; therefore, biodiesel has not been evaluated as a contributor to global warming (Yesilyurt et al., 2020).

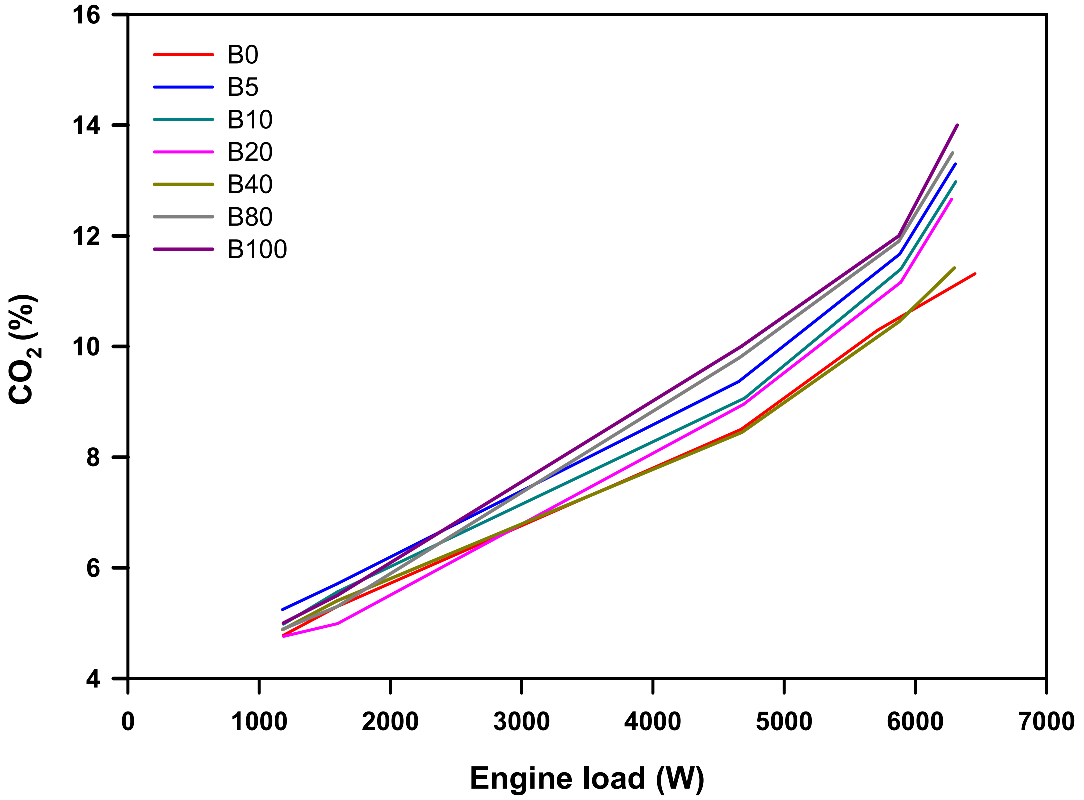

FIGURE 4. CO_2 according to engine load and sesame biodiesel blends.

In the present study, diesel (B0) produced lower NOx emissions than sesame biodiesel blends (Figure 5). A high oxygen concentration, residence time, and peak combustion temperature favor the formation of NOx (Mohsin et al., 2014). However, Nox have been reported by several researchers to increase with biodiesel temperature (Mofijur et al., 2014; Yesilyurt et al., 2020; Aydın, 2021) and in the presence of adequate oxygen in the mixture (Thiyagarajan et al., 2020). According to a review by Mofijur et al. (2014), the use of biodiesel from different oilseeds generally increases NOx emissions. High combustion temperatures and the presence of combustible oxygen during the combustion of mixtures cause higher NOx emissions (Aydin & Bayindir, 2010).

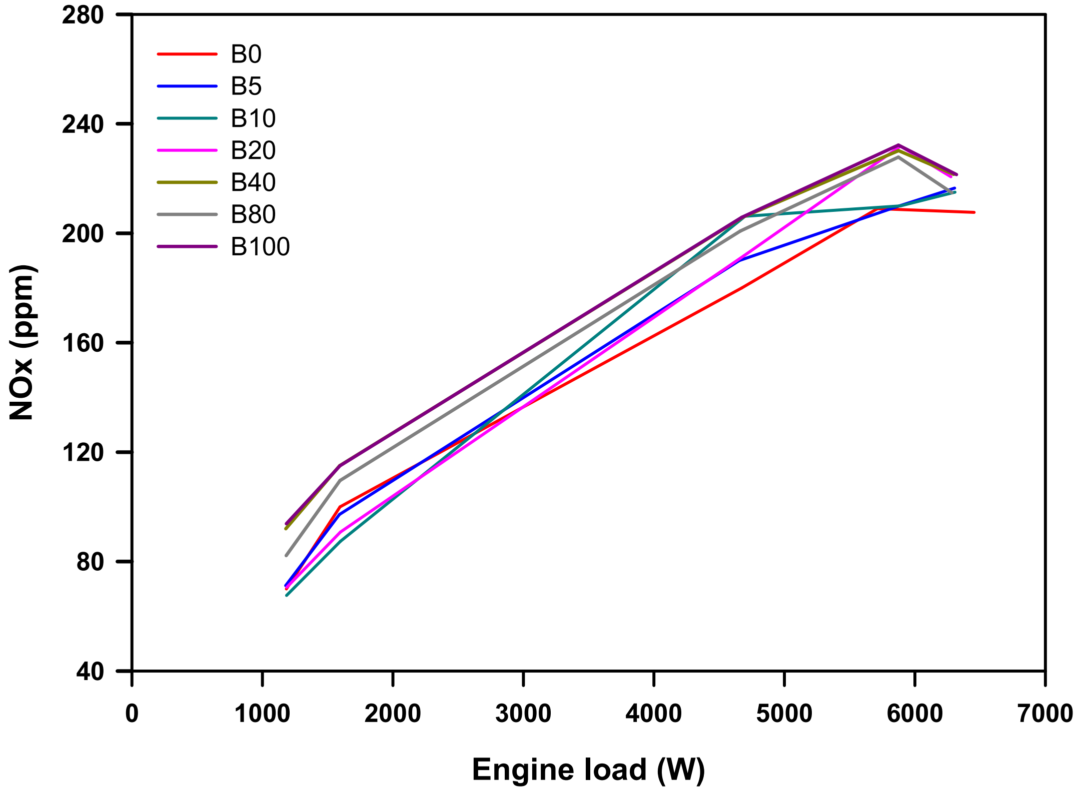

FIGURE 5. NOx according to engine load and sesame biodiesel.

CONCLUSIONS

In this study, the emissions and performance of a generator engine using sesame biodiesel blends were studied. An increase in the sesame biodiesel blend content caused a reduction in the SFC, CO emissions, and an increase in NOx emissions. Therefore, sesame biodiesel is a viable alternative for partial replacement of conventional diesel, especially up to B20. With this blend, lower SFC than diesel and lower gas emissions than B80 and B100 blends were observed. However, further investigations must be carried out with optimization methods and additives to make sesame biodiesel commercially viable.

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