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Engine Performance with Diesel-Biodiesel Blends Fuel and Emission Characteristics

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K E Y W O R D S

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A B S T R A C T

In this study, the sunflowers oil was utilized as for producing biodiesel via a chemical operation, which is called trans-esterification reaction. Iraqi diesel fuel suffers from high sulfur content, which makes it one of the worst fuels in the world. This study is an attempt to improve the fuel specifications by reducing the sulfur content of the addition of biodiesel fuel to diesel where this fuel is free of sulfur and has a thermal energy that approaches to diesel.20%, 30% and 50% of Biodiesel fuel were added to the conventional diesel. Performance tests and pollutants of a four-stroke single-cylinder diesel engine were performed. The results indicated that the brake thermal efficiency a decreased by (4%, 16%, and 22%) for the B20, B30 and B50, respectively. The increase in specific fuel consumption was (60%, 33%, and 11%) for the B50, B30, and B20 fuels, respectively for the used fuel blends compared to neat diesel fuel. The engine exhaust gas emissions measures manifested a decreased of CO and HC were CO decreased by (13%), (39%) and (52%), and the HC emissions were lower by (6.3%), (32%), and (46%) for B20, B30 and B50 respectively, compared to diesel fuel. The reduction of exhaust gas temperature was (7%), (14%), and (32%) for B20, B30 and B50 respectively. The NOx emission increased with the increase in biodiesel blends ratio. For B50, the raise was (29.5%) in comparison with diesel fuel while for B30 and B20, the raise in the emissions of NOx was (18%) and (3%), respectively.

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1. Introduction

In previous decades, biodiesel has received much attraction owing to its capability for replacing the fossil fuels that are likely to run out during this century. Particularly, the issues of environmental regarded with the emission of the exhaust gases via using fossil fuels also promote to use biodiesel, which has proved to be eco-friendly far more than fossil fuels. It is known that the biodiesel is a carbon neutral fuel, since the carbon the carbon presents in the exhaust is originally fixed from the atmosphere [1]. The highly usual common procedure for producing a biodiesel is trans-esterification the oil of the vegetable, the waste fats of the animal, and the waste greases (yellow color greases) of the restaurant with a short-chain alcohol. Such oils are described as one of the future contenders to carry out the required gap made via the fossil diesel fuels depletion [2]. Comparing to the traditional diesel fuels, the biodiesel is (100%) renewable. Nevertheless, such proportion is decreased to about (90%) when the balance in the mass is done or (95%) when the balance in the mass of carbon is done, if the fossil alcohol (commonly methanol) is utilized. The (CO_2) emissions should be considered for evaluating the biodiesel impact on the influence of the global greenhouse [3].

The effect of biodiesel on the emissions and performance has been addressed in a considerable number of publications and critical literature reviews [4]. Nevertheless, the majority of such investigations were performed under steady-state circumstances and on a calibrated engine for using the traditional diesel fuel. The circumstances of the biodiesel blends that are considered a big challenge in terms of the emissions and the management of the engine performance are remote from the steady-state circumstances if both the diesel and the biodiesel fuels are utilized. This fact joined to that related to the potential to optimize the modern engine control when biodiesel at high concentrations is used. Chaichan et al. [5] investigated the influence of the biodiesel made from the waste feed stocks of restaurant on the emissions and performance of an engine. Two various mixtures of biodiesel were made from the waste yellow grease of various vegetable oils of restaurants. The pure fuels and their (20%) mixtures with a diesel fuel were investigated at the steady-state working circumstances of the engine in a 4-cylinder, direct-injection Fiat diesel engine. Despite the two biodiesel fuels gave important decreases in CO, particulate matters and unburned HC, the nitrogen oxides rose by (11) and (7%) for the yellow grease B100 and B20, correspondingly.

Igbokwe et al. [6] used a two-cylinder, direct injection, four-stroke diesel engine to study the performance characteristics of using palm kernel methyl ester and blended with petro-diesel at a ratio of (20% biodiesel). The results showed that the fuel blend (B20) produced a higher torque at low and medium engine speeds than with pure biodiesel (B100) and neat petro-diesel. The neat petro-diesel has a higher brake power and torque than (B100) also the lowest brake specific fuel consumption.

Islam et al. [7] Investigated a diesel engine performance and emissions utilizing the castor biodiesel and its mixture with the diesel from (0%) to (40%) by volume. The blending percentage of biodiesel with diesel was [B0, B10, B20, B30, and B40]. The smoke emission test revealed that B40 had the less black smoke in comparison with the traditional diesel. The performance test of the diesel engine exhibited that the biodiesel mixture specific fuel consumption raised enough after the optimization of the mixing ratio. The decrease in exhaust emissions and the decrease in the brake-specific fuel consumption caused the caster seed oil (B_20) mixtures a proper substituted fuel for the diesel and could assist in the governing of air pollution.

Swamy et al. [8] studied the performance, emission, and combustion characteristics by utilizing butanol mixed fuels in various volume ratios with the diesel fuel. The results depicted that the brake thermal efficiency rose with an increment in contents of butanol in the mixed fuels at the entire working circumstances. At the greater loads, the decreased emission levels of (CO) were noticed for the butanol mixtures. Butanol showed the lowest smoke opacity at high engine loads compared to diesel fuel operation.

The sunflower biodiesel blends (B20, B50) were used by Salih, and Ahmed [9] to study the performance parameters of engine and emissions characteristics. The results revealed a reduction in the brake thermal efficiency by (7.7%) for B50 mixture and (3.6%) for B20 mixture. This efficiency rose by around (13.1%), (6.2%) for the mixtures (B50 and B20), correspondingly in comparison with the diesel fuel. The gas emissions of the in terms of (CO) was obtained to be more than the diesel fuel by (7.3%), (4.1%) for (B50) and (B_20), respectively.

Imdadul et al. [10] manifested that by using blends of biodiesel, the nitric oxide emission results were higher, while the carbon monoxide emission and unburned hydrocarbon emission were reduced by 15% and 20%, respectively. So, the engine performance can be improved without any engine modification.

Chaichan [11] Investigated the addition of gaseous hydrogen to the diesel engine intake manifold that utilizes a biodiesel fuel as a pilot fuel. This study was performed under the heavy-EGR circumstances. The results revealed that the provided gaseous hydrogen raised the concentrations of (NO_x) in the gas emissions of the exhaust, and the high rates (EGR) decreased the brake thermal efficiency. The decrease in emissions of (NO_x) relied upon the added gaseous hydrogen and the ratios

of (EGR) ratios in comparison with the combustion of pure diesel. The addition of gaseous hydrogen to the important quantities of the recycled exhaust gas decreased significantly the emissions (PM), (CO), and unburned (HC). The outcomes demonstrated that the use of biodiesel and gaseous hydrogen raised the noise of engine that was decreased with the addition of high (EGR) levels.
Emiroğlu, and Şen, [12] added the biodiesel with various alcohols to petroleum-diesel fuel. The outcomes depicted the longer delay (ID) of ignition of the alcohol mixtures and biodiesel than the diesel. The values of the brake specific fuel consumption (BSFC) of alcohol mixtures and (B20) were high and caused a little increment in the emissions of (NO_x) and (HC) with a reduction of smoke and carbon monoxide (CO) emissions.
Mofijur [13] used a multi-cylinder diesel engine for evaluating the emission of the waste cooking oil biodiesel at (20%) (B20) at different engine speeds and full load condition. The properties of biodiesel were found comparable to diesel fuel. The results of the engine emissions indicated that using the waste cooking oil biodiesel in the diesel engine reduced the (CO) emission by 28.30 % compared to the diesel fuel. Eventually, it was inferred that the (20%) of waste cooking biodiesel can considerably share to reduce the harmful emissions of an unaltered fixed diesel engine in the ambient.
The aim of this study is to evaluate the engine performance and emitted pollutants when it is fueled by Iraqi diesel and sunflower biodiesel. The Iraqi origin diesel is characterized by its high sulfur content, which causes severe and hazard pollutants. The use of biodiesel whether totally or partially will reduce the sulfur content and as a result reduce the emitted pollutants, which reflect on the better air quality.
The effect of fuel properties on the engine operating parameters, engine emissions and performance is the main goals of this study.

2. Experimental Setup

I. Equipment

The experiments were conducted on one cylinder, four-stroke engine, direct-injection diesel engine with main the specifications listed in Table 1. The engine was coupled to a hydraulic dynamometer to govern the exerted load on it via raising the torque. The (CO), (CO_2), (NOx) and (HC) concentrations were obtained via Multi gas mode HG-550 emissions analyzer. A pneumatic box with orifice system was used to measure the amount of air flowing using pressure gauge scale (manometer). The engine speed measurements (rpm) were conducted using digital tachometer. A fixed size was used to measure the amount of fuel consumed. Thermocouples were used to measure the exhaust temperature. The schematic diagram of the experimental setup is depicted in Figure 1 and the test system consisted of the engine and the measuring devices.

Table 1: The specifications of the tests engine

Type of engine	One Cylinder, 4-stroke
Model of engine	Loben-RB170F/ Diesel engine rig
Displacement	0.221 (L)
Bore	70 (mm)
The stroke	55 (mm)
Ratio of compression	17
Injection of fuel	Direct injection
Engine speed	3000-3600 rpm

II. Biodiesel Preparation

The fuel used in this work conventional Iraqi diesel. Biodiesel was prepared from (sun flower oil) by trans esterification process by utilizing a stirring reactor was used to produce biodiesel. Biodiesel, or alkyl ester, is an alternative renewable, biodegradable and nontoxic diesel fuel made via the oil catalytic trans-esterification, as shown in the Figure 2. It can be successfully employed in diesel engines and liquid fuel burners. Before starting the trans-

esterification reaction, the oil must be free of any water content in the form of suspended drops. Thus, the oil was heated alone (before adding methanol) to 80ºC to evaporate any possible drop of water. After that, the oil was cooled to the reaction temperature between 45-70º C. Methanol can now be added to the oil in the container along with the catalyst (NaOH) to embark the reaction. The stirrer was switched on during the reaction at a speed of 500 rpm. The reaction lasted up to 2 hours, after that, the stirrer was stopped and the mixture was poured into another plastic container open to air to let any remaining methanol to evaporate.
After another one hour, the mixture stratified to two layers: a bottom layer composed of glycerol, and a top layer of liquid fatty acids (biodiesel) ready to be collected from the top of the plastic container. The collected biodiesel contains some residues of methanol, NaOH, soap and glycerin. These residues can be removed by mixing the biodiesel with distilled water and shaking the mixture well for about one minute. After that, the mixture was let to re-separate into 2 layers of biodiesel and water. The washing process was repeated several times using fresh water each time to ensure the highest purity of the fuel. The amount of water necessary for washing was about 30% of the fuel volume. The stoichiometric trans-esterification process of the vegetable oil is considered as triglyceride. The reaction requires that one mole of tri-glyceride is mixed with three moles of methanol to produce three moles of fatty acid methanol ester (biodiesel) and one mole of glycerin. Figure 3 evinced the schematic of fuel preparation and Table 2 illustrates some the rmophysical properties of biodiesel and its test method compared with the values of standard diesel. This preparation and the tests was made in University of Al Mustansiriyah laboratory.

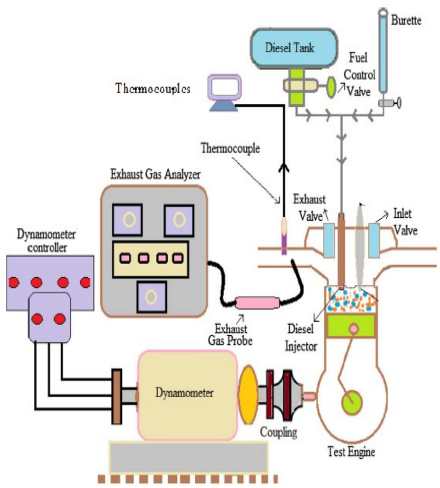

Figure 1: The schematic diagram of the experimental setup

Figure 2: The biodiesel preparation system

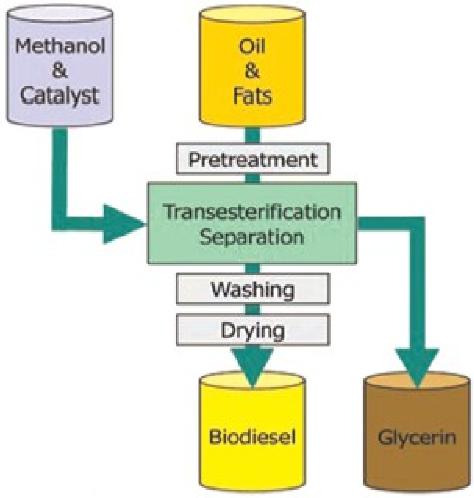

Figure 3: The schematic of biodiesel preparation

Table 2: The diesel fuel properties and the three blends constitutions

Fuel type	Flash point (C°)	Cloud point (C)	Cetane No.	Viscosity cSt (40 C°)	Density (kg/m^3)	Calorific value (kJ/kG)	Test method	Property
Diesel fuel	67	-	52	2.72	840	42500	ASTM D445	Viscosity cSt at (40 C°)
Biodiesel (B100)	176	4	67	4.92	870	37000	ASTM D2500	Cloud point (C°)
B50	121	2	60.3	3.86	851	40465	ASTM D93	Flash point (C°)
B30	103	0	58.5	3.49	846	41400	ASTM D1298	Density at (15C°)(kg/m3)
B20	89	-1	57.4	3.22	844	41785	ASTM D976	Cetane index

III. Analysis of error

The accuracy of the measurement is described as the reliance potential extent of the results of study. The sources of error were defined via the calibration of the employed measuring instruments, and the uncertainty in the present investigation was obtained. Table 3 illustrates the types of measurement with their calibration accuracy for the devices utilized in the current study. The uncertainty is defined as [14]:

$$e\text{-}R=[(\partial R/(\partial V\text{-}1)e\text{-}1)^2+(\partial R/(\partial V\text{-}2)\,e\text{-}2)^2+\cdots+(\partial R/(\partial V\text{-}n)\,e\text{-}n)^2]^{0.5} \quad (1)$$

Where:
e-R: The uncertainty result
R= A function composes of variables, or R = R(V1, V2, …., Vn)
ei: The variable uncertainty range
The partial derivative (∂R/∂V1) denotes the results' sensitivity of a single variable. Then, the uncertainty for the results of the current study was:
$\boldsymbol{e\text{-}R} = [(0.6)^2 + (1)^2 + (2)^2 + (1.3)^2 + (2.4)^2 + (0.67)^2 + (0.82)^2 + (1.034)^2 + (0.003)^2)]^{0.5} = \mp 3.873\ \%$

IV. Procedure of Tests

In the experiments, (3) mixtures (B20), (B30) and (B50) of biodiesel were used to operate the engine. Meanwhile, the characteristics combustion and the emissions were measured and analyzed at the same speed of engine and load. Furthermore, such characteristics of the engine were compared with the results obtained from the engine fueled with a pure diesel so as to indicate the biodiesel fuel influence combustion.

3. Results and Discussion

Biodiesel is the solely renewable substituted fuel and its properties are identical to those of the diesel fuel that is dissolved in petroleum. It can be blended in any proportion without any obstacle and can be utilized straightly in any diesel engine without having to make adjustments to the engine.

Table 3: Measurement Type and Its Accuracy of the Devices Used in the Current Study

Type of measurement	Accuracy of measurement
Measurement of Temperature	± 0.6%
Measurement of Fuel mass flow	± 1%
Measurement of Air mass flow	± 2%
Measurement of Engine speed	± 1.3%
Measurement of Engine torque	± 2.4%
Measurement of Exhaust gases concentrations	± 0.82%

Figure 4 shows the variation of the brake specific fuel consumption (BSFC) with the engine speed at the condition of constant load. BSFCs of B50, B30and B20 blends were observed to be higher by 60%, 33%, 11% than that of the diesel fuel, respectively for the utilized fuels. It's apparent from the curve that when the speed increased the (BSFC) decreased for the all type fuels as anticipated. In addition, the (BSFC)rose with the increment in the biodiesel fuel concentration in the mixtures. The greater consumption of fuel (B50) with its mixtures can be firstly correlated to the lower (B50) heating magnitude. Many authors documented that an increase was obtained in the consumption of biodiesel fuel in proportion to the content of biodiesel in mixtures and to the heating magnitude loss [4–16]. Labeckas and Slavinskas [17] claimed that the greater (BSFC) of mixtures can be correlated to the Lower, on mean by (12.5%) of net, heating magnitude of the rapeseed oil methyl.

Figure 5 reveals the engine's brake thermal efficiencies (BTEs) which is fueled with the diesel fuels (B20, B30 and B50). At the condition of constant load, BTEs of the B20, B30, B50 fuels were noticed to be decrease by (4%), (16%), and (22%) than that of the diesel fuel, respectively. The (BTE) increases with increasing the engine speed. This can be attributed to increase in the brake power and the reduction of (BSFC) with high speeds. The (BTE) decreased with the rise in the concentration of biodiesel due to lower calorific value, and higher viscosity compared with the diesel fuel. The obtained (BTE) with (B20) is near to that determined with diesel fuel. From the other side, Ramadhas et al. [18] determined higher (BTEs). Many investigators have reported similar behavior Salih and Ahmed [8] who found that the engine (BTE) decreased by (2.9614%) for (B20) and (8.117%) for (B50) compared to a neat diesel. The exhaust gas temperatures (EGT) revealed an influential heat energy utilization of a fuel. A higher (EGT) is unwanted as it will decrease the heat energy conversion of the fuel to create a beneficial work [19]. Figure 6 illustrates the variation of the exhaust gas temperature (EGT) with the engine speed at the constant load condition. It was noticed that the (EGT) increased with the increased engine speed of, because no more time is available for the combustion to complete at higher speeds. Generally, the biodiesel blends (EGT) is lower in comparison with the baseline diesel. The general reasons beyond such phenomenon are principally owing to the less calorific magnitude and the presences of the chemically bound O_2 of biodiesel mixtures, which decrease the all released energy and enhance combustion, correspondingly. Indeed, several investigators also documented that the (EGT) is lower when the engine is fueled with the biodiesel mixed fuel in comparison with the baseline diesel [19-22]. The (EGT) of B20, B30, B50 fuels were observed to be lower by 7 %, 14 %, and 32 % than that of diesel fuel, correspondingly.

The variations of HC emissions with the engine speed for the diesel and biodiesel are depicted in the Figure 7. The unburned (HC) emission is negligibly less for the whole fuels. The emissions of (HC) of the fuels (B20, B30 and B50) were less by (6.3 %, 32 %, and 46 %) than that of diesel fuel, respectively. because of higher cetane no., and the high oxygen content of biodiesel which are responsible for such reduction, that the oxygen content in biodiesel influenced the amount of hydrocarbon oxidation. This behavior was similarity with researchers for biodiesel reduction in the emissions of (HC) owing to the reduction in the delay of combustion [23].

Figure 8 evinces CO emission with the engine speed for different fuels type. It was noted that the CO emission decreased with the increase in engine speed. The CO emissions of B20, B30 and B50 fuels were lower by 13 %, 39 %, and 52 % than that of diesel fuel, correspondingly. At the low speeds of engine, the emissions of (CO) of the fuel blends were lower than that of diesel fuel. Such reductions may be owing to the O2 amount of the mixtures, this case indicates that the oxygen content of biodiesel fuel leads to improve in the combustion process and reduction of CO emission. Similar results can be found in other studies [16, 24].

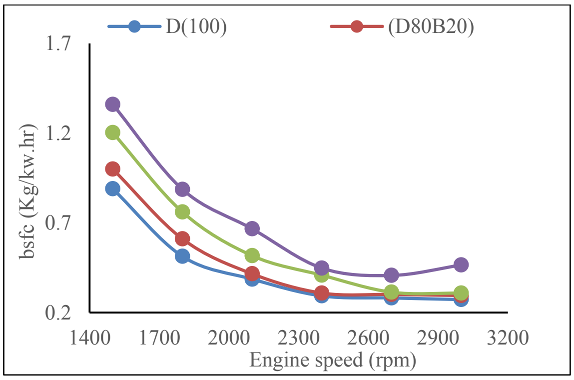

Figure 4. The impact of engine speed on the (BSFC) of tested blends

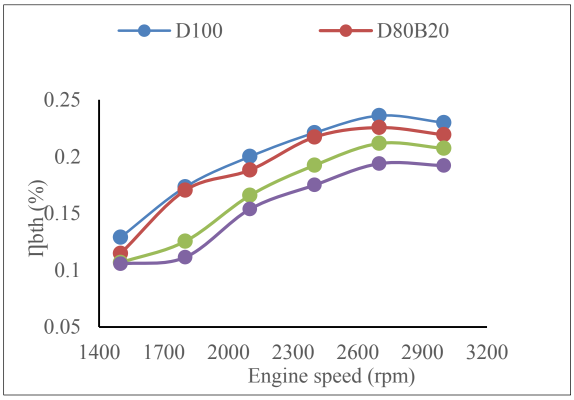

Figure 5: The impact of engine speed on the brake thermal energy for studied blends

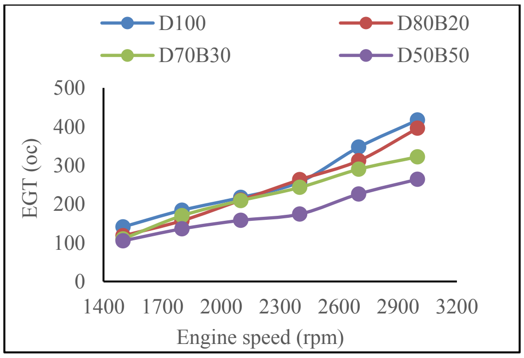

Figure 6: The engine speed impact on (EGT) for studied blends

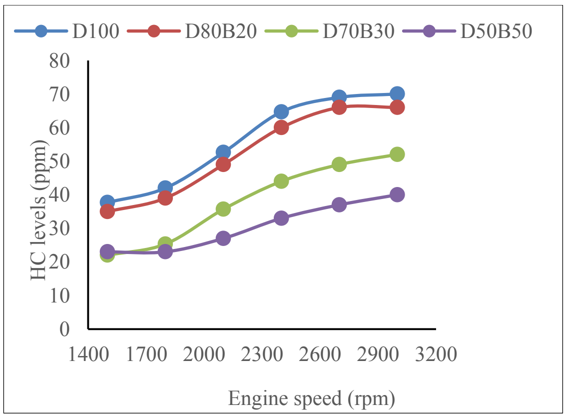

Figure 7: The engine speed impact on the (HC) levels emitted for studied blends

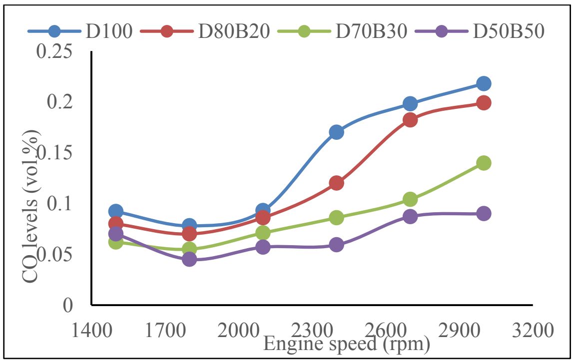

Figure 8: The engine speed impact on the (CO) levels emitted for studied blends

Figure 9 reveal the variation of The NOx emission with the engine speed for the fuel types blended B20, B30 and B50 in compared with diesel fuel. It is well aware that the formation of (NOx) depends on the volumetric efficiency, and the fuel distribution. Despite the temperatures of gas exhaust raised, the emissions of (NOx) emissions were noticed to reduce with the increment in the speed of engine. That is firstly owing to the increment in the volumetric efficiency and the motion of fuel flow within the cylinder of engine under the higher speeds of engine, causing a rapid blending between air and fuel, and a shorter delay of ignition. The results show NOx emissions gradually increased with the increasing fraction of biodiesel in the blend is a result of increasing oxidation. The oxygen content of biodiesel and higher cetane number is an important factor in the high NOx formation levels. In additionو higher density of biodiesel blends results in larger mass flow rate for the same volume of fuel and more oxygen is responsible for complete combustion that results in high in-cylinder temperature. The NOx emissions increased engine speed from (1900-2700 rpm) makes less time available for heat transfer to cylinder walls and thus higher in-cylinder temperature which results in higher NOx emissions. This resulted lower emissions (NOx) under higher speeds of engine. The increment in the in the emissions of (NOx) was (29.5%) for (B50) compared to diesel fuel. Also, there were (3%) and (18%) increment in the emissions of (NOx) for (B20) and (B30), correspondingly. Same conclusions were reached via the other investigators in literature [15, 25–26]. Nevertheless, Dorado et al. [27] exhibited a reduction in the emissions of (NOx) using waste olive oil methyl ester place of diesel fuel. It was suggested in literature that the biodiesel include more O_2 component in comparison with diesel fuel. Therefore, it's apparent that the amount of O_2 to reacting with the N_2 component in the air, causing formation of a higher quantity of (NOx) [24, 28].

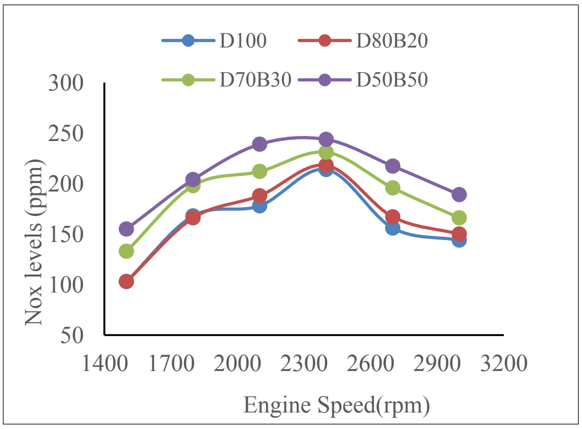

Figure 9: The engine speed impact on the (NO_x) levels emitted for studied blends

4. Conclusions

The diesel engine performance and emissions which fuelled with sunflower biodiesel was investigated experimentally. The fuel used in the tests was derived from the sunflower oil and its blends (20%, 30% and 50%) with a diesel fuel. The results of the tests exhibited that:

1. The solely low concentration mixtures in terms of performance efficiency and environmentally friendly emissions (especially for (B20) and lower mixtures) can be realized as the potential candidates to be certificated for full scale utilization in the unmodified diesel engines.
2. The enhancement of brake thermal efficiency of engine for B20 was found higher than to other fuels blends.
3. The utilization of sunflower oil as a mixture has no any positive influence on the engine (BSFC).
4. The higher (NO_x) formation occurred in the use of biodiesel.
5. The biodiesel fuels possess a higher cetane no. and therefore can supply better quality of ignition. The higher O_2 amount and higher viscosity of the biodiesel fuels also give better air-fuel blending. Moreover, the raised O_2 improves the process of combustion. Thus, it was obtained that utilizing the (SME) fuels in the diesel engine can decrease the (EGT).

Therefore, a research is needed to propose (NO_x) reduction strategies for biodiesel combustion. The use of a biodiesel decreases the temperatures of the exhaust gas for the whole tested loads and the ranges of engine speed. Nevertheless, more research and development on the additional fuel characteristic measures, the long-term operation and the biodiesel-fuelled engine wear analysis are also significant together with the timing and period of injection for better biodiesel combustion in the diesel engines.

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