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Article

# Effect of Norozak (Salvia lerrifolia) biodiesel fuel on diesel engine performance

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**ABSTRACT**

Most energy is produced from fossil fuels, and the use of these fuels has increased over the past years. Fossil fuels are the main cause of global pollution and global warming. Using vegetable oils as alternative fuels for diesel engines is one of the ways to reduce pollutant emissions. Biodiesel from Norozak (Salvia lerrifolia) oil has been produced using a transesterification process. Biodiesel is mixed with diesel oil in different proportions B05, B10, B15, and B20. Biodiesel's physical and chemical properties are measured according to ASTM standards. A single-cylinder diesel engine is employed as the test engine in the present work. The torque, power, Special Fuel Consumption (SFC), and Exhaust Gas Temperature (EGT) are measured and compared with diesel oil. Torque, power, and EGT are larger, and SFC is lower for biodiesel mixture B05 than diesel fuel.

## 1. Introduction

The use of biodiesel in compression ignition engines has increased in recent years to reduce the pollution of fossil fuels [1]. In order to use biodiesel instead of fossil fuels, it is necessary to perform engine-related tests to investigate the replacement of diesel fuel in compression ignition engines [2]. In this paper, the use of biodiesel fuel obtained from Norozak oil (see Table 1 data) in a combustion engine was used, and the parameters of power, EGT, SFC, and biodiesel fuel output torque were investigated in comparison to diesel fuel [3]. These are the parameters that affect the performance of compression ignition engines [4]. Increasing the biodiesel fuel percentage increases the density of the fuel mixture and reduces its thermal energy due to its higher density and lower thermal value than diesel. Increasing the fuel mixture's density increases the fuel mixture's mass consumption, and the fuel's thermal expansion increases the released energy and thus generates more power [5]. At full load, the SFC for biodiesel of 5%, 20%, 50%, 75%, and 100% methyl ester cotton seed at a rotational speed of 2000 rpm is more than diesel fuel [6]. The EGT of pure sunflower oil is higher for a mixture of B20 due to incomplete combustion, higher ignition delay, high viscosity, high surface tension, and high boiling point [7]. The EGT for diesel fuels and cotton methyl ester increases by 9.9% and 6.2-7.8%, respectively, due to the heat problem caused by the gas inside the combustion chamber [8]. The EGT increases with increasing biodiesel concentration. This is due to more oxygen in the vegetable oil methyl ester, which improves combustion performance [9]. The SFC for a 20% Pongamia biodiesel at a full load is higher than a small amount compared to diesel fuel because the biodiesel thermal value is lower than diesel fuel [10].

**Table 1.** Specifications of oil recycled from Norozak [1]

| Parameter | Unit | Norozak |
|---|---|---|
| Dynamic viscosity in **40**℃ | Mp.s | 28.435 |
| Kinematic viscosity in **40**℃ | $\frac{mm^2}{s}$ | 31.433 |
| Density in **40**℃ | $\frac{gr}{cm^3}$ | 0.9046 |
| The molecular weight of oil | $\frac{gr}{mol}$ | 930 |
| Free fatty acids | % | 0.71 |

Most studies show that with increasing biodiesel blending, the amount of SFC increases in all operating conditions [11-13]. The number of cetanes is greatly important in diesel fuel and improves the combustion properties. The number of cetane affects the engine's performance parameters such as combustion, stability, driving ability, thickened soot, disorder and engine disturbances, carbon monoxide particles, and unburnt hydrocarbons. The more biodiesel cetane number compared to diesel fuel results in greater combustion and combustion efficiency [14, 15]. The temperature of biodiesel blends is higher than diesel fuel. Biodiesel has a higher viscosity that opens the needle valves more quickly, resulting in a faster start of combustion and higher combustion temperatures [16]. In a mixture of 30% biodiesel Jatrofa, there is a higher thermal effect in all cases. Increasing the percentage of mixtures reduces the thermoset's thermal efficiency because of the high viscosity and incomplete combustion [17]. Using biodiesel sources such as Jatropha, palm, algae, and waste cooking oil, biodiesel blends B10 and B20 with A single-cylinder diesel engine were run [18]. For the first time, the Norozak oil biodiesel fuel was used to obtain the torque, power, SFC, and EGT engine's parameters in a single-cylinder compression ignition engine to use as a substitute for conventional diesel fuel without changing the structural characteristics of the engine.

## 2. Materials and methods

The biodiesel was tested using an ASTM standard Transesterification method, and a mixture of biodiesel and diesel fuel after preparation was shown in Table 2. Biodiesel compounds are often indicated as BX. B represents fuel biodiesel fuel, and X represents the percentage of biodiesel in the mixture [19, 20].

**Table 2.** The contents of the fuel mixture used

| Fuel type | B00 | B05 | B10 | B15 | B20 |
|---|---|---|---|---|---|
| Diesel Percentage | 0 | 05 | 10 | 15 | 20 |
| Biodiesel percentage | 100 | 95 | 90 | 85 | 80 |

The engine used in this research has a cylinder made in Italy. The characteristics of the engine are given in Table 3. It has a direct spray type with a displacement of 510 $cm^3$, a compression ratio of 18:1, and a maximum torque of 32.8 Nm at an operating speed of 1800 rpm. The maximum recommended rotation speed is 3000 rpm and at least 1500 rpm, with rotational speeds of 1800 and 2500 rpm; using fuel mixtures of 0, 5, 10, 15, and 20, the percentage of biodiesel obtained from the Norozak plant oil was evaluated at 0, 50 and 100% load at three loads.

**Table 3.** Diesel engine technical specifications of single-cylinder air-cooled Lumbardini

| Description | Specifications |
|---|---|
| Engine type | Lobardini_diesel 3LDS510 |
| Engine displacement volume (cubic centimeter) | 510 |
| Induction type | No Super Charging |
| Number of cylinders | 1 |
| Piston Course (mm) | 90 |
| Inner cylinder diameter (mm) | 85 |
| Maximum torque (Nm per minute) | 32.8/1800 |
| Volumetric density ratio | 18:1 |
| Maximum Rotational Speed (RPM) | 3000 |

Each of the combinations of B00 (petroleum gas), B05 (5% biodiesel with 95% diesel oil), B10 (10% biodiesel with 90% diesel oil), B15 (15% biodiesel with 75% diesel oil), and B20 (20 % Biodiesel with petroleum diesel) was placed in two bottles of 1-liter containers, which was used to test any mixture of 2 liters of this mixture. For testing the mixture, fuels were poured into a fuel tank with a capacity of 0.75 liters, and fuel was poured into the reservoir again using fuel combinations and emptying the fuel tank, and then the engine was turned on to burn fuel for 10 minutes with fuel and adapt to the new combustion. Also, it is important to burn fuel in the engine completely, and better fuel-polluting analyzes can be obtained to achieve the oil temperature to the optimum level for the engine start test. The engine was set at 1800 rpm and 2500 rpm for each test and was considered 0%, 50%, and 100% loads for each engine load, and carrying out the test in each load was considered each 6-point fuel mixture (see Table 4) by the operator. For each fuel composition, 100% load was tested first. At this time, the operator control system automatically and continuously performed the test in rounds that were manually given to the control system so that when the test was completed at a rotational speed of 1800 rpm, that was considered to be the minimum after taking the data from the engine and the analyzer device, the engine was raised by a control system of rotational speed 2500 rpm that was considered to be the maximum and the experiment was carried out with a new engine load at 100% load and as well as the data in time intervals were taken at 0.5 seconds.

**Table 4.** Matrix of experiments

| Fuel | Engine speed rpm | Engine load % |
|---|---|---|
| B05 | 1800<br>2500 | 0<br>50<br>100 |
| B05 | 1800<br>2500 | 0<br>50<br>100 |
| B10 | 1800<br>2500 | 0<br>50<br>100 |
| B15 | 1800<br>2500 | 0<br>50<br>100 |
| B20 | 1800<br>2500 | 0<br>50<br>100 |

They set the engine speed from 1800 to 2500 rpm at a load of 100% for each fuel composition and obtained the engine torque at each rotational speed. The test can be carried out at 50% load for the same combination at two rotational speeds of 1800 rpm and 2500 rpm, which will be explained below. Average torque was obtained at 100% load for each compound at a rotational speed of 1800 rpm and 2500 rpm. The average torque of each speed was divided into two so that the tested torque was obtained at a rotational speed of 50% to come and then, by placing the torque obtained for 50% load in the desired range separately in the control system and starting the test, the pollutant analysis should be performed by pressing the button to conduct the pollutant test. As a result, the time needed to reach the torque of the dynamometer should be calculated by the torque to be calculated, and the system monitor has no disturbances in the dynamometer between the torque being calculated and shown in the system. The values of these two torque are close together. At 0% load, no torque is entered on the dynamometer. In this test, the torque, power, Special fuel consumption (SFC), and Exhaust Gas Temperature (EGT) were calculated after the engine arrived at stable conditions.

## 3. Results and discussions

Table 5 shows the experimental data in the test. A comparison of the measured characteristics for diesel fuel and the biodiesel obtained from the Norozak oil shows that biodiesel and its mixtures have the required fuel characteristics for compression ignition engines [21-23]. Theoretical topics can easily be considered a substitute fuel for a compression ignition engine.

Biodiesel has fewer pollutants than conventional diesel fuel in Iran and can be used to reduce pollution, especially in metropolitan cities, in combination with conventional diesel [24]. The higher the amount of oxygen in the biodiesel fuel and the higher the cetane number of this fuel than conventional diesel fuel in Iran can reduce air pollution and clean air, but fuel consumption in the engine increases with biodiesel consumption [25].

**Table 5.** Data from the research matrix

| Row | Attributes The combination | Load engine (٪) | Rotational speed (rpm) | Special fuel consumption (gr/kwh) | Torque (Nm) | Exhaust gas temperature (°C) | Power (kW) |
|---|---|---|---|---|---|---|---|
| 1 | B00 | 100 | 1800 | 433.5233 | 17.38571 | 526.4286 | 3.612381 |
| | | | 2500 | 470.3503 | 15.83591 | 680.1136 | 4.547273 |
| | | 50 | 1800 | 375.3718 | 10.35522 | 362.3152 | 2.150433 |
| | | | 2500 | 453.6003 | 9.408909 | 474.3273 | 2.685636 |
| | | 0 | 1800 | 10000 | 0.018929 | 178.2857 | 0.00964 |
| | | | 2500 | 10000 | 0.084167 | 293.125 | 0.024167 |
| 2 | B05 | 100 | 1800 | 431.095 | 17.64 | 548.1 | 3.662 |
| | | | 2500 | 515.725 | 14.558 | 666.12 | 4.1772 |
| | | 50 | 1800 | 516.45 | 9.4137 | 358.1522 | 1.95333 |
| | | | 2500 | 697.3683 | 6.45 | 451.5 | 1.84 |
| | | 0 | 1800 | 10000 | 0.018727 | 178.2857 | 0.001964 |
| | | | 2500 | 10000 | 0.084167 | 293.125 | 0.024167 |
| 3 | B10 | 100 | 1800 | 441.5786 | 16.96304 | 526.8261 | 3.536087 |
| | | | 2500 | 498.1051 | 14.89864 | 661.7727 | 4.272727 |
| | | 50 | 1800 | 390.8837 | 8.4347 | 335.5588 | 1.751373 |
| | | | 2500 | 488.0289 | 8.934 | 472.476 | 2.552615 |
| | | 0 | 1800 | 10000 | 0.051143 | 181.7143 | 0.01 |
| | | | 2500 | 7111.119 | 0.353019 | 305.6745 | 0.101604 |
| 4 | B15 | 100 | 1800 | 437.258 | 17.28136 | 530.8636 | 3.609545 |
| | | | 2500 | 509.7204 | 15.06958 | 667.125 | 4.33625 |
| | | 50 | 1800 | 419.6284 | 9.318571 | 349.4643 | 1.937143 |
| | | | 2500 | 483.5139 | 9.546712 | 497.3425 | 2.728219 |
| | | 0 | 1800 | 10000 | 0.095957 | 183.6223 | 0.020106 |
| | | | 2500 | 10000 | 0.160952 | 297.7143 | 0.045714 |
| 5 | B20 | 100 | 1800 | 437.8279 | 17.26727 | 535.6364 | 3.589545 |
| | | | 2500 | 502.9433 | 14.92333 | 665.1429 | 4.269048 |
| | | 50 | 1800 | 379.6148 | 10.08716 | 365.6554 | 2.093649 |
| | | | 2500 | 481.2963 | 8.392012 | 467.9112 | 2.39201 |
| | | 0 | 1800 | 10000 | 0.016709 | 174.9304 | 0.001646 |
| | | | 2500 | 9667.337 | 0.162727 | 301.4318 | 0.046591 |

### 3.1 The torque changes from the dynamometer relative to the engine speed

The torque variations are presented in terms of the rotational speeds of the engine tested in 0%, 50%, and 100% engine loads. The experiment begins with recording the desired data so that the turbulence with the torque at the tested speed is as low as possible and has a stable process with the least disturbance. At the beginning of the test, the torque changes fluctuate relative to the speed of the test, and in order to increase the accuracy of the test, it should take a while before these changes become stable, and then data is taken from the test with high precision. Figures 1 to 2 show torque variations relative to rotational speeds of 1800 and 2500 rpm at loads of 0%, 50%, and 100 %. Figure 1 shows the torque changes from the dynamometer relative to the engine speed for the biodiesel blend at three engine loads of 0%, 50%, and 100% at an engine speed of 1800 rpm. As can be seen, there is no oscillation in engine torque at a rotational speed of 1800 rpm in engine 0% load since the torque at this load is 0 Nm. At full load, the engine had the highest torque for combining B00 at rotational speeds of 1800 rpm. The torque at 50% load was less than the engine load of 100%. The torque fluctuations were reduced by both 50% and 100% loads at the speed of 1800 rpm over time until the amount of these oscillations reached acceptable stability. The engine variation at different loads at 2500 rpm is similar to changes at the engine speed of 1800 rpm. At this rotational speed, it is also observed that the torque is greater than the engine loads of 50% and 0% at full load, and as well as the fluctuations in the engine have become stable in less time. It indicates that less time is needed to achieve a steady state at a high engine speed so that the engine fluctuations become uniform to start the delivery of exhaust gases (see Figure 2). In Figures 1 to 2, the torque fluctuations of the engine for combining B10 and B15 in the full engine load have reached a monotonous state in very little time, and it is well illustrated to improve the engine's return to monotonicity using biodiesel combinations. Figure 2 shows that in the combination of B15 at rotational speeds of 2500 rpm for a full load of the engine, torque variations became very uniform in very little time, but a different trend was observed for the engine load of 50% and more time was spent to smooth the torque fluctuations.

### 3.2 Torque changes relative to biodiesel percentage and rotational speed

Figure 3 shows the effect of increasing the biodiesel percentage to diesel fuel on engine torque production at rotational speeds of 1800 rpm and 2500 rpm. Each of these speeds is tested at 50% and 100% loads. Table 4 shows the value of the measured data, and Figures 3 to 10 are based on the data in Table 4. The torque produced at a rotational speed of 1800 and 2500 rpm and a load of 100% is greater than the torque at 50% load at both rotational speeds. According to Figure 3, the highest torque was observed in the combination of B05 at 100% load and a rotational speed of 1800 rpm with a value of 17.64 Nm, and this value for the torque of conventional diesel fuel of 14.558 Nm shows that it increases 21.17% torque for B05 than B00 and also the lowest of these values in B05 but at rotational speeds of 2500 rpm and the engine load of 50% with a value of 6.45 Nm. The torque increases with increasing engine load for all rotational speeds and decreases torque at each engine load with increasing rotational speed. It was observed that with increasing engine speed from 1800 to 2500 rpm at 100% load, the amount of torque was reduced, and similarly, for the load of 50%, this same decrease in torque was observed with the increasing speed of rotation, which shows this trend process for both the 50% and 100% engine load.

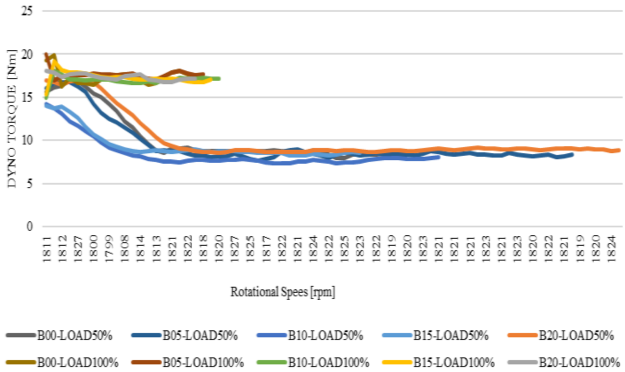


**Figure 1.** The torque changes from the dynamometer relative to the engine speed

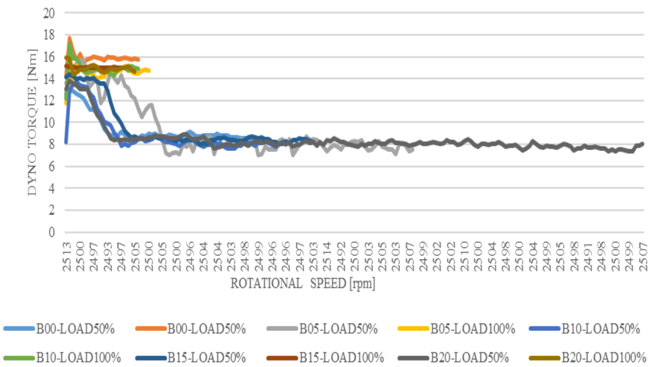


**Figure 2.** The torque changes from the dynamometer relative to the engine speed for the biodiesel blend

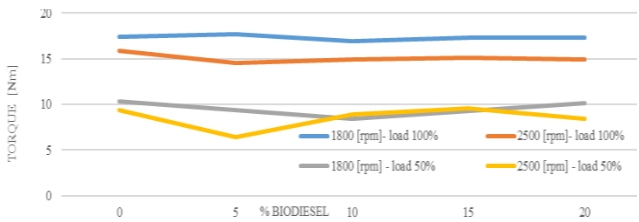


**Figure 3.** The Effect of adding biodiesel to diesel fuel on generating the engine's torque under test

At 100% load, with increasing biodiesel from B00 to B20 at a rotational speed of 1800 rpm, the first increase in torque was observed from B00 to B05, and then the B10 decreased, followed by a slight increase in the graph of Figure 3, A steady trend was observed. At a speed of 1800 rpm for the engine load of 50%, the torque was reduced from B00 to B10, and an increasing trend was shown from B10 to B20. The process torque was reduced from B00 to B05, but the trend of increased torque was observed from B05 to B20. In both the 50% and 100% engine load charts for rotational speeds of 2500 rpm, the highest torque was found in B00. The thermal value of biodiesel fuel is lower than diesel fuel. By increasing the biodiesel fuel content in combination with diesel fuel, the thermal value of the mixture is also lower, affecting the amount of torque produced by the mixture. At 50 % engine load for both rotational speeds and 100% engine load for a rotational speed of 2500 rpm in the B05 mixture, the torque was reduced compared to conventional diesel fuel, but at 100% engine load and engine speed of 1800 rpm, this value increased slightly compared to conventional diesel. As described above in Figure 3, for all combinations of biodiesel, the amount of torque produced is reduced with increasing engine speed from 1800 to 2500 rpm. It can be seen that the engine behavior in Figures 3 and 4 for biodiesel fuel blends is similar to engine behavior for diesel fuel charts, and the difference in torque produced by the engine at rotational speed and different loads using biodiesel fuel mixtures are also visible in these charts as compared to the time when conventional diesel fuel is used.

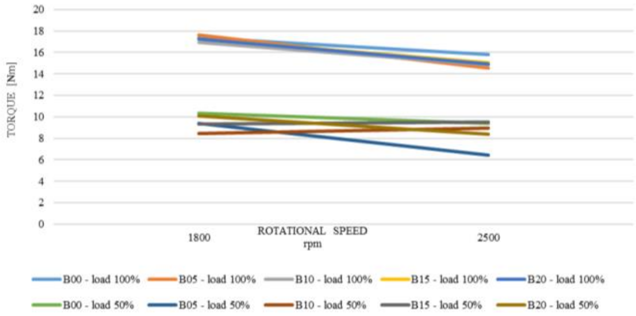


**Figure 4.** Effect of rotational speed on engine torque production under different biodiesel and diesel combinations

### 3.3 Specific fuel consumption changes based on biodiesel percentage and rotational speed

In Figure 5, B05 at 50% engine load and for both rotational speeds of 1800 rpm and 2500 rpm and as well as the engine load of 100% at a rotational speed of 2500 rpm, the highest SFC is for three graphs and trends were almost identical in their diagrams, but this value was initially slightly lowered in B05 at 100% engine load at the rotational speeds of 1800 rpm and then slightly increased in B10 to B15.

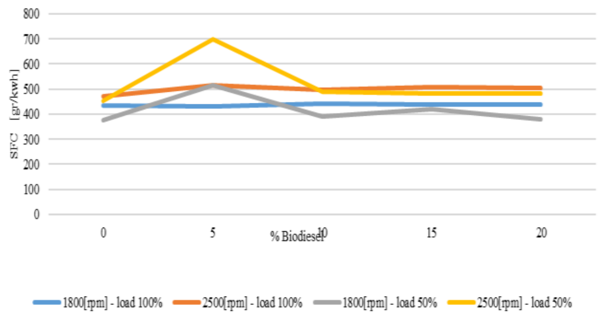


**Figure 5.** The effect of increasing the percentage of biodiesel composition in diesel fuel on fuel-specific consumption

### 3.4 Power variations relative to biodiesel percentage and rotational speed

Figure 6 shows the effect of the biodiesel increase on the fuel mixture. As shown in Figure 6, engine power is increased by increasing engine load and speed. The maximum production power between 50% and 100% engine loads and rotational speeds of 1800 rpm and 2500 rpm is at 100% load and rotational speed of 2500 rpm. The maximum production power is B00, B15, B10, B20, and B05, with values of 4.547273, 4.33625, 4.272727, 4.269048, and 4.1772 kW. The lowest power is also available for the B10 at 50% load and 1800 rpm at the value of 1.751373 kW.

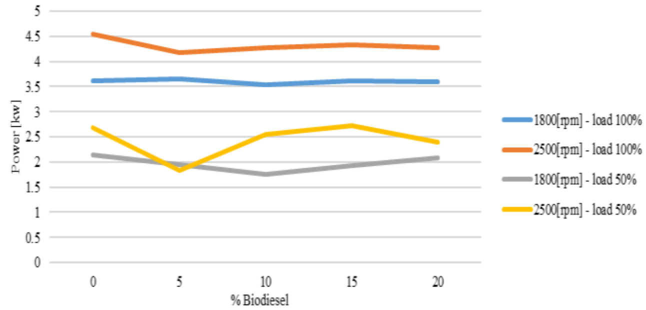


**Figure 6.** The Effect of biodiesel increases on the fuel blend on the brake power of the tested engine

With an increase in engine speed from 1800 to 2500 rpm, the engine power increases for both loads of 50% and 100%, and only in the combination of B05 at 50% engine load reduced very little in power was observed (see Figure 7). At rotational speeds of 1800 rpm and 100% engine load, the highest production power is observed for the B05 composition. In Figure 6, it is seen that at 100% load for both rotational speeds, the values obtained for the biodiesel and diesel fuel mixture are not significantly different from conventional diesel fuel; however, diesel fuel will be combustible faster than the biodiesel-diesel mixture. At a rotational speed of 1800 rpm and 100% engine load for the B05 blend, the power increased by 13.73%, while B10, B15, and B20 decreased by 2.1%, 0.079%, and 0.632%, respectively, and at the engine load of 100% and rotational speed of 2500 rpm for the mixes B05, B10, B15 and B20 showed 8.13%, 6.04%, 4.64% and 6.126% decrease in the amount of power compared to conventional diesel fuel, respectively.

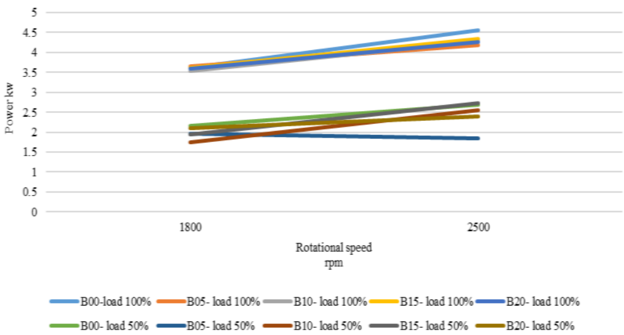


**Figure 7.** Effect of engine speed on the engine power

### 3.5 The EGT

Tables 5 and 6 give the values of the percentage of oxygen volumes and production power in the combination of biodiesel and diesel. In the combination of B05 at a rotational speed of 1800 rpm and a 100% engine load, the highest percentage of the oxygen volume and the maximum amount of generated power were observed with values of 16.14205 %vol and 3.662 kW, respectively. In the combination of B05 with the higher oxygen content in the exhaust gas, it is better to burn the engine in the presence of sufficient oxygen. Also, the maximum production power was observed in the B05 composition with increasing rotational speed and engine load. Table 6 shows oxygen data at the engine load of 100% and the rotational speed of 1800 rpm and 2500 rpm for different combinations of biodiesel and conventional diesel in Iran (see Figures 8 and Figure 9).

**Table 6.** Available oxygen data for different combinations of biodiesel and conventional diesel at full engine load and rotational speeds of 1800 rpm and 2500 rpm

| O2 [%vol] | Data amount | | | | |
|---|---|---|---|---|---|
| | B00 | B05 | B10 | B15 | B20 |
| 1800[rpm] | 15.741 | 16.14205 | 15.75432 | 15.21342 | 15.01895 |
| 2500[rpm] | 14.012 | 14.47319 | 14.52409 | 13.97684 | 13.84895 |

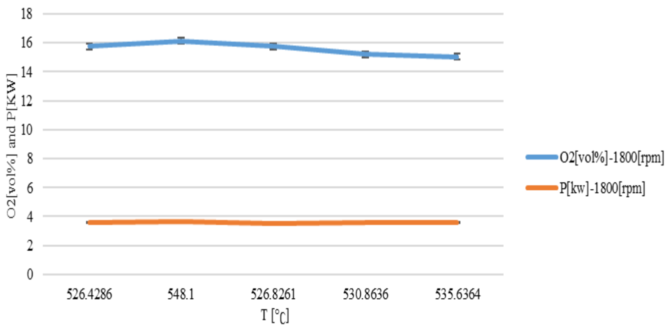


**Figure 8.** The rate of changes in the percentage of oxygen and power in the engine load

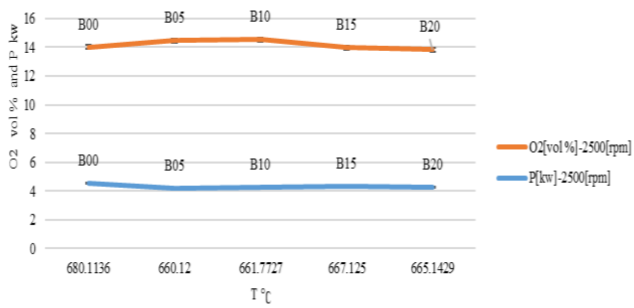


**Figure 9.** The rate of change in the percentage of oxygen and power in the engine load

The highest volumes of oxygen in the exhaust gases were observed for B10 and B05 compounds with values of 14.52409% and 14.47319 % vol, respectively. The highest production power at the rotational speed of 2500 rpm was recorded for a conventional diesel engine of 4.55 kW. With tests on fuel combinations at full load, it can be seen that the best combination of biodiesel and diesel at full load was introduced B05 at rotational speeds of 1800 rpm. Table 7 shows the percentage of variations in SFC, Torque, EGT, and power relative to conventional diesel.

**Table 7.** The percentage of changes in SFC, Torque, EGT, and power relative to conventional diesel

| Performance | Speed rpm | Blend B05 | B10 | B15 | B20 |
|---|---|---|---|---|---|
| Torque | 1800 | 1.47% | -2.4% | -0.6% | -0.68% |
| | 2500 | -8.1% | -5.91% | -4.84% | -5.76% |
| EGT | 1800 | 4.12% | 0.076% | 0.84% | 1.75% |
| | 2500 | -2.1% | -2.7% | -1.91% | -2.2% |
| Power | 1800 | 1.37% | -2.1% | -0.08% | -0.63% |
| | 2500 | -8.13% | -6.04% | -4.64% | -6.12% |
| SFC | 1800 | -0.56% | 1.86% | 0.86% | 0.99% |
| | 2500 | 9.65% | 5.9% | 8.37% | 6.93% |

## 4. Conclusion

Increasing the engine load from 0% to 100% increases the torque produced from the biodiesel and diesel fuel mixture. The torque was reduced in all tested fuel combinations by increasing engine speed. For biodiesel fuel produced from Norouzk oil in a mixture with Iranian conventional diesel, the torque was reported at a speed of 1800 rpm more than the torque at 2500 rpm. The result is that all fuel blends achieved the best results at full engine load and at rotational speed of 1800 rpm. The SFC is increased with an increase in engine speed from 1800 rpm to 2500 rpm and increasing engine load from 0% to 100%. In the engine load of 50% among all fuel combinations, the highest SFC was observed for B05. Increasing the engine speed for all combinations of biodiesel produced from Norouzk oil in combination with conventional Iranian diesel increases engine power. At a rotational speed of 2500 rpm, the maximum power of the fuel mixture is achieved, and the engine load increases the power output. Resulting in the use of a fuel mixture, more power was generated by increasing the engine load from 50% to 100%. With experiments on the Norozak oil biodiesel fuel, it has been found that this fuel can be used as a substitute for diesel fuel in compression ignition engines. It can also be combined with B05 fuel of Norozak oil at the rotational speed of 1800 rpm and 100% engine load introduced as an optimal combination. Considering the favorable results obtained from experiments on biodiesel, it can be combined with B05 to reduce the environmental pollution caused by diesel engines.

### Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The authors adhere to publication requirements that the submitted work is original and has not been published elsewhere.

### Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

### Conflict of interest

The authors declare no potential conflict of interest.

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