Advances in Science and Technology Research Journal

*Advances in Science and Technology Research Journal* 2023, 17(4), 46–52
https://doi.org/10.12913/22998624/168257
ISSN 2299-8624, License CC-BY 4.0

Received: 2023.05.06
Accepted: 2023.07.15
Published: 2023.08.15

# Performance Comparison of Four-Stroke Diesel Engine Fuelled by Various Biodiesel Blends and Diesel

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## ABSTRACT

The objective of this study is to compare the performance of diesel engines, fuelled with biofuel blends extracted from corn, sunflower, and palm oils, against pure diesel. The experiments were performed using Lister LVI, single-cylinder, direct injection, four-stroke engines, with a compression ratio of 17:1. The following parameters were analysed: brake torque, brake mean effective pressure (BMEP), brake specific fuel consumption (BSFC), brake thermal efficiency, and exhaust gas temperature. The findings indicate that the characteristics of biodiesels are close to diesel fuel. Therefore, biodiesel becomes a viable alternative to diesel fuel without any modifications. Pure diesel has higher brake thermal efficiency and lower BSFC than all the biodiesel blends tested in this study. In addition, the engine consumes less fuel for biodiesel blends than pure diesel. High exhaust temperatures are conducive to nitrogen oxides ($NO_x$) generation; hence, this study reveals that the exhaust temperature is reduced when utilizing biodiesel compared to pure diesel. According to several tests, palm biodiesel provides greater torque and BMEP than the rest of the biodiesel blends, and pure diesel due to emitting less $NO_x$. Therefore, it stands to reason that it would be utilized in a diesel engine.

**Keywords:** biodiesel, diesel engine, performance, comparison, vegetable oils

## INTRODUCTION

The continuous growth of the transportation sector affects the global share of diesel engines, which is predicted to increase by ca. 3% between 2021 and 2026. As a substitute for fossil fuels, bio-based alternatives are continuously investigated. Therefore, the liquid fuel industry has a huge focus on developing biodiesel as a substitute for crude oil. Biodiesel is a renewable and reliable fuel option for internal combustion engines, in countries like Jordan and Poland, which rely on imported petroleum. The chemical composition of biodiesel is based on alkyl ester obtained from renewable feedstocks like animal fat wastes, vegetable oil, and algae [1]. Currently, the feedstock for biodiesel production is mainly selected from the agri-food sector, where the highest potential is associated with vegetable oils.

Moreover, due to the increase in crude oil prices and environmental concerns, researchers showed renewed interest in vegetable oils for producing a suitable alternative to diesel fuel [2, 3]. Recent studies are mainly focused on the comparison of sunflower biodiesel with commercial biodiesel in terms of emissions and performance of an engine using various biodiesel blends [4], and concluded that the use of sunflower biodiesel and commercial biodiesel blends reduces $NO_x$ by 15% at high loads of 3000 W. Verma et al. [5] used experimental and empirical approaches to characterize the fuel blends (diesel and roselle biodiesel), while operating at engine loads of 25, 50, 75, and 100%, with fuel injection timing of 19º, 21º 23º, 25º, and 27º before top dead center.

The addition of roselle-based biodiesel lowered the emissions of $NO_x$ and smoke which shows the potential of using this feedstock as an alternative liquid fuel. Tran et al. [6] tested the performance of diesel ultra-low sulfur-fuel (ULSF) and its blends with biodiesel based on coconut oil methyl ester (from 10 to 50%). They concluded that the addition of biodiesel improved the low viscosity of ULSF; however, the power and torque of the engine when using biodiesel fuels have decreased by 3–6% in comparison to ULSD. Furthermore, the addition of bioethanol to a diesel-coconut biodiesel blend improved further the $NO_x$, CO, and smoke emissions [7]. In general, biodiesel blends show better combustion performance (i.e., lower emission rates) at higher compression rates [8, 9]. Abu-Zaid [10], performed tests on diesel engines using 100% biodiesel alone and concluded that the brake power and thermal efficiency increased significantly.

Large quantities of corn are subjected to starch and ethanol production, where the corn oil remains as a by-product [11], which arises its high potential to be a feedstock for biodiesel. The corn-oil-based biodiesel was found to be successfully supplied in diesel engines after modifying it with pentanol and titanium dioxide, where for selected mixtures, it improved the brake power and thermal brake efficiency [12]. Furthermore, the co-combustion of corn-oil biodiesel and diesel decreases the $NO_x$ emission, due to the reduction of in-cylinder temperature. On the other hand, the abovementioned blends cause an ignition delay which directly affects the increased CO content in the exhaust [13].

Palm oil is one of the most prospective feedstocks for biodiesel production in the world as palm trees require fewer fertilizers, sunlight, water, and pesticides to produce one unit of oil per hectare compared to other oily plants [14]. Consequently, the lower market price than other oils make palm oil biodiesel an attractive fuel alternative for the energy and transportation sector. Furthermore, because of its high triglyceride content, palm oil indicates high conversion efficiency to biodiesel during transesterification [15]. The research performed by Devarajan et al. [16] proved that palm oil-based biodiesel can successfully be a feedstock for diesel engines; however, the obtained brake thermal efficiency was lower than for petroleum diesel at all tested loads.

In comparison to other biodiesels, sunflower oil-based fuel is found prone to oxidative degradation, hence it must be stabilized by antioxidants such as Orox PK, Naugard P and/or Anox 20 [17]. This drawback indicates the use of sunflower oil biodiesel mostly in fuel blends [18, 19, 20].

The objective of this study is to compare the performance of diesel engines, fuelled with various biofuel blends extracted from corn, sunflower, and palm oils, against pure petroleum diesel.

## MATERIALS AND METHODS

Materials used in the experiments included pure petroleum diesel, and biofuel blends extracted from corn, sunflower, and palm oils. Four fuel samples were tested: a biodiesel mixtures in proportion of 20% vegetable oils mentioned above, and 80% pure diesel.

The experiments were conducted in the Internal Combustion Engines Laboratory, Department of Mechanical Engineering, Faculty of Engineering at Mutah University, Jordan. The following procedures were used to produce the biodiesel blends:

- In a glass blender, 200 mL of methanol ($CH_3OH$) was poured, and 3.5 g of sodium hydroxide (NaOH) was added slowly at the lowest settings.
- After 2 minutes of stirring, 1 liter of vegetable oil (corn, palm, or sunflower) was added to the methanol and sodium hydroxide mixture.
- The mixer was mixed for 20 to 30 minutes on low speed.
- The mixture was poured into a glass jar and left for a few hours until it separated into two layers.
- The biodiesel (upper layer) was poured into a large glass container.

**Table 1.** Technical data of a PETTER PHIW diesel engine

| Technical data | Specification |
|---|---|
| Type | Lister LVI |
| Max. power | 7 kW at 2500 rpm |
| No. of cylinders | Single |
| Engine operation | Four stroke |
| Speed range | 1000–3000 rpm |
| Compression ratio | 17:1 |
| Combustion chamber | Direct injection |

The experiments in this study were conducted with a 1-cylinder, four-stroke engine. The specifications of the test engine were presented in Table 1. Before executing the tests, the engine was run for 10 minutes with no load using only diesel fuel, and then the operational status of the measuring parameters of the equipment was evaluated. The engine then operated for 30 minutes at 50% load and 1500 rpm to stabilize its thermal status.

## RESULTS AND DISCUSSION

Typically, alternative fuels for engines are evaluated based on engine performance. The most important parameters considered by researchers in the field of internal combustion engines are power output, brake thermal efficiency, brake-specific fuel consumption, and exhaust gas temperature.

### Effects on torque

Figure 1 illustrates the relationship between torque and brake power for various biodiesel blends. Torque represents a fundamental performance parameter for the engine, and the magnitude of the rotational effort developed by the engine against a torque load applied. The graph demonstrates that torque increases, reaches a maximum, and then decreases. Palm biodiesel has the highest torque, whereas sunflower and corn biodiesels have torque lower than conventional diesel. The maximum brake torque is 21.4 J for palm oil biodiesel, and the minimum value is 18 J for sunflower biodiesel.

### Effects on the break mean effective pressure

The relation between break mean effective pressure (BMEP) and brake power is depicted in Figure 2. The BMEP is a function of torque, and as anticipated, as brake power increases, the BMEP increases, reaches its maximum, and then decreases. The graph demonstrates that palm has the maximum values at 950 kPa and 3.5 kW. This value was 4% greater than that of diesel. It is worth mentioning that the palm biodiesel has BMEP higher than the rest of the blends. This trend can be explained by the oxygenated conditions of the palm blend, which promote more uniform combustion of the fuel [21]. The minimum BMEP was 872 kPa using sunflower.

### Effects on total fuel consumption

Figure 3 illustrates the relationship between total fuel consumption and brake power. It is obvious from the chart that the fuel consumption of biodiesel and pure diesel increases proportionally with brake power. Sunflower biodiesel appears to utilize significantly less fuel compared to other blends. The trends indicate that the percentage reduction in total fuel consumption is inversely proportional to the brake power.

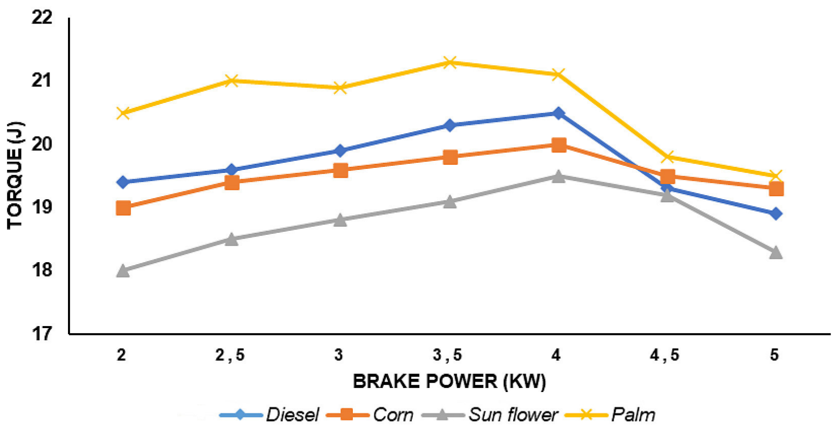


**Figure 1.** Torque vs brake power

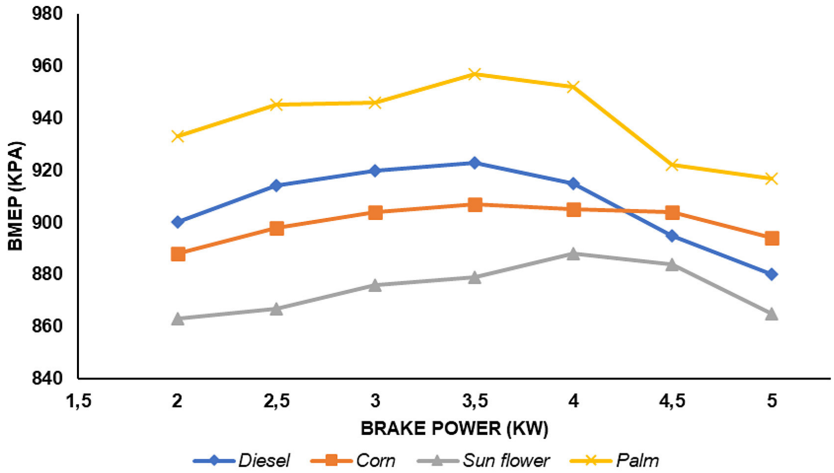


**Figure 2.** Break mean effective pressure vs brake power

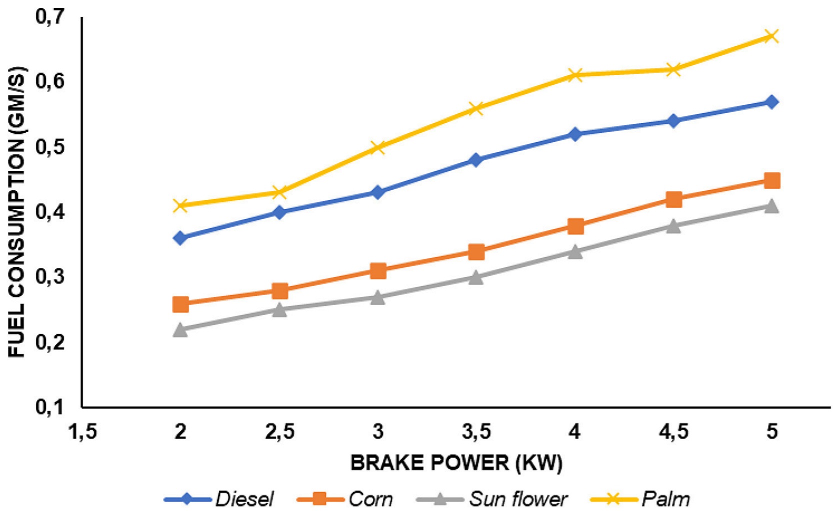


**Figure 3.** Fuel consumption vs brake power

## Effects on break-specific fuel consumption

The break-specific fuel consumption (BSFC) is the actual mass of fuel consumed to produce 1 kW in an hour. It is the ideal criterion to compare the economic performance of an engine, since it takes care of both the mass flow rate and the heating value of the fuel. Figure 4 depicts the BSFC for various biodiesel blends and pure diesel. The BSFC of all tested fuels is found to decrease with an increase in brake power, reaching a minimum value commonly referred to as the optimum point (the fuel burned to produce the maximum brake power), and then rising as the power output increases. This may be attributed to the lower heating value, higher density, viscosities, and boiling point of biodiesel blends compared to pure diesel. It is clear from the figure that the BSFC for all biodiesel blends is higher than that of pure diesel.

## Effects on exhaust gas temperature

The variation of exhaust gas temperature with brake power is shown in Figure 5. From the graph, as brake power goes up, so does the exhaust gas temperature. The increase of total energy at higher brake power followed the higher fuel consumption. Moreover, blended biodiesel has a lower exhaust temperature than pure diesel. This is due to the combustion of biodiesel blends, which have a lower heating value, higher density, and increased viscosity, resulting in inadequate atomization and fuel vaporization, thereby lowering the exhaust gas temperature. Since $NO_x$ is formed more easily at higher temperatures, exhaust temperature has a direct effect on $NO_x$ emissions as stated by Pandey et al. [22]. As a result, biodiesel blends used in diesel engines reduce the amount of $NO_x$ released into the atmosphere.

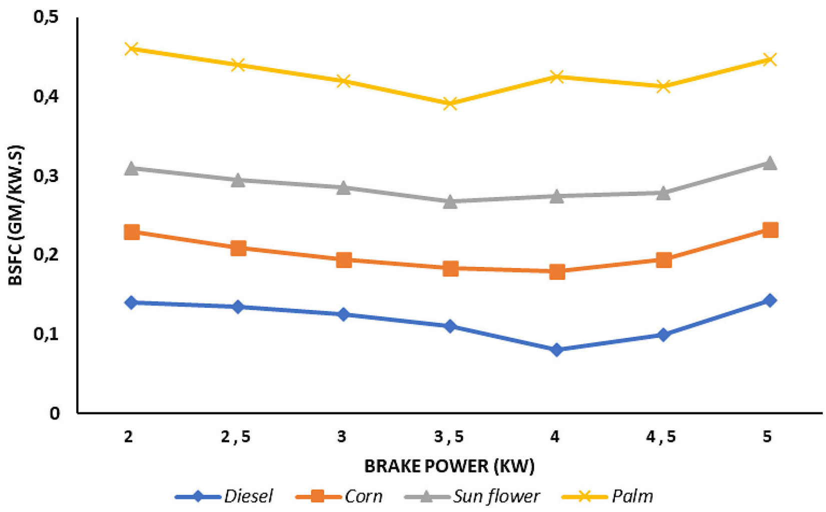


**Figure 4.** Break-specific fuel consumption vs brake power

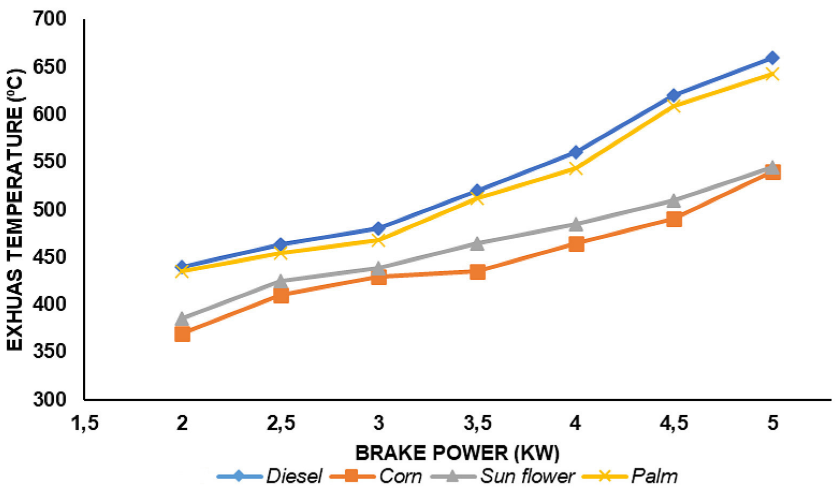


**Figure 5.** Exhaust gas temperature vs brake power

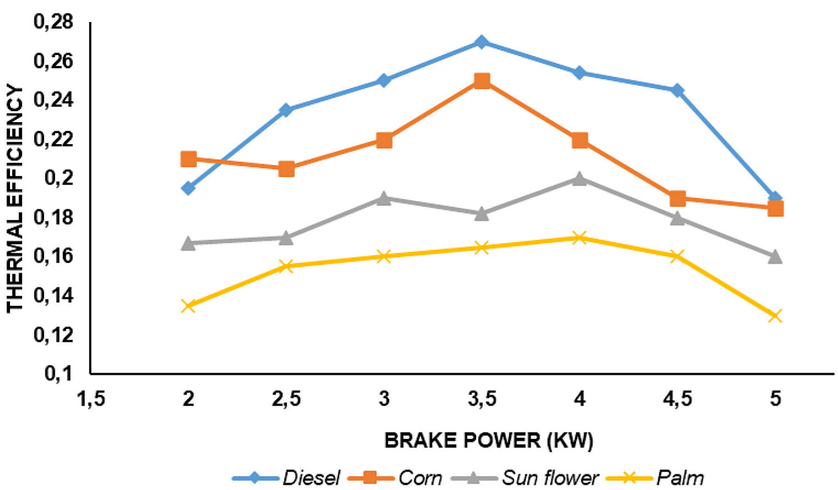


**Figure 6.** Thermal efficiency vs brake power

### Effects on brake thermal efficiency

Brake thermal efficiency, also known as the fuel conversion efficiency, is the proportion of fuel energy that is converted into useful energy. If different fuels are to be compared for the same engine, brake thermal efficiency is the most suitable parameter instead of specific fuel consumption.

Brake thermal efficiency versus brake power for all the fuels used in the experiment was illustrated in Figure 6. It was shown that pure diesel has the highest value of brake thermal efficiency. This may be attributed to better spray characteristics in the combustion chamber, which leads to effective utilization of air resulting in more complete combustion. Due to greater viscosity and low heating value of the biodiesel blends, the brake thermal efficiency was notably decreased when compared with pure diesel.

## CONCLUSIONS

In this study it was found that using biodiesel blends as fuel for diesel engine reduces $NO_x$ emissions compared to pure diesel. Moreover, diesel engines can operate with biodiesel blends without requiring any engine modifications. Results showed that palm biodiesel appears to be the best blend for use in diesel engines among others used in tests. It produced greater torque and brake mean effective pressure. However, pure diesel had a higher thermal efficiency, and a lower brake-specific fuel consumption, compared to the biodiesel blends considered in tests.

### Acknowledgements

The authors are grateful to the Middle East University, Amman, Jordan, for the financial support granted to cover the publication fees of this research article.

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