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Article

Investigation of the Impact of Castor Biofuel on the Performance and Emissions of Diesel Engines

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Abstract: Fossil fuel is a non-renewable fuel, and with the development of modern industry and agriculture, the storage capacity of fossil fuels is constantly decreasing. In this study, a systematic study and analysis were conducted on the combustion characteristics, engine performance, and exhaust emission characteristics of castor biodiesel–diesel blends and pure diesel fuel in different proportions at different speeds of a single-cylinder four-stroke diesel engine under constant load. The castor biodiesel required for the experiment is generated through an ester exchange reaction and mixed with diesel in proportion to produce biodiesel–diesel blends. The experimental results show that as an oxygenated fuel with a higher cetane number, the CO, HC, and smoke emissions of diesel and B80 blend fuel at 1800 rpm were reduced by 16.9%, 31.6%, and 68%, respectively. On the contrary, the NOx and CO_2 emissions increased by 17.3% and 34.6% compared to diesel at 1800 rpm. In addition, due to its high viscosity and low calorific value, the brake thermal efficiency and brake-specific fuel consumption of the biodiesel–diesel blends are slightly lower than those of diesel, but the biodiesel–diesel blends exhibit lower exhaust gas temperatures. Comparing B80 and diesel fuel at 1800 rpm, the BSFC of diesel at 1800 rpm is 3.12 kg/W·h, whereas for B80 blended fuel, it increases to 4.2 kg/W·h, and BTE decreases from 25.39% to 21.33%. On the contrary, B60 blended fuel exhibits a lower exhaust emission temperature, displaying 452 °C at 1800 rpm. Based on the experimental results, it can be concluded that castor biodiesel is a very promising clean alternative fuel with low waste emissions and good engine performance.

Keywords: biofuel; diesel engines; engine performance; exhaust emissions; castor plant

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1. Introduction

Diesel engines are widely used in transportation, industry, agriculture, and navigation due to their high power, high thermal efficiency, good durability and service life, and low fire risk [1,2]. Diesel is the main fuel for diesel engines and is a non-renewable fossil fuel that requires a long period of evolution. With the continuous development of modern industrial and agricultural civilization, the storage of fossil fuels has sharply decreased, and diesel prices are also constantly rising. In addition, diesel engines generate a large amount of exhaust emissions during use, causing significant damage to the ecological environment. In order to improve environmental issues worldwide, various countries have taken various measures separately. The European Commission has passed a series of agreements hoping to reduce greenhouse gas emissions by more than 55% by 2023 compared to 1990. China has implemented the "Green Great Wall Plan", reducing and closing factories with high pollution, and implementing the latest vehicle usage system to improve the protection and restoration capabilities of the ecosystem. The Environmental Protection Agency of the United States has enacted the Clean Air Act to limit air pollution and designated the Clean Water Act to protect water sources. Japan's "Sustainable Energy Development Strategy" aims to increase the utilization rate of renewable energy to 22–24% by 2040. Various issues have sparked strong interest among scholars around the world in alternative fuels for diesel engines, hoping to find a renewable alternative fuel that is beneficial to the environment.

Biodiesel is a clean and renewable green fuel that is sustainable, renewable, biodegradable, and environmentally friendly. It can be obtained from plants, animal fats, and waste edible oils [3]. Compared with diesel, biodiesel has an oxygen content of around 9–12%, which can effectively reduce the exhaust emission temperature and CO, HC, smoke, and other exhaust emissions [2,4,5]. Polycyclic aromatic hydrocarbon emissions (PAH) are hazardous due to their toxicity, and biodiesel does not contain aromatic compounds, which can reduce the emission of toxic gases [6]. In addition, the cetane number of biodiesels is generally higher than that of diesel, and a high cetane number will reduce the ignition delay of the engine, thereby enabling more complete combustion of fuel in the engine, improving combustion efficiency, reducing fuel waste, improving engine fuel economy, and reducing exhaust gases and harmful emissions caused by incomplete combustion.

So far, biofuels have become one of the most important development directions for alternative fuels for automobiles, and technological and industrial upgrading and transformation are brewing. Figure 1 illustrates the changes in the raw materials required for the production of biodiesel fuel. Initially, biodiesel was produced from edible food crops, with extremely high production costs and a high demand for water, fertilizers, and land area. With the deepening of research, the use of non-edible lignocellulose, food crop waste, urban catering waste, and algae as the main production of biofuels has become dominant [7]. Non-edible crops and food waste do not conflict with food resources and reduce environmental pollution issues. As shown in Figure 2, castor is a perennial herbaceous plant. The castor plant oil produced by its seeds has a slight pungent odor, a light-yellow color, and is not easily volatile. It is often used as a laxative in medicine. Castor bean seeds contain a substance called ricin, which affects the synthesis of proteins in the human body and is a non-edible oil crop [8]. In addition, castor bean has particularly excellent drought resistance, which can rapidly grow and reproduce in arid areas while also playing a green role in the natural environment. Compared to other oil crops, castor bean seeds have the advantages of high yield, high oil content (about 40–60%), and low production costs, which have good economic benefits [9].

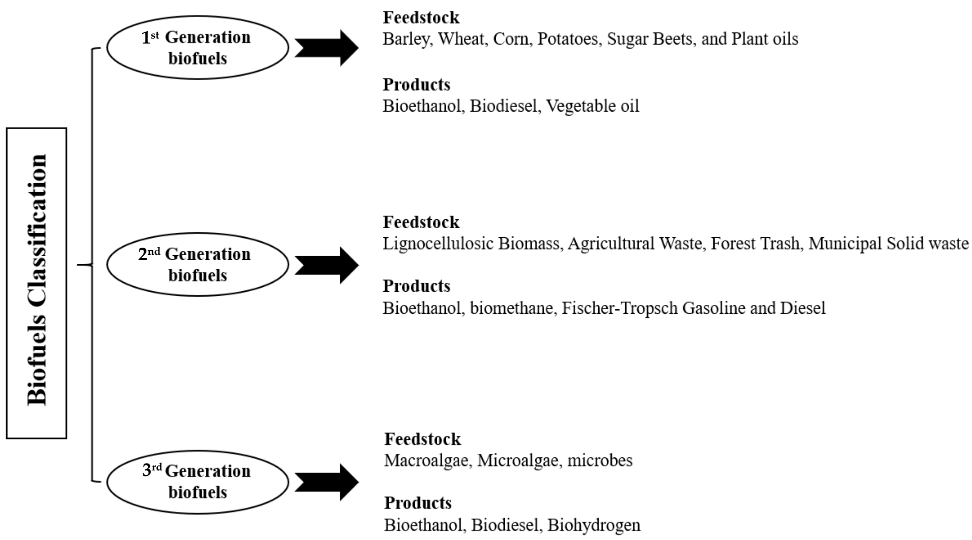

Figure 1. Changes in raw materials used for biofuel production [10].

Figure 2. Castor plant.

The research results of many scholars have shown that the use of biodiesel–diesel blends effectively reduces the emissions of some harmful gases. Akash Deep et al. [11] reported that the CO and HC emissions of B10 and B20 castor biodiesel–diesel blends were lower than other experimental fuels, and the lowest exhaust emission temperature under B20 blends reflects the conversion of maximum heat energy into useful work. For NOx emissions, there is not much difference among all experimental fuels, which is attributed to the fact that the peak temperature in the cylinder of all experimental fuels is almost the same. Prasert Aengchuan et al. [12] found that the mixture of castor biodiesel and ethanol can optimize the fuel performance of ethanol–diesel, thereby not being limited by diesel fuel usage regulations. With the combustion of castor oil blended fuel, the HC and CO emissions of castor biodiesel–diesel blends slightly increase, but the NOx emissions show a decreasing trend. Compared with diesel, the smoke emissions have not changed much. Roopesh Kanwar Gaur et al. [13] studied the exhaust emissions of waste edible oil biodiesel mixed with diesel in diesel engines. Biodiesel, due to its high oxygen content, increased CO_2 and NOx emissions compared to diesel, but significantly reduced emissions of incomplete combustion products such as CO, HC, and PM. Hafiz Muhammad Bilal Ameer et al. [14] compared the engine performance and exhaust emissions of several different types of biodiesel with diesel. Among them, the combustion performance curve of the B20 Jatropha biodiesel–diesel blend was the closest to that of diesel. Compared with the other biodiesel–diesel blends, the B20 Jatropha biodiesel–diesel blend also showed the highest thermal performance. Selvakumar Ramalingam et al. [15] investigated the performance and emissions of Moringa biodiesel–carbon black-water emulsion of diesel blends in a conventional diesel engine. Research has shown that this hybrid fuel has the same performance, combustion, and emission characteristics as traditional diesel, which helps to control air pollution while ensuring engine power and economy.

The castor plant has many advantages mentioned above, but it has not been widely used in commerce. This article believes that its easy survival, high oil content, and inedibility can be used as a good raw material for producing biodiesel. In addition, using castor oil to produce biodiesel is carbon neutral, and castor plants can absorb carbon dioxide during their growth process, improving the greenhouse effect. This study investigated the performance and exhaust emission characteristics of a single-cylinder four-stroke diesel engine using different castor biodiesel–diesel blends and diesel alone. The experiment was conducted at 75% constant load and different rotational speeds (1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm) to determine the optimal ratio of castor biodiesel to diesel, evaluate its feasibility as a substitute for diesel, and its potential environmental and economic advantages. I hope this study can provide strong support for reducing fossil fuel dependence, improving air quality, reducing greenhouse gas emissions, and promoting the achievement of sustainable development goals.

2. Materials and Methods

2.1. Experimental Equipment

This experiment was completed under constant load and different rotational speeds (1200 ppm, 1400 ppm, 1600 ppm, and 1800 ppm). The four-stroke single-cylinder water-cooled agricultural diesel engine used in the experiment is shown in Figure 3, with a rated output power of 7.4 kW. The power output under constant load conditions in the experiment was measured using an eddy current dynamometer. The distribution diagram of the experimental device and the detailed specifications of the engine are detailed in Figure 4 and Table 1, respectively.

Figure 3. Experimental engine.

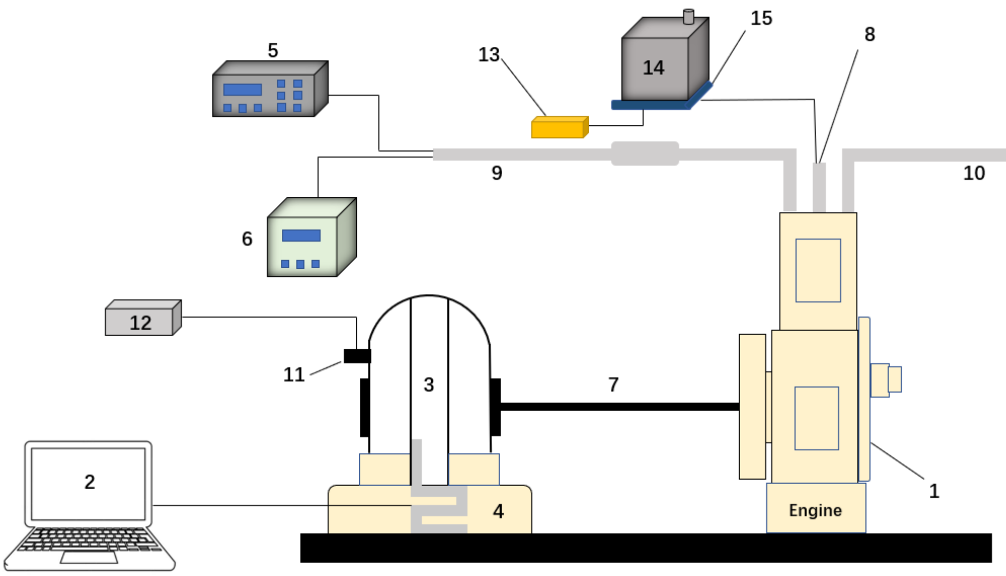

Figure 4. Experimental setup. (1) Single-cylinder water-cooled diesel engine; (2) torque measurement; (3) Eddy current dynamometer; (4) load cell for torque; (5) gas emission analyzer; (6) smoke analyzer; (7) propeller shaft; (8) injector; (9) exhaust pipe; (10) air intake; (11) RPM sensor; (12) RPM display; (13) fuel weight display; (14) fuel tank; (15) load cell for fuel weight.

Table 1. Engine specification.

Parameters	Description
Engine Type	Horizontal, 4-stroke
Manufacture	Daedong Ltd., Daegu City, Republic of Korea
Engine Cooling	Water Cooled
Rated Power Output (kW)	7.4
Injection Pressure (kg cm^{-2})	200
Number of Cylinders	1
Displacement (cc)	673
Compression Ratio	21
Bore (mm)	95
Stroke Length (mm)	95

The combustion gas is analyzed and measured using the CGA-4500 gas analyzer (Jastec Ltd. in Seongnam, Republic of Korea) shown in Figure 5. The exhaust gas analyzer sucks the gas into the condenser through a gas sampling probe and then filters out the gas particles through a particle filter before entering the gas analyzer sensing chamber. The final result is displayed on the display screen. The BS-8000 smoke meter (Auto Company Ltd., Seoul, Republic of Korea) (Figure 6) is used to detect engine smoke emissions. The working principle is similar to that of the CGA-4500 gas analyzer, and the exhaust emission temperature is measured using a K-type thermocouple with a measurement range of 0–1200 °C.

Figure 5. CGA-4500 gas analyzer.

Figure 6. Smoke opacity meter (Model: BS-8000).

During the experiment, first start the engine and set the load and speed to 75% and 1200 rpm, respectively. After the engine runs smoothly, obtain readings from the experimental equipment, and then adjust the engine speed to 1400 rpm, 1600 rpm, and 1800 rpm in sequence. After each adjustment, wait for the engine to run smoothly before collecting data. Each speed is collected four times, with an interval of two minutes between each collection. Finally, the average value of the results is taken. After the experiment of fuel is completed, completely pour out the fuel in the fuel tank and then pour in new experimental fuel. After replacing the fuel, start the engine and run for a certain period of time to ensure that the last experimental fuel in the engine is completely depleted.

2.2. Error Analysis and Uncertainty

During the experimental process, errors and uncertainties in the experimental results caused by factors such as experimental environment, excessive operation, data collection, and experimental conditions are inevitable and can have adverse effects on the experimental results. The error and uncertainty analysis of the gas analyzer and K-type thermocouple used in the experiment is shown in Table 2. In order to eliminate these errors, mathematical and statistical methods were used in the collection and calculation of experimental data.

Table 2. Measurement and error range of experimental equipment.

Exhaust Emission	Accuracy and Uncertainties	Resolution	Range
CO_2	±0.1%	%	0.0–20.0
CO	±0.01%	%	0.00–10.00
O_2	±0.1%	%	0.00–25.00
HC	±1 ppm	ppm	0–10,000
NOx	±1 ppm	ppm	0–5000
Thermocouple (K-Type)	±0.1 °C	°C	0–1200
Smoke	±0.05%	%	0–100

2.3. Biodiesel Production

Ester exchange reaction is the most commonly used method for producing biodiesel at present. Its principle is to react with free fatty acids (FFA), oil, or fats through methanol under the action of a catalyst, thereby generating fatty acid methyl esters (FAME). Potassium hydroxide (KOH) and sodium hydroxide (NaOH) are widely used in ester exchange reactions due to their high catalytic activity, short reaction time, and high raw material conversion rate. The production process of castor biodiesel is as follows:

(1) As shown in Figure 7, first, use a magnetic stirrer to stir 125 mL of methanol and 2.5 g of potassium hydroxide until they are completely mixed. To reduce the viscosity of vegetable oil, heat 500 mL of castor plant oil to above 30 °C.
(2) Pour the methanol potassium hydroxide mixture into castor plant oil while stirring, and place it on a magnetic stirrer. Stir evenly at a constant speed of 700 rpm, maintain the reaction temperature at 55 °C–60 °C, and continue the reaction for 2 h.
(3) After the reaction, the mixture is left to stand in a separating funnel for more than 12 h. The mixture is divided into two layers, with methyl ester at the top.
(4) After removing the glycerol mixture at the bottom, wash the methyl ester 4–5 times with hot water above 90 °C to remove impurities. Then, heat the washed biodiesel to above 100 °C and maintain it for 20 min until the excess water evaporates completely.

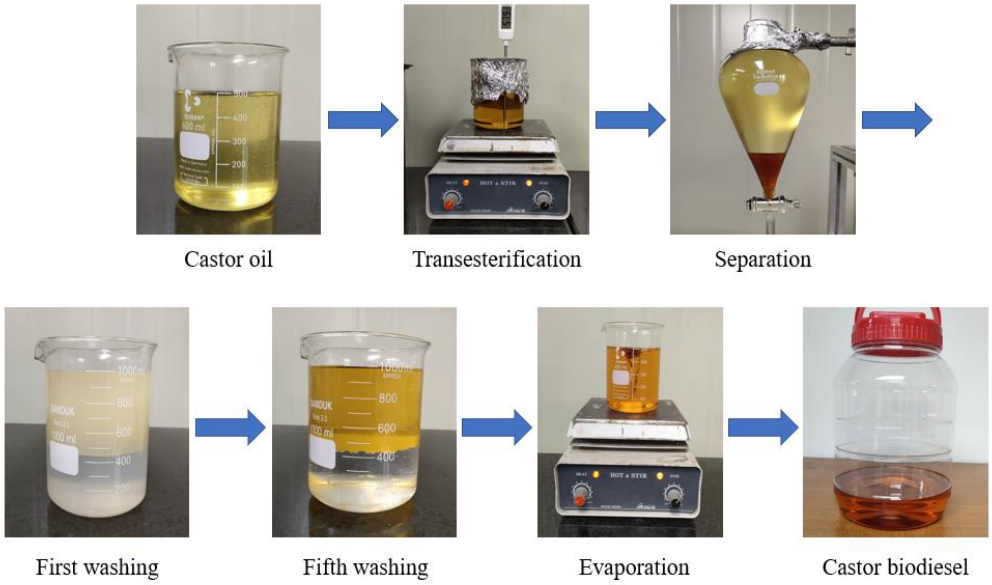

Figure 7. Castor biofuel ester exchange process.

2.4. Castor Biodiesel Characteristic

Table 3 provides a detailed list of the physical and chemical properties of diesel fuel and four blend fuels used in this experiment. By analyzing the chart information, it can be seen that the characteristics of the blends are relatively similar to diesel fuel and fully comply with the ATS standards shown in Table 4.

Table 3. Properties of diesel and castor seed biodiesel.

Property	Standard (ASTM)	Castor Biodiesel	B20	B40	B60	B80	Diesel
Density (kg/m^3)	800–880	896	831	843	851	869	820
Cetane Number	48–65	62	50	53	56.5	59	48.7
Flash Point (°C)	>130	102	75	79	85	93	58
Kinematic Viscosity (mm^2/s)	1.9–6	7.35	3.34	4.61	5.42	5.94	2.87
Calorific Value (MJ/kg)	>35	38.156	44.121	43.855	41.564	40.152	45.512

Table 4. ASTM standards for fuel.

Test	ASTM Limits	ASTM Test
Cetane Number	40 min	D613 [16]
Kinematic Viscosity (mm^2/s)	1.9–4.1	D445 [16]
Density	15–35 °C	D5002 [16]
Flash Point (°C)	52 °C min	D93 [16]
Pour Point (°C)	4.4–5.5 °C	D97 [16]

3. Results and Analysis

3.1. Hydrocarbon (HC)

Figure 8 is a schematic diagram of the relationship between HC and speed at 75% load. From the graph, it can be seen that among all experimental fuels, the HC emissions of diesel are much higher than those of biodiesel blends. At various speeds, the emissions are 70 ppm, 66 ppm, 61 ppm, and 57 ppm, respectively. By increasing the percentage of biodiesel in the blends, the oxygen content in the biodiesel–diesel blends can be increased, allowing the fuel to burn more fully [17]. In addition, as the proportion of biodiesel increases, the cetane number of the mixed fuel increases, which improves combustion efficiency while reducing HC emissions [18]. It was also observed that as the engine speed increased, the HC emissions of all experimental fuels showed a decreasing trend. This is because at high speeds, the combustion process of the engine is more complete, and the fuel is burned more fully, which can reduce the release of unburned hydrocarbons in the exhaust. In addition, high-speed combustion is often accompanied by higher temperatures and pressures, which help achieve better mixing and combustion in the combustion chamber. Compared with the research results of other researchers, we found the same trend, that is, the HC emissions of castor biodiesel blends are lower than that of diesel fuel [19,20], which further confirms that biodiesel fuel has lower HC emissions.

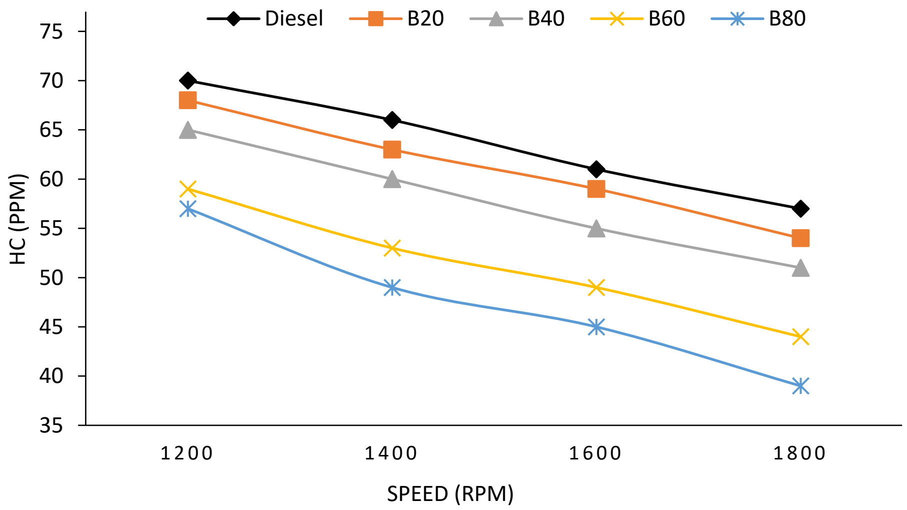

Figure 8. HC changes with fuel type and engine speed.

3.2. Carbon Dioxide (CO_2)

It is evident from Figure 9 that the CO_2 emissions of biodiesel–diesel blends are higher than those of pure diesel fuel. The CO_2 emissions of diesel fuel at four different speeds are shown to be 1.4%, 1.5%, 2%, and 2.6%, respectively, which is the lowest among all experimental fuels. As the proportion of biodiesel continues to increase, the oxygen content of the blends increases. Oxygen is released during the combustion phase to promote combustion, and excess oxygen atoms undergo oxidation reactions with carbon atoms [21], resulting in an increase in CO_2 emissions. B80 blend has the highest CO_2 emissions among all experimental fuels. As the engine speed increases, the engine produces a higher combustion temperature, and carbon atoms in the fuel are more easily oxidized to form CO_2. The CO_2 emissions of all experimental fuels show an increasing trend. In addition, as the engine speed increases, the total amount of fuel entering the cylinder for combustion also increases [22], which is another reason for the increase in CO_2 emissions. Sadegh Azizzadeh Hajlari et al. [23] also observed a similar trend when using castor biodiesel blends, where CO_2 emissions increased compared to diesel.

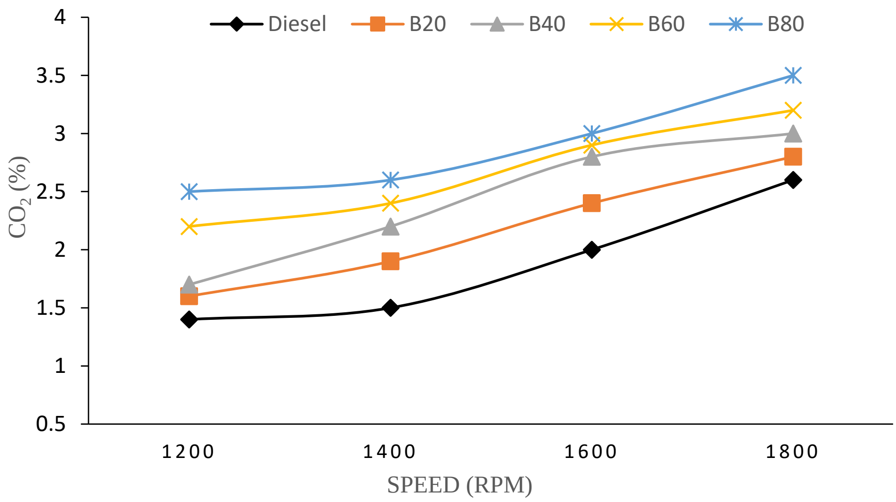

Figure 9. CO_2 changes with fuel type and engine speed.

3.3. Carbon Monoxide (CO)

Similar to the generation principle of HC, CO is a product of incomplete combustion. As shown in Figure 10, among the five experimental fuels, pure diesel has the highest CO emissions, with 1.11%, 0.89%, 0.78%, and 0.71% at each speed, respectively. As the proportion of biodiesel in the blends continues to increase, CO emissions show a downward trend. Among them, B80 mixed fuel has the lowest CO emissions, with 0.89% and 0.72% at different speeds, respectively, as well as 0.64% and 0.59%. This phenomenon is due to the presence of oxygen in biodiesel, which effectively promotes combustion to a certain extent, increases combustion temperature, increases the oxidation rate of carbon atoms, increases CO_2 emissions, and decreases CO emissions [24]. In addition, in diesel engines, the cetane number is an important parameter that can improve combustion. As a high cetane number fuel, the use of biodiesel reduces incomplete combustion rate [25]. When the engine speed increases, the combustion temperature and pressure increase, which promotes the oxidation reaction and continuously reduces CO emissions. Compared with other researchers' experimental results, it was found that when castor biodiesel was mixed with diesel, CO emissions were significantly reduced. They explained that the improved fuel atomization effect at higher temperatures reduced the occurrence of localized fuel-rich areas [11]. The results of this article confirm this result and emphasize the role of castor biodiesel blends in reducing CO emissions.

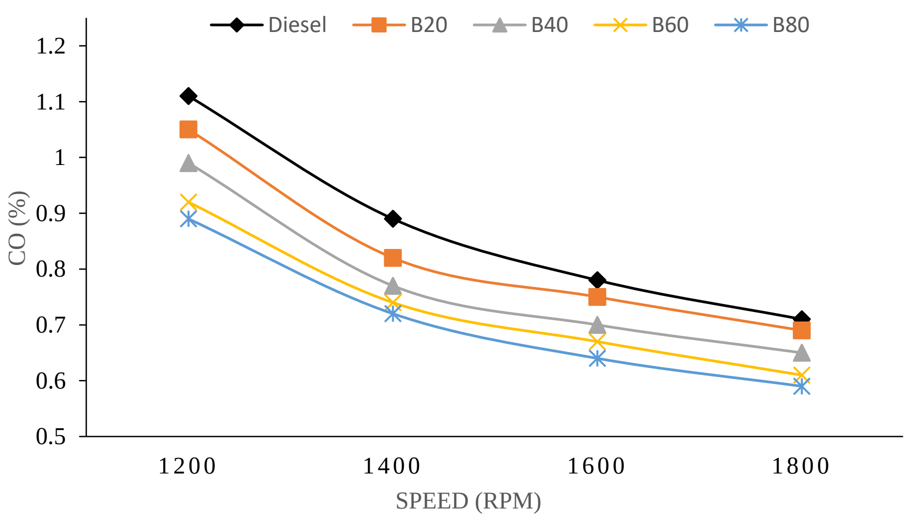

Figure 10. CO changes with fuel type and engine speed.

3.4. Nitrogen Oxide Compound (Nox)

Figure 11 is a schematic diagram of the changes in the speed of five different experimental fuels. It can be clearly seen from the figure that the NOx emissions of diesel are the lowest among all experimental fuels. The NOx emissions of biodiesel–diesel blends are higher than those of diesel and increase with its specific gravity. On the one hand, the cetane number of biodiesel–diesel blends is higher than that of diesel, which has better self-ignition performance. The blends burn earlier in the injection and compression stages, the ignition delay time decreases, and on the other hand, the oxygen and nitrogen atoms in biodiesel undergo chemical reactions to form nitrogen oxides, resulting in an increase in NOx emissions [26]. As the speed increases, the combustion process becomes faster and more intense. This will cause an increase in the temperature inside the combustion chamber, as each combustion process takes a shorter time but releases more concentrated energy. A higher combustion temperature will promote the faster reaction of nitrogen and oxygen atoms in the air, generating more NOx. Comparing our results with other experimental results, A. Velmurugan et al. [27] also found a similar trend. In their experiment, the NOx emissions of biodiesel were also higher than those of diesel, but after adding nitrogen, the NOx emissions decreased because nitrogen, as an inert gas, would lower the combustion temperature.

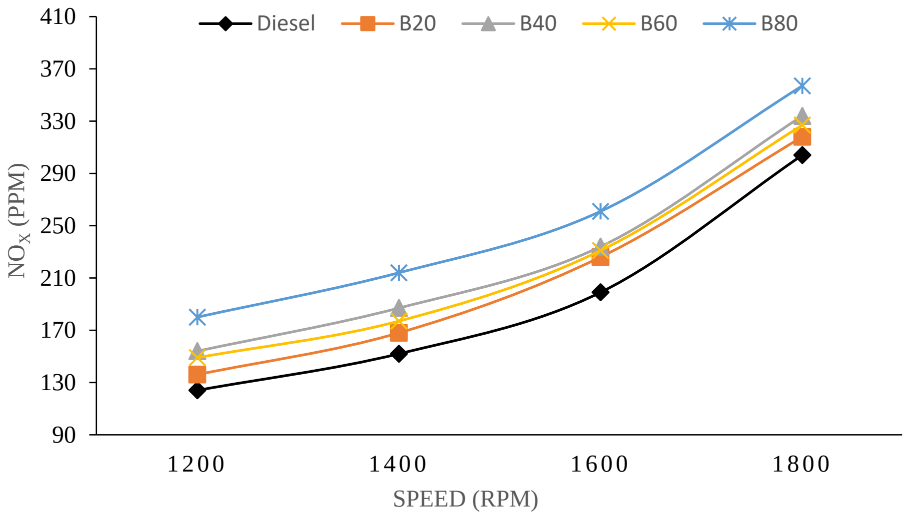

Figure 11. NOx changes with fuel type and engine speed.

3.5. Smoke

Smoke is a harmful gas produced during incomplete combustion, and the engine's operating status can be judged by its emission [28]. Figure 12 depicts the variation in smoke emissions with engine speed for different fuels. Among them, pure diesel fuel has the highest smoke emissions. On the contrary, the B80 biodiesel blend has the lowest emissions. Compared with diesel fuel, smoke emissions when using the B80 biodiesel blend are effectively reduced by more than 50%, which can be explained by the biological diesel with lower carbon and sulfur content, no aromatic compounds, and higher oxygen content. These characteristics enable better combustion of blends added with biodiesel, thereby reducing smoke emissions [29]. From the observation results, it can be seen that smoke emissions show a significant decreasing trend with an increase in engine speed. Higher combustion temperatures at high speeds promote a more complete combustion process, thereby reducing the formation of unburned carbon particles. This is considered a major reason for the reduction in smoke emissions. Compared with previous research results [30–32], it was found that the use of biodiesel blends significantly reduced smoke emissions, which is similar to our experimental results. These conclusions also suggest that the higher the oxygen content in the fuel, the lower the smoke emissions, as oxygen accelerates the oxidation of soot.

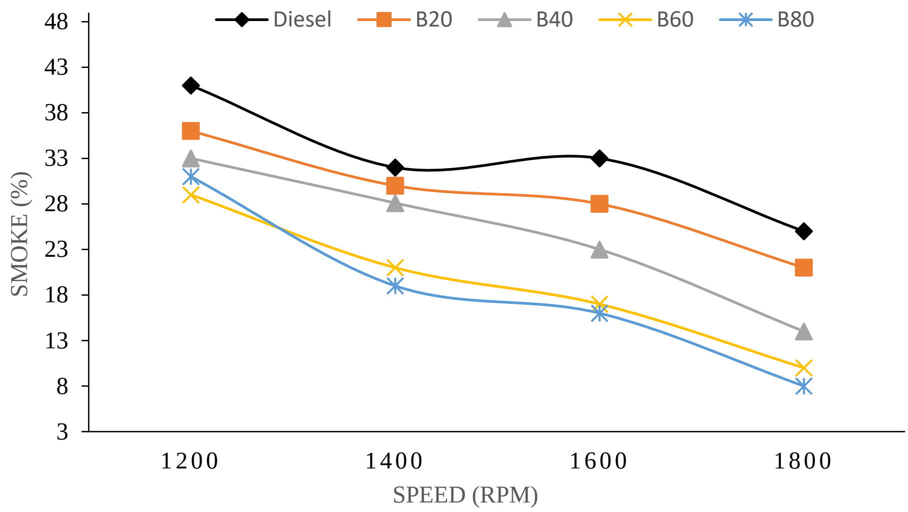

Figure 12. Smoke changes with fuel type and engine speed.

3.6. Brake Thermal Efficiency (BTE)

The average BTE of biodiesel–diesel blends and diesel fuel is shown in Figure 13. It is observed that diesel fuel has the highest BTE. At the same speed, the BTE of biodiesel–diesel blends is generally lower compared to diesel. Moreover, as the content of biodiesel in the blends increases, the BTE shows a lower result. This may be due to the high density and viscosity of biodiesel, as well as the low calorific value [33,34]. This can lead to poor mixture generation and fuel atomization, resulting in incomplete combustion of the fuel in the combustion chamber, increasing fuel consumption while reducing combustion efficiency. All experimental fuels have the highest BTE at 1200 rpm, with diesel fuel, B20 blends, B40 blends, B60 blends, and B80 blends accounting for 33.73%, 31.31%, 29.35%, 27.24%, and 26.07%, respectively. When the engine speed increases, the BTE shows a decreasing trend. This may be because at high engine speeds, the mixing effect of air and fuel decreases and the atomization effect is poor [35], the combustion process is unstable, the efficiency of converting energy generated during fuel combustion into useful work decreases, and the BTE decreases. Comparing their research results, Youssef A. Attai et al. [36] found the same phenomenon when studying the emissions of castor biodiesel, that is, the addition of castor biodiesel to diesel fuel results in a decrease in BTE.

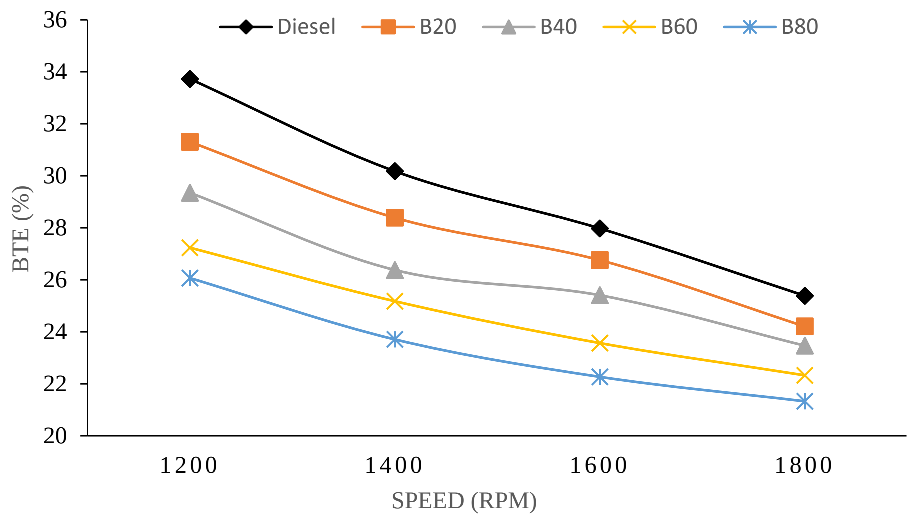

Figure 13. BTE changes with fuel type and engine speed.

3.7. Brake Specific Fuel Consumption (BSFC)

The BSFC of B20, B40, B60, and B80 blends and diesel fuel at the same speed are shown in Figure 14. The experiment found that the B80 blend has the highest BSFC, and shows better BSFC with a decrease in biodiesel content. Compared with the B80 blend, diesel fuel has the lowest BSFC, reducing by 31.7%, 30.7%, 30%, and 25.7% at the same speed, respectively. This can be attributed to the lower calorific value of biodiesel–diesel blends compared to diesel fuel, which requires more fuel consumption to obtain the same power as diesel [37]. When the engine speed increases, the BTE of the engine decreases because the combustion time is shortened and incomplete, which can cause fuel waste and correspondingly increase the BSFC. Compared with the research results of other scholars [38], when using castor biodiesel blend fuel, there is a varying degree of increase in fuel consumption compared to diesel, which is consistent with the conclusion of this article.

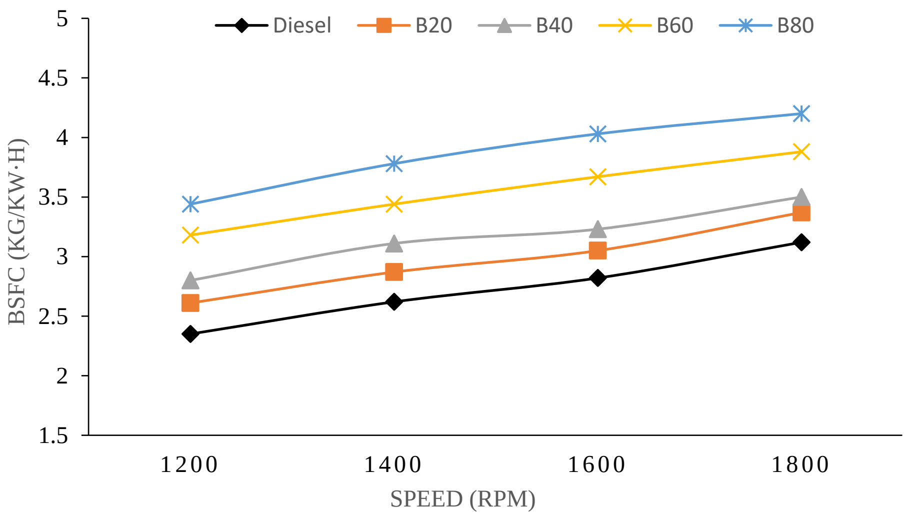

Figure 14. BSFC changes with fuel type and engine speed.

3.8. Exhaust Gas Temperature (EGT)

The exhaust gas temperature in a diesel engine reflects the heat released during the final stage of combustion, which is influenced by various parameters, including heat release rate, post-combustion effect, and combustion duration. When the temperature of the exhaust gas increases, it means that more heat is taken away by the exhaust gas, which actually represents an increase in the heat loss of the engine [39]. Figure 15 is a schematic diagram of the changes in all test fuels and engine speeds. At all engine speeds, diesel fuel has the highest exhaust emission temperature, while the B80 blend has the lowest exhaust emission temperature. At 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm, this performance is 401 °C, 415 °C, 432 °C, and 456 °C. The cetane number of biodiesel fuel is higher than that of diesel, making ignition easier and ignition delay time shorter [40]. This means that fuel can be burned earlier, and the fuel can be fully mixed during the combustion process, improving combustion efficiency and fuel economy and reducing exhaust emission temperature. When the engine speed increases, the engine consumes more fuel while gaining more power, resulting in an increase in exhaust emission temperature. Compared with previous experimental results, Ali M.A. Attia et al. [30] also found that diesel fuel had the highest EGT, while biodiesel blends had a lower EGT, further confirming the results of this experiment.

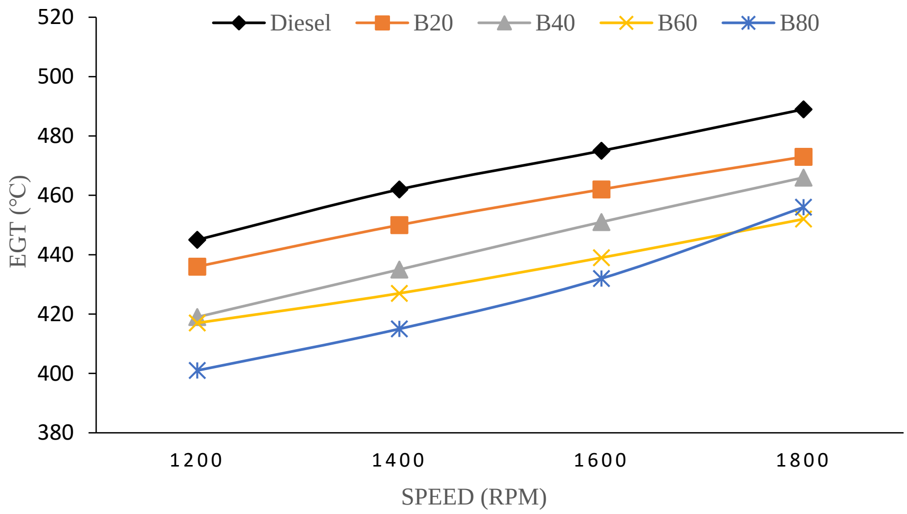

Figure 15. EGT changes with fuel type and engine speed.

4. Conclusions

In order to improve the shortage of fossil fuels and air pollution, and search for new clean alternative fuels, this study used castor plant oil as raw material to produce castor biodiesel using the ester exchange method. The physical and chemical properties of castor biodiesel were measured, which met ATSM standards. In order to measure the engine characteristics and emissions of castor biodiesel blends, experimental studies were conducted on a single-cylinder four-stroke engine at constant load (75%) and different engine speeds (1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm). The results are as follows.

Compared with diesel, the emissions of harmful gases such as CO, HC, and smoke generated during incomplete combustion of castor biodiesel blends are significantly reduced. Comparing the CO, HC, and smoke emissions of diesel and B80 blended fuel at 1800 rpm, the emissions were reduced by 16.9%, 31.6%, and 68%, respectively. On the contrary, due to the presence of oxygen in biodiesel and its release promoting combustion and oxidation reactions, the NOx and CO_2 emissions of B80 blended fuel increased by 17.3% and 34.6%, respectively, compared to diesel at 1800 rpm. For BSFC and BTE, as the proportion of biodiesel mixed with fuel increases, the BSFC of diesel at 1800 rpm is 3.12 kg/W·h, whereas for B80 mixed fuel, it increases to 4.2 kg/W·h, and BTE decreases from 25.39% to 21.33%. Due to the high cetane number, the ignition delay is shortened, the fuel combustion efficiency is improved, and the exhaust emission temperature is lower than that of diesel.

As the speed increases, HC, CO, and smoke emissions decrease due to the higher combustion temperature at higher speeds. As the rotational speed increases, the fuel consumption increases, the BSFC and exhaust emission temperature increase, and the engine BTE decreases. During this process, the oxidation reaction becomes faster, and NOx and CO_2 emissions increase.

Castor biodiesel, as a renewable energy source, can be mixed with diesel for use in existing diesel engines, which can to some extent reduce exhaust emissions. However, NOx and CO_2 emissions have increased compared to diesel, whereas BTE and BSFC performance has decreased. In future research, the addition of catalysts such as nano additives to biodiesel blends will be considered to improve these issues by changing the combustion rate, combustion area, and atomization effect. In addition, castor biodiesel raw materials are easy to obtain, survive, have high yield, high oil content, and have extremely high economic benefits. When applied in commercial applications, it has low risks and is an excellent clean alternative fuel.

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Nomenclature

RPM	Revolutions Per Minute
PPM	Parts Per Million
NaOH	Sodium Hydroxide
KOH	Potassium Hydroxide
BTE	Brake Thermal Efficiency
BSFC	Brake-Specific Fuel Consumption
EGT	Exhaust Gas Temperature
NOx	Nitrogen Oxide
CO	Carbon Monoxide
HC	Hydrocarbon
CO_2	Carbon Dioxide
B20	20% Biodiesel + 80% Diesel
B40	40% Biodiesel + 60% Diesel
B60	60% Biodiesel + 40% Diesel
B80	80% Biodiesel + 20% Diesel

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