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Combustion and Emission of Castor Biofuel Blends in a Single-Cylinder Diesel Engine

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Abstract: Fossil fuels confront the problem of strategic resource depletion since they have been continuously utilized for more than 200 years and cause serious damages to the ecological environment of the planet. In this work, the transesterification of castor plant oil was utilized to make biodiesel, and castor biodiesel's physicochemical qualities were assessed. On a single-cylinder, four-stroke, water-cooled agricultural diesel engine, an experimental study was conducted to compare and analyze the engine performance and emission characteristics of diesel and biodiesel blends in various amounts. The B20, B40, B60, and B80 biodiesel blends were evaluated at different engine speeds (1200, 1400, 1600, and 1800 rpm) with a constant engine load (50%). According to the experimental findings, the brake thermal efficiency (BTE) declines as the engine speed rises, and the biodiesel fuel blend has a lower brake thermal efficiency (BTE) than diesel fuel because of its higher density and viscosity and lower calorific value. The amount of gasoline required to create power increases as the speed does, and the brake-specific fuel consumption (BSFC) trend is upward. Due to their low calorific value and high viscosity properties, biodiesel blends have a greater brake-specific fuel consumption (BSFC) than diesel. The fuel's exhaust gas temperature (EGT) has an upward trend with an increased rotational speed. The biodiesel blend's high cetane number shortens the ignition delay and lowers the exhaust gas temperature (EGT) compared to diesel. A fuel with oxygen added, biodiesel enhances combustion, increases the combustion temperature, speeds up the oxidation process, and lowers carbon monoxide (CO) and hydrocarbon emissions. B80 produces the lowest carbon monoxide and hydrocarbon emissions at 1800 rpm, at 0.33%, and 30 ppm, respectively. On the other hand, increased carbon dioxide (CO_2) emissions result from a high oxygen concentration. In addition, compared to diesel fuel, biodiesel's greater combustion temperature causes the creation of increased nitrogen oxide (NOx) emissions. According to the research findings, a castor biodiesel fuel blend is an excellent alternative fuel for engines since it can be utilized directly without modifying the current engine construction and has good engine and exhaust emission performance.

Keywords: biofuel blends; diesel; emissions; engine performance

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1. Introduction

Nuclear energy, fossil fuels, and renewable energy are the three main types of energy. Fossil fuels are regarded as non-renewable resources since it takes a very long period for them to develop [1]. Since the Industrial Revolution, the development of contemporary industry has been considerably aided by the usage of fossil fuels. However, as fossil fuel use continues to rise, fossil fuel reserves are being used up quickly.

Furthermore, while people like the convenience they provide, the overuse of fossil fuels presents significant harm to the natural environment and human health. With the ongoing incidence of challenges, such as global warming, acid rain, and human health, the hunt for alternative renewable and clean fuels has become a primary goal for many researchers.

Up to the present, new alternative diesel engine fuels have mostly included compressed natural gas (CNG), ethanol and hydrogen, liquefied petroleum gas (LPG), and biodiesel [2–4]. With the depletion of fossil fuels and rising energy demand, researchers are focusing more on alternative renewable energy sources with the goal of replacing old fossil fuels with new energy sources [5,6].

In the alternative fuel business, a definition of biodiesel is broadly accepted. It is a form of alternative energy that can not only alleviate environmental problems but also reduces the use of fossil fuels. It is typically produced using the transesterification of vegetable oil or animal fat with methanol in the presence of a catalyst [7,8]. Biodiesel is one of several emerging alternative fuels that, due to its high oxygen concentration, high cetane number, and low sulfur content, can improve combustion efficiency, is less hazardous, and produces fewer greenhouse gases [9]. Furthermore, biodiesel is regarded as the best new alternative fuel because its renewability, biodegradability, and chemical and physical qualities are similar to diesel and may be utilized without modifying the existing engine construction. According to one study, using biodiesel fuel in engines can reduce carbon monoxide (CO), smoke, and hydrocarbon (HC) emissions. However, NOx (nitrogen oxide) emissions are rising since biodiesel is an oxygenated fuel that generates oxygen during combustion [10–12].

Non-edible oils, such as Jatropha curcas, Azadirachta indica, Karanja, castor, and Mahua, are more appropriate for biodiesel production than edible oil seed crops. They can reduce present fossil fuel shortages and environmental pollution without triggering problems with food supplies [13,14]. Castor, a member of the Eurphor biaceae family, is a widely widespread and easy-to-grow non-edible oil seed crop. It is grown in India, China, Brazil, Central Africa, Australia, and the United States, and it is resistant to dry environments. In nature, it may grow quickly in the desert, on hillsides, on alkaline soil, and in other dry and hard environments [15]. It may be employed as a new alternative fuel for engine production while also enhancing the natural environment. Furthermore, as compared to other vegetable oils, castor plant oil is poisonous and cannot be utilized as a food oil [16]. Furthermore, castor seeds have a large yield, a low price, and are easy to obtain, with an oil content of up to 40–60%. They are potential oil crops that have a substantial influence on biodiesel production.

Because biodiesel has a high viscosity, density, and volatility, it can affect engine performance to some level [17]. When biodiesel is used as an alternative fuel, it mostly utilizes a diesel–biodiesel combination, with catalysts, antioxidants, and other ways added to enhance engine efficiency and emissions.

Scholars have undertaken substantial studies over the years to determine the best type of biodiesel and biofuel–diesel mixture ratio, improve engine combustion performance, and minimize exhaust pollutants.

Akash Deep et al. [1] studied the performance and emissions of castor biofuel blends in compression ignition engines. The results showed that the B20 mixed fuel exhibited the highest brake thermal efficiency (BTE) and lower exhaust gas temperature (EGT), fully reflecting the conversion of maximum heat energy into useful work. In addition, compared to diesel and other blends, the B10 and B20 biofuel blends exhibited the lowest exhaust emissions. Therefore, B20 biofuel blends have the closest characteristics to diesel. Mithun Das et al. [13] discovered that the pressure increase rate of castor biofuel blends in the quick combustion stage is faster than that of diesel due to the greater reactivity of castor biodiesel. Furthermore, the braking thermal efficiency of engines running on biofuel blends is better than that of diesel, and the emission parameters of biofuel blends do not differ significantly from diesel. As a result, they found that the B20 blend may be utilized efficiently for engine operation, hence reducing fossil fuel usage. Ameren Kondaiah et al. [18] produced and evaluated castor biodiesel by a transesterification reaction. They discovered that the flash and ignition points of castor biodiesel were much greater than those of diesel, although their calorific value was lower. When castor biofuel blends were utilized in engines, they showed a greater peak pressure than diesel and a BTE similar to diesel. This is because biodiesel includes more oxygen, which aids in combustion. S. Jafarmadar et al. [19] prepared 5%, 10%, 15%, 20%, and 30% castor biofuel blends and tested their performance and emissions using a semi-heavy-duty Motorsazan MT4.244 agricultural engine under various loads. They discovered that the B15 and B20 fuel blends offered the best brake-specific fuel economy at full load operation, while PM emissions were dramatically reduced. The results revealed that castor biodiesel could replace some diesel and that there is no need to change the present engine construction.

Catalysts improve the combustion process and minimize pollutants by enhancing the oxidation reaction of the fuel and increasing the rate of heat transfer. Abhishek Bharti et al. [20] dispersed TiO_2 nanoparticles uniformly in the fuel blends using ultrasound and a 10 lpm hydrogen (H_2) gas stream in the engine and discovered that the engine's braking thermal efficiency increased, the brake-specific fuel consumption decreased, and CO and HC emissions were significantly reduced. TiO_2 nanoparticles are metal oxide nanoparticles that boost combustion temperatures by increasing the surface area of the reaction and releasing oxygen during combustion. In contrast, hydrogen burns fast, diffuses broadly, and cools quickly, increasing the rate of combustion in the cylinder and improving the combustion process.

Adding antioxidants to biodiesel and its blends may improve oxidative stability, which is a major concern for biodiesel fuels [21,22]. M. Senthil et al. [23] investigated the effects of adding antioxidants to rapeseed oil biodiesel on exhaust emissions. They observed that adding antioxidants to biofuels lowered NOx and HC emissions by 40.16% and 37.97%, respectively.

Castor oil is used as a raw material, potassium hydroxide and methanol are used as catalysts to produce castor biodiesel through transesterification, and the castor biodiesel obtained is mixed with diesel in a specific proportion (B20, B40, B60, and B80). In order to identify the ideal diesel–castor–biofuel mixed ratio, the engine performance, emissions, and combustion characteristics were tested at different speeds (1200 ppm, 1400 ppm, 1600 ppm, and 1800 ppm) in a single-cylinder diesel engine.

2. Materials and Methods

2.1. Castor Biodiesel Production

Transesterification was used in this study to produce castor biodiesel. First, 500 mL of castor oil was heated to 30° in a beaker to lower its viscosity, then 125 mL of methanol and 2.5 g of potassium hydroxide were combined on a magnetic stirrer and constantly swirled until the methanol and potassium hydroxide were entirely mixed. The heated castor oil with the methanol potassium hydroxide solution was mixed in a molar ratio of 10:1, placed on a magnetic stirrer, and heated at a continuous speed of 700 rpm to 55–60 °C, then reacted for two hours. After the obtained mixture was put into a separatory funnel and allowed to stand for 12 h, the top was methyl ester, and the bottom was glycerin. The separatory funnel was used to extract glycerin, and the water washing technique was used to wash the methyl ester 4–5 times to remove contaminants and the residual catalyst. The cleaned biodiesel was heated to more than 100 °C until the surplus water evaporated entirely. Figure 1 depicts the castor biodiesel synthesis process.

After transesterification, pure biodiesel was produced, and the yield of biodiesel was estimated using the formula provided below.

$$
\begin{aligned}
\text{Biodiesel Yield } \% &= \frac{\text{weight of the biodiesel produced}}{\text{weight of the sample taken for reaction}} \times 100\% \\
&= \frac{489}{500} \times 100\% = 97.8\%
\end{aligned}
$$

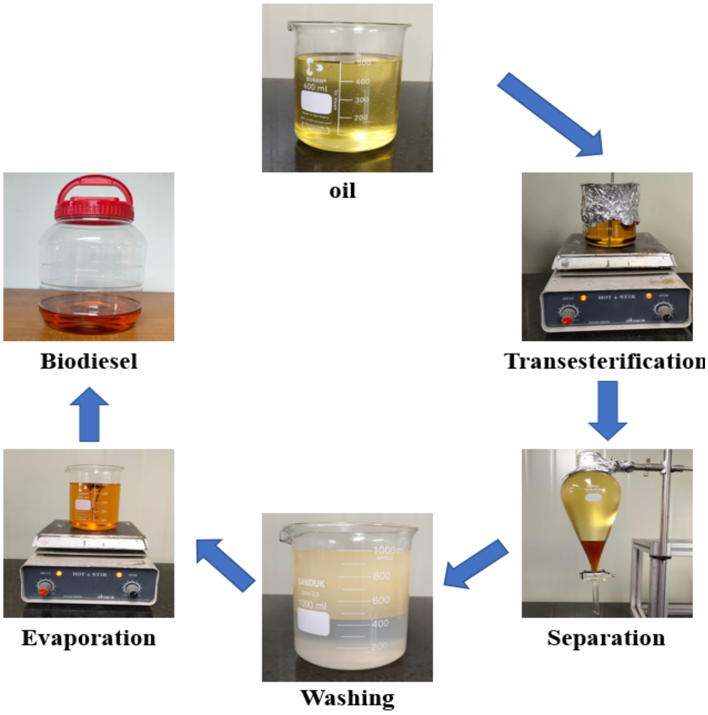

Figure 1. Castor biodiesel production process.

2.2. Castor Biodiesel Characteristic

Table 1 shows the chemical and physical parameters of the castor biodiesel and diesel used in the experiment. The figure shows that the properties of castor biofuel blends are similar to diesel and fulfill the ATSM limit standards in Table 2.

Table 1. Properties of diesel and castor seed biodiesel.

Property	Diesel	Castor Biodiesel	B20	B40	B60	B80	Standard (ASTM)
Kinematic Viscosity (mm^2/s)	2.87	7.35	3.34	4.61	5.42	6.24	1.9–6
Flash Point (°C)	58	102	75	79	85	93	>130
Cetane Number	48.7	62	50	53	56.5	59	48–65
Density (kg/m^3)	820	896	831	843	851	869	800–880
Calorific Value (MJ/kg)	45.512	38.156	44.121	43.855	41.564	40.152	>35

Table 2. ASTM standards for fuel.

S.No.	Test	ASTM Test	ASTM Limits
1	Kinematic Viscosity (mm^2/s)	D445	1.9–4.1
2	Flash Point (°C)	D93	52 °C min
3	Cetane Number	D613	40 min
4	Density	D5002	15–35 °C
5	Pour Point (°C)	D97	4.4–5.5 °C

2.3. Experimental Setup

At a constant load (50%) with varied speeds (1200 ppm, 1400 ppm, 1600 ppm, and 1800 ppm), a four-stroke single-cylinder water-cooled farm diesel engine with a rated output power of 7.4 kW was used in this experiment. Figure 2 depicts the experimental setup. The diesel engine manufacturer is Daedong Korea Ltd. (Daegu Gwangyeoksi, Republic of Korea), whose exact specifications are shown in Table 3. A CGA-4500 gas analyzer produced by Jastec Ltd. in Seongnam, Republic of Korea was used to examine engine exhaust emission characteristics in order to measure changes. A BS-8000 smoke meter which was made by Taeshin Precision Machinery Co., Ltd. (Busan, Republic of Korea) was used to monitor engine smoke, and a K-type thermocouple was used to measure exhaust gas temperature. The existence of various equipment faults and uncertainties throughout the experimental procedure may have had an effect on the results. The correctness of the experimental results could be ensured using uncertainty analysis. Table 4 details the measurement range and uncertainty analysis of the gas analyzer and K-type thermocouple utilized in the experiment. In order to obtain accurate experimental data and reduce error rates, the engine was started, and the required speed and load were set. After waiting for the engine to run stably, more than four readings were collected, with an interval of two minutes between each reading, and the average value was calculated.

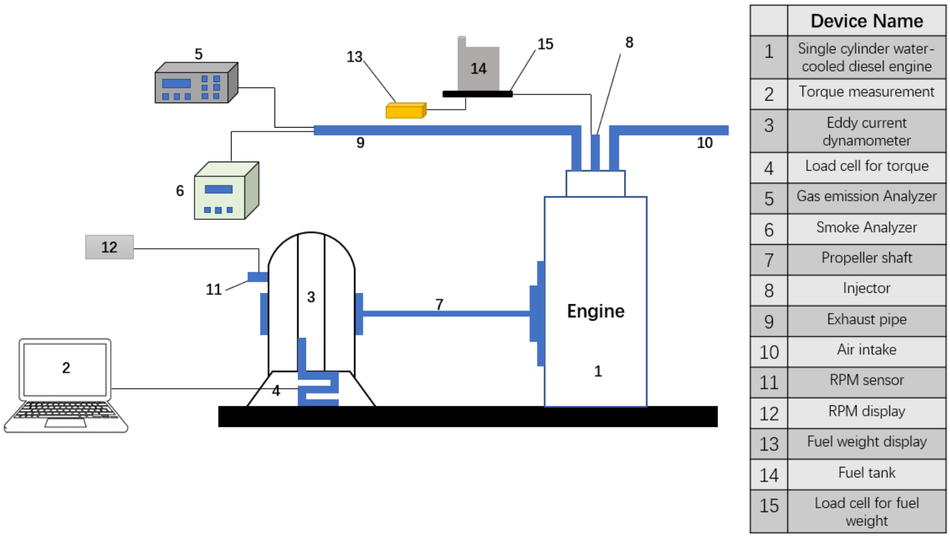

Figure 2. Experimental setup.

Table 3. Engine specification.

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

Table 4. Measurement range of experimental instruments and accuracy of calculation results.

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

3. Results and Analysis

3.1. Carbon Monoxide (CO)

The fluctuation of CO emissions with the engine speeds for various castor biofuel blend ratios are shown in Figure 3. The graph shows that the CO emissions of diesel fuel at 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm are 0.8%, 0.69%, 0.61%, and 0.55%, respectively. However, at all speeds, the CO emissions of the biofuel blends are much lower than those of the diesel fuel, and they also trend downward as the amount of biodiesel in the blended fuel increases. Biodiesel has a larger oxygen content than diesel, which raises the combustion temperature by releasing oxygen during combustion, encourages combustion and oxidation processes, and lowers the engine's CO emissions [24]. Additionally, Table 1 shows that the cetane number of all the blended fuels is higher than that of the diesel fuel. A higher cetane number can decrease the likelihood of knock and fuel-rich zones during combustion, resulting in better oxidation of the fuel particles and increased combustion efficiency. The air volume and combustion rate are low at low engine speeds, and the fuel is not completely burnt, leading to greater CO emissions. A drop in CO emissions is seen when the engine speed rises while maintaining the same fuel volume because more air is involved in the combustion process, and the fuel burns more quickly as a result.

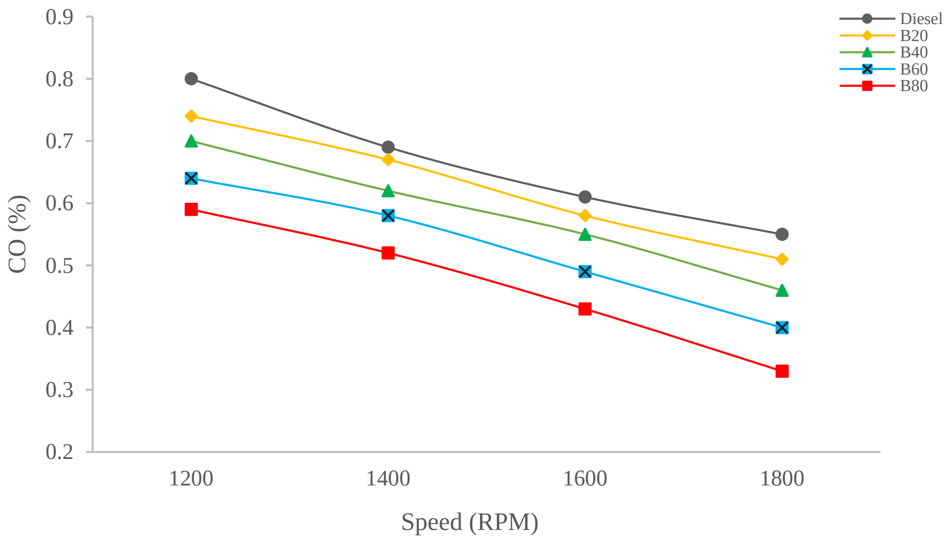

Figure 3. Variation of CO at different engine speeds and blends.

3.2. Carbon Dioxide (CO_2)

A greater CO_2 level suggests that the fuel blends are burnt effectively in the combustion chamber [25]. At various engine speeds, Figure 4 depicts the CO_2 emissions of diesel and castor biofuel blends. The figure indicates the CO_2 emissions of diesel fuel, B20, B40, B60, and B80 fuel blends at 1200, 1400, 1600, and 1800 rpm. The B20 performance is 1.3%, 1.4%, 2%, and 2.4%; B40 shows 1.7%, 1.9%, 2.5%, and 2.7%; B60 shows 2%, 2%, 2.6%, and 2.8%; and B80 shows 2.2%, 2.4%, 2.7%, and 3%. As can be seen, diesel produces somewhat fewer CO_2 emissions than biofuel blends, which makes sense given that biodiesel has a high oxygen content. The oxidation reaction of the fuel is an exothermic reaction that generates a significant amount of heat energy. This energy is utilized to drive the piston and supply power to the engine. Excess oxygen atoms combine with carbon atoms during burning to form carbon dioxide at high temperatures [26]. As the engine speed rises, more fuel must be used during combustion in order to provide the engine with the necessary power, which raises CO_2 emissions.

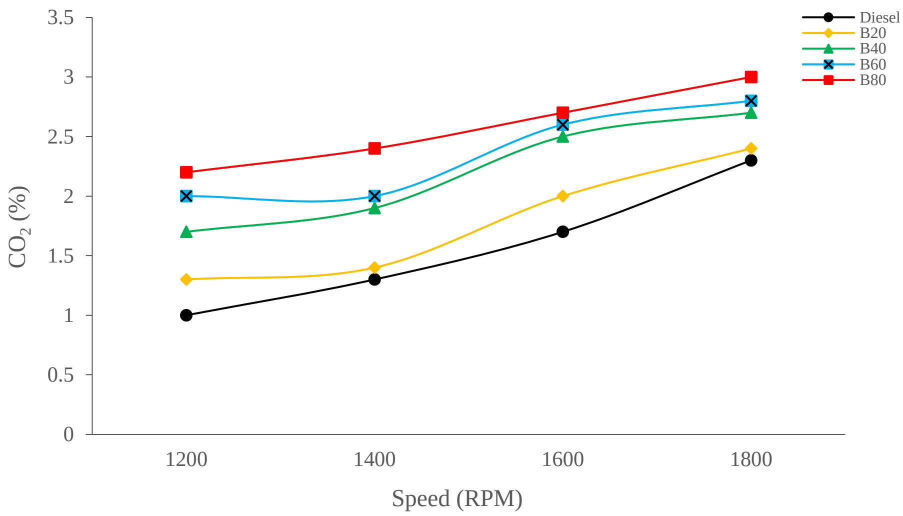

Figure 4. Variation of CO_2 at different engine speeds and blends.

3.3. Hydrocarbon (HC)

Figure 5 depicts the connection between HC emissions and the engine speed for diesel and castor biofuel blends with various mixing ratios. Diesel fuel emits more hydrocarbons (HCs) than biofuel blends, with corresponding measurements of 58 ppm, 55 ppm, 49 ppm, and 42 ppm at speeds of 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm. The HC emissions of the castor biofuel blends are much lower than those of pure diesel fuel, and they are also on the decline as the fraction of biodiesel increases. The greatest HC emissions of the castor biofuel blends are found in B20, which has values of 55 ppm, 51 ppm, 47 ppm, and 41 ppm at various speeds, respectively. The lowest HC emissions are found in the B80 blended fuel, which has values of 43 ppm, 39 ppm, 36 ppm, and 30 ppm at various speeds.

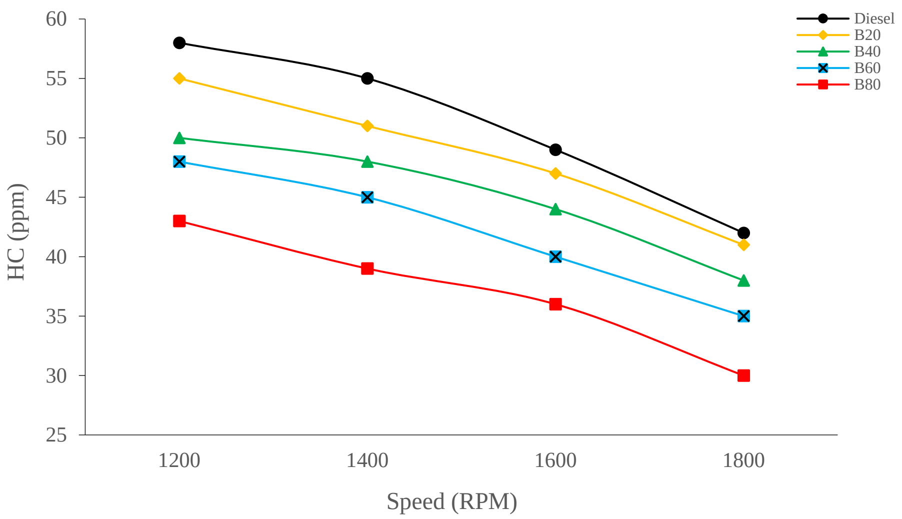

Figure 5. Variation of HCs at different engine speeds and blends.

This trend in emissions is reasonable. One benefit of using biodiesel is the release of oxygen during the diffusion combustion phase. These additional oxygen molecules help enhance the combustion process, promote the mixing and reaction of fuel and air, and improve the combustion efficiency of the fuel. Another benefit is that the reduced hydrocarbon ratio of the fuel reduces the requirement for hydrogen atoms to generate HC, thereby minimizing HC emissions.

The air–fuel mixture in the cylinder burns more quickly as the engine speed rises, resulting in the more complete burning of the fuel and a reduction in HC emissions.

3.4. Nitrogen Oxide (NOx) Compound

Complete combustion produces NOx, whose generation is substantially influenced by the equivalency ratio, oxygen content, and combustion temperature [27]. Ali Zare et al. [28] examined the reasons for NOx formation using the chemical equation:

$$NO + HO_2 \rightarrow NO_2 + OH$$

$$NO_2 + OH \rightarrow NO + HO_2$$

$$NO_2 + H \rightarrow NO + OH$$

The change in the diesel and castor biofuel blends with the rate of NOx is depicted in a line graph in Figure 6. At speeds of 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm, respectively, the NOx emissions of the diesel fuel showed 112 ppm, 141 ppm, 184 ppm, and 290 ppm. The NOx emissions from the castor biofuel blends are somewhat higher than those from the diesel. Among them, the B80 fuel blend has the greatest NOx emissions with 151 ppm, 183 ppm, 231 ppm, and 356 ppm, respectively. In contrast, the castor biofuel blends have a high oxygen content, which provides the oxygen needed for combustion. Biodiesel has a higher density and cetane number. A higher cetane number indicates that the fuel has a better spontaneous combustion performance. During fuel injection and compression, the fuel starts burning earlier, reducing the ignition delay time, and increased amounts of the fuel after premixed combustion leads to higher cylinder pressure and temperature, higher fuel consumption, and higher NOx emissions under the same injection conditions [29,30]. Oxygen and nitrogen atoms undergo oxidation as the combustion temperature rises, resulting in NOx [31]. The swirl in the cylinder increases at higher engine speeds as the engine speed rises, allowing for a quicker and better diffusion of fuel and air, raising the combustion temperature in the cylinder, and raising the NOx emissions.

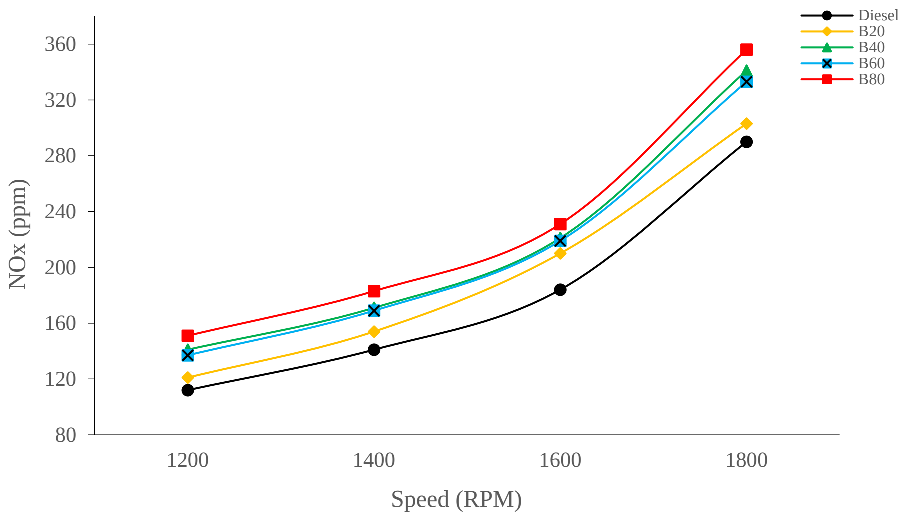

Figure 6. Variation of NOx at different engine speeds and blends.

3.5. Smoke Opacity

The smoke emission curves for five experimental fuels with the engine speeds are shown in Figure 7. The graph indicates that at a 50% load, the diesel fuel exhibits higher smoke emissions compared to the four castor biofuel blends. The emissions reach 22%, 17%, 13%, and 9% at 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm, respectively. In contrast to diesel, the B20 fuel blend demonstrates a decrease in smoke emissions by 9.1%, 5.9%, and 15.4% at the same speeds. The B40 fuel blend shows reductions of 13.6%, 17.6%, 30.8%, and 22.2%; the B60 fuel blend exhibits decreasements of 27.3%, 23.5%, 6.2%, and 44.4%; and the B80 fuel blend displays reductions of 40.9%, 35.3%, 53.8%, and 55.6%, respectively.

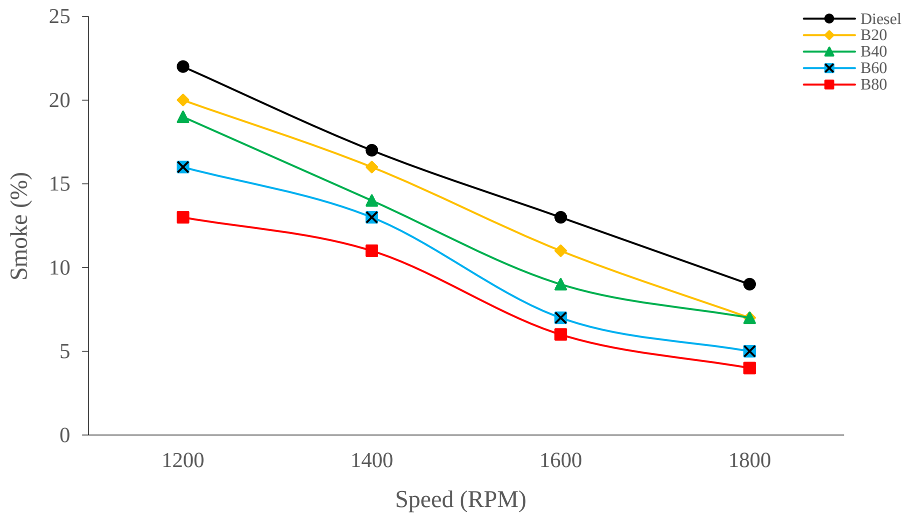

Figure 7. Variation of smoke at different engine speeds and blends.

Because biodiesel has a high cetane number and high oxygen content, it burns more quickly after being compressed and injected, which decreases the ignition delay time and results in higher combustion efficiency, lower hydrocarbon emissions, and less smoke [32]. As a result, the smoke emissions from biofuel blends are reduced, and the smoke opacity reduces as the biodiesel content of the blends rises. As the engine speed rises, the air–fuel mixture in the cylinder burns more quickly, completely, and efficiently, reducing hydrocarbon emissions and smoke opacity.

3.6. Brake Thermal Efficiency (BTE)

The BTE, which is the ratio of braking power to fuel energy consumption, indicates how fuel energy is converted into useful work [9]. Figure 8 depicts the BTE of diesel and castor biofuel blends at various engine speeds. According to the trial results, diesel has the greatest BTE, with 27.16 percent, 24.7%, 21.69%, and 19.9 percent at 1200 rpm, 1400 rpm, 1600 rpm, and 1800 rpm, respectively. Due to the high density, high viscosity, and low calorific value of biodiesel, castor biofuel blends have a comparatively low BTE in comparison. Fuel in the cylinder burns partially, which lowers the combustion efficiency and raises the fuel consumption [33–35].

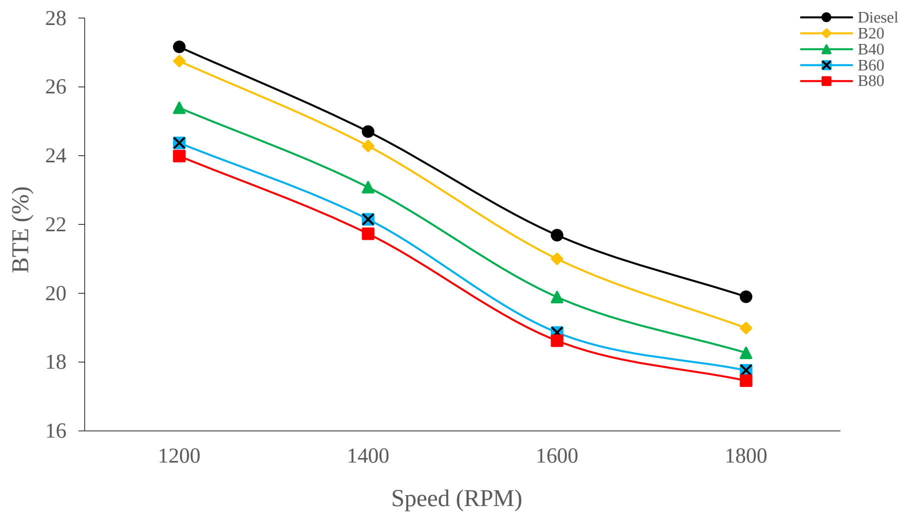

Figure 8. Variation of BTEs at different engine speeds and blends.

Diesel, B20, B40, B60, and B80 showed the highest BTEs at 1200 rpm, with values of 27.16%, 26.75%, 25.39%, 24.37%, and 23.99%, respectively; at 1800 rpm, they exhibited the lowest BTEs, which were 19.9%, 18.99%, 18.27%, 17.76%, and 17.46%, respectively. From 1200 rpm to 1800 rpm, the BTE of the diesel, B20, B40, B60, and B80 decreased by 7.26%, 7.76%, 7.12, 6.61%, and 6.53%, respectively. This is because at high engine speeds, the spray characteristics of the fuel and the air–fuel mixture are poor [36]. As the engine speed increases, the BTE shows a decreasing trend. This is due to the fact that at higher speeds, the air–fuel combination is poor, and the air cannot completely mix with the fuel. Consequently, the efficiency of converting fuel energy into useful work diminishes, leading to a decrease in combustion efficiency.

3.7. Brake-Specific Fuel Consumption (BSFC)

Figure 9 illustrates the fluctuation of diesel and castor biofuel blends with different engine speeds at a 50% load. With 2.91 Kg/W·h at 1200 rpm and 3.97 Kg/W·h at 1800 rpm, diesel had the lowest BSFC trend of all the experimental fuels. In contrast, the BSFC of the castor biofuel blends rose as a result of their lower calorific value, higher density and viscosity, and the requirement to burn more fuel to produce the same amount of power. Therefore, BSFC has the tendency to rise as the amount of biodiesel increases. At 1200 rpm, the BSFC of the B20, B40, B60, and B80 blended fuels has the lowest trend with 3.05 Kg/W·h, 3.23 Kg/W·h, 3.55 Kg/W·h, and 3.74 Kg/W·h, respectively; at 1800 rpm, it has the highest trend with 4.3 Kg/W·h, 4.49 Kg/W·h, 4.88 Kg/W·h, and 5.14 Kg/W·h.

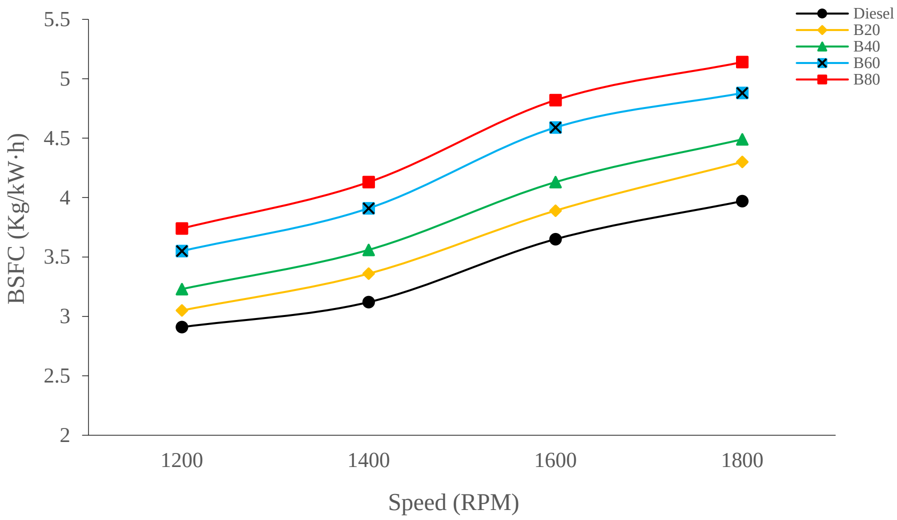

Figure 9. Variation of BSFC at different engine speeds and blends.

When the engine speed rises, the BSFC rises along with it, requiring more fuel to produce the same amount of power [37].

3.8. Exhaust Gas Temperature (EGT)

The EGT of diesel and castor biofuel blends at various engine speeds is shown in Figure 10. Diesel fuel, as seen in the figure, displayed greater EGTs at all engine speeds, at 342 °C, 354 °C, 371 °C, and 379 °C, respectively. The EGT of the castor biofuel blends dropped as compared to diesel, with the B80 fuel blend having the lowest EGT at 251 °C, 273 °C, 293 °C and 312 °C, respectively. Ignition delay has an impact on the EGT [38]. The shortened ignition delay means that the fuel starts burning earlier, allowing the combustion process to be more synchronized with the fuel injection process. This helps to improve combustion efficiency, increase engine power output and fuel economy, and improve engine emission performance, reducing environmental pollution. In comparison to diesel fuel, biodiesel has a lower calorific value and a greater cetane number. The cetane number rises along with the quantity of biodiesel in the blended gasoline, and the ignition delay shortens [26,36]. During burning, biofuel blends have a better combustion efficiency and a lower EGT. Contrarily, diesel has a lower cetane number than castor biofuel blends, which causes the ignition delay to lengthen and the EGT to rise as a result.

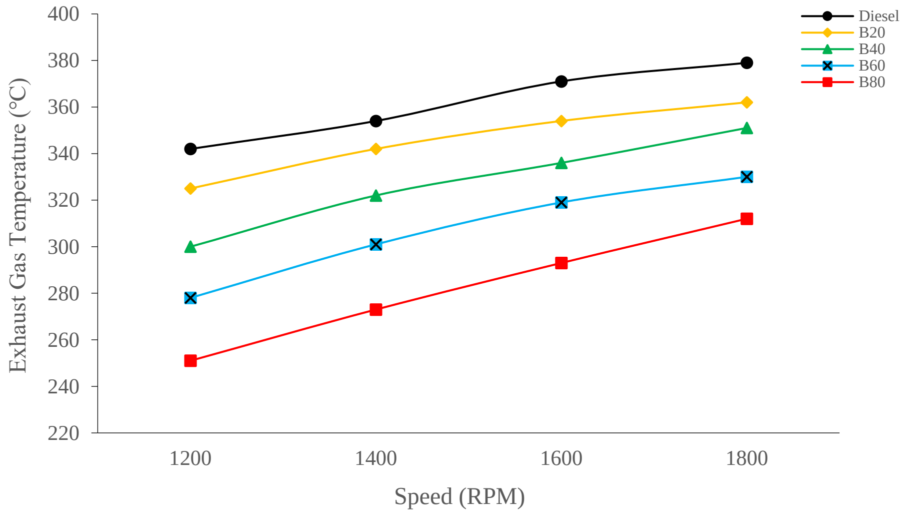

Figure 10. Variation of EGTs at different engine speeds and blends.

4. Conclusions

The findings demonstrate that biodiesel greatly lowers carbon monoxide (CO), hydrocarbon (HC), and smoke emissions because it is an oxygenated fuel with a high cetane number that releases oxygen to enhance combustion; oxygen atoms combine with nitrogen and carbon atoms at a high combustion temperature, increasing the amount of nitrogen oxide (NOx) and carbon dioxide (CO_2) emissions. However, the difference with diesel is not great. Castor biofuel blends have a lower brake thermal efficiency (BTE) than pure diesel because of the high viscosity, high density, and low calorific value of biodiesel. The fuel's exhaust gas temperature (EGT) trends upward with increased rotational speed. The biodiesel blend's high cetane number shortens the ignition delay and lowers the exhaust gas temperature (EGT) compared to diesel.

Fuel combustion is completed more fully as the engine speed rises and the carbon monoxide (CO), hydrocarbon (HC), and smoke emissions fall. Due to the worse air–fuel mixing effect at higher engine speeds, the BTE diminishes as the engine speed rises. According to the findings, castor biofuel blends may be utilized routinely without modifying the engine's current construction and have similar engine performance and emission characteristics as diesel fuel.

In this study, it is concluded that the production of biodiesel from castor oil is a promising method due to the characteristics of castor plants, including easy growth, easy access, high oil production, and inedibility. Moreover, when mixed with diesel, castor biodiesel exhibits good engine performance and emission characteristics, which can be applied commercially. However, further research can still be conducted to improve the availability of biodiesel fuel, such as optimizing engine performance and emissions through catalysts, antioxidants, and other means.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

PPM	Parts-Per-Million
RPM	Revolutions Per Minute
CI	Compression Ignition
IC	Internal Combustion
BP	Brake Power
KOH	Potassium Hydroxide
NaOH	Sodium Hydroxide
BSFC	Brake-Specific Fuel Consumption
BTE	Brake Thermal Efficiency
EGT	Exhaust Gas Temperature
CO	Carbon Monoxide
CO_2	Carbon Dioxide
HC	Hydrocarbon
NOX	Nitrogen Oxide

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