





## Article

# A Study on Performance and Emission Characteristics of Diesel Engine Using Ricinus Communis (Castor Oil) Ethyl Esters

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**Citation:** Arunkumar, M.; Mohanavel, V.; Afzal, A.; Sathish, T.; Ravichandran, M.; Khan, S.A.; Abdullah, N.A.; Bin Azami, M.H.; Asif, M. A Study on Performance and Emission Characteristics of Diesel Engine Using Ricinus Communis (Castor Oil) Ethyl Esters. *Energies* **2021**, *14*, 4320. <https://doi.org/10.3390/en14144320>

Academic Editor: Constantine D. Rakopoulos

Received: 7 June 2021

Accepted: 12 July 2021

Published: 17 July 2021

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**Abstract:** Countries globally are focusing on alternative fuels to reduce the environmental pollution. An example is biodiesel fuel, which is leading the way to other technologies. In this research, the methyl esters of castor oil were prepared using a two-step transesterification process. The respective properties of the castor oil (*Ricinus Communis*) biodiesel were estimated using ASTM standards. The effect of performance and emission on diesel engines was noted for four various engine loads (25, 50, 75, and 100%), with two different blends (B5 and B20) and at two different engine speeds (1500 and 2000 rpm). The study determined that B5 and B20 samples at 1500 rpm engine speed obtained the same power, but diesel fuel generated greater control. The power increased at 2000 rpm for B5 samples, but B20 samples, as well as diesel, were almost the same values. In the 40–80% range, load and load values were entirely parallel for each load observed from the engine performance of the brake power in all samples.

**Keywords:** emission; performance; *Ricinus Communis*; biodiesel; renewable energy

## 1. Introduction

An energy resource can produce heat, power, life, move objects, or produce electricity. Energy resources can be classified into three main divisions: fossil fuels, nuclear energies, and renewable energies. Non-renewable resources are natural resources that cannot be readily replaced by natural means. Very long time is required to produce fossil fuels; thus, they are considered a non-renewable resource [1]. A large part of energy consumption is currently obtained from coal, natural gas, and oil. In provisioning energy necessities in the future, renewable energy resources, such as geothermal, hydrogen, wind, biomass, and solar, play a vital role [2]. By the year 2040, one in two global energy resources will be renewable and will generate significantly more than 80% of the electricity globally. Alternative energy resources also mean renewable energy resources [3]. Technologies of renewable energy produce natural items that can be used for the production of energy.

Generally, renewable energy sources provide 14% of the demand for global energy, and also delivers a large amount of power—up to 20% of global electricity. Biomass is produced by solar energy, which is stored in animals and plants and is also part of chemical energy resources [4].

The performance, emission, and combustion of a DI diesel engine using rapeseed oil and its blends of 5%, 20%, and 70% with standard fuel have been studied. Biodiesel has lower smoke emission and higher brake-specific fuel consumption than diesel fuel [5]. The combustion delay for standard diesel, B20, B5, B70, and B100 fuels was calculated as 8.5o, 7.75o, 7.25o, 6.50o, and 5.75o CA, respectively [6]. The combustion delay was shorter for rapeseed oil, CO and smoke were reduced considerably, and the thermal brake-efficiency of biodiesel and its blends were comparable with that of diesel fuel [7].

The effect of blends of ethanol, methanol, and vegetable oil with diesel fuel on a naturally aspirated DI diesel engine has also been studied. It was found that the ethanol and methanol blends yielded lower brake power, higher SFC, and lower CO emission [8]. The oxygenates and metal-based additives reduced PM emissions. The NOx emission increases when using biodiesel due to the higher oxygen content in biodiesel [9].

A four-cylinder four-stroke DI and turbo-charged diesel engine used biodiesel blends of waste oil, rapeseed oil, and corn oil with regular diesel. It was observed that the biodiesel types did not result in any significant differences in peak cylinder pressure and BSFC [10]. The peak cylinder pressure of the engine running with biodiesel was slightly higher than that of diesel due to the advanced combustion process initiated by the higher lubrication effects of biodiesel and its other physical properties such as density and viscosity. Furthermore, it has also been concluded that biodiesel increases the BSFC up to 15% due to its lower heating value, higher viscosity, and density [11]. The combustion delay for biodiesel was lower when compared to that of diesel, and the heat release rate was more during diffusion combustion of biodiesel blend. The effects of biodiesel types, their fraction, and the emission characteristics of CI engine by corn oil biodiesel were studied [12]. It was found that NOx emission was increased when using alternative fuels other than the diesel fuel. In addition, other emission parameters, such as hydrocarbon (HC), carbon dioxide (CO<sub>2</sub>), and carbon monoxide were reduced for 15, 30, and 40% blend ratios when compared to diesel [13]. A four-stroke direct-injection diesel engine experiment was conducted using various vegetable oil biodiesels, such as corn oil, Salicornia oil, waste cooking oil, in the proportion of 10 and 20% added to diesel fuel [14].

Chemical energy can be acquired through burning biomass as a fuel. The old way of not applying biomass means burning it directly. Including liquidation, gasification, and pyrolysis, the technologies of thermochemical biomass transformation are effective methods, nevertheless, more than 97% of the globe's production of bioenergy is consumed [15,16]. The average energy of biomass produced from wood and wood waste is 64%, solid wastes are 24%, waste of agriculture is 5%, and landfill gases are 5% [17]; biomass is considered a renewable energy resource to compensate for the amount of fossil fuel reduction in the present world [18]. The kinds of biomass conversion into energy are thermochemical and biochemical transformation. The production of biodiesel is a well-known transformed biomass using biochemical transformation [19].

Experts have recorded that the gas reserves and existing oil will be sufficient only for a limited number of years [20]. Biodiesel, bioethanol, and several other such biofuels are required to face the increasing demand, because of the replacement of energy and declining oil reserves [21]. Biofuels will supply more amount of energy which are pollution free and cost concern of normal fuels are high at the time of import and export, and it will provides social revenues in rural sector [22]. There is a growth in modern and developing technologies using biofuels with high energy exchange in developed countries [23]. This alternative fuel needs to be easily available, environmentally acceptable, and economically competitive [24].

When burning alternative fuels, they are similar to diesel fuel in producing the same pollutants. However, biodiesel emissions have reduced pollution, which has different

effects on various factors [25]. Biodiesel is created from soya bean, sunflower, cotton, corn, sunflower micro-algae, palm, and waste cooking oil during the trans-esterification process. These fuels can be used as they are or by blending with diesel fuel [25,26]. Several biodiesel properties of such oils can be changed by the type of fatty acids in the oil. In many cases, biodiesel has a good performance compared to diesel fuel comparing sulfur content, organic content, biodegradability content, and flash content [27]. To improve the process of combustion, researchers have tried to determine the best blend of biodiesel. The results of these efforts have determined that biodiesel fuel's properties play a vital role in the process of combustion [28]; thus, a diesel engine's pollution characteristics and its performance depend entirely on the fuel properties. The biodiesel of each resource has various thermophysical properties, and variations result during the production of the resources (e.g., the climate can affect the plants' growth, etc.) [29]. The foremost imperative biodiesel properties of the fuel that impact engine execution is air, and more significantly, heating, cloud point value, density, flash point, cetane number, and viscosity. Storing, transporting, and saving the biodiesel is less hazardous when equating it to ordinary diesel, since its features have a higher flash point than diesel fuel [30]. Biodiesel may be mixed to different extents with regular diesel. Biodiesel remains an elective fuel connected with ordinary diesel engines, which has low diesel fuel mixes [31]. There have been different investigations held into utilizing biodiesel in diesel engines. These investigations have found that the biodiesel's assets are very important in the process of combustion [32]. The fuel's advantages are accessibility, transportability, high-efficiency combustion, renewability, reduced sulfur content, fragrance, anti-knock properties, and biodegradability [33].

The biodiesel delivered from routine vegetable oils, as a rule, includes five kinds of single esters of greasy acids, such as palmitic, linoleic, and stearic oleic. Linolenic, even though castor oil carries ricinoleic unsaturated fatty acids (UFA), can influence thermal and physical characteristics and combustion of the biodiesel [34]. The essential fatty acids of castor oil are ricinoleic, a fatty acid of unsaturated hydroxy. Greasy acids in castor oil are 90% ricinoleic acid, 3.6% linoleic acid, 3% oleic acid, 1% stearic acid, 0.7% di-hydroxyl stearic acid, 1% acid palmitic, and 0.3% eicosanoic acid. A few investigations are going on to develop castor methyl ester [35].

To our knowledge, comprehensive research about ethyl ester is still lacking in the literature. There are no comprehensive investigation about developing and using castor oil ethyl ester in diesel engine execution and outflow characteristics. The main aim is to find the optimum blending ratio of castor (*Ricinus Communis*) oil biodiesel and to evaluate its overall performance and emission traits on a diesel engine.

## 2. Materials and Procedure

### 2.1. Yielding of Castor Ethyl Ester

In this delving, through the process of transesterification, castor oil ethyl ester was obtained. In this way, at 160 °C, castor oil was boiled, and ethanol was mixed with NaOH's catalyst. The product obtained through this process is known as ethoxy [36,37]. These ethoxys were mixed with oil, and also these were whirl for 30 min and were boiled at 80 °C. The solution was kept in the laboratory to separate the glycerine from the obtained product of this process. With the help of hydrochloric acid, it was neutralized after completing the process [38]. The water at 50 °C was mixed with the solution to separate the glycerine, remaining after the process with few impurities. The solution was separated into three phases after 48 h [39]. The three phases were soap, ester, and water. Finally, the required product, ethyl ester (Biodiesel), was obtained at the top layer of emulsion and filtered, shown in Figure 1. The mixtures of the biodiesel in the ratio of 5% and 20% respectively were produced (samples of B5 and B20) to check the physical characteristics of ethyl esters of *Ricinus Communis* (castor oil).

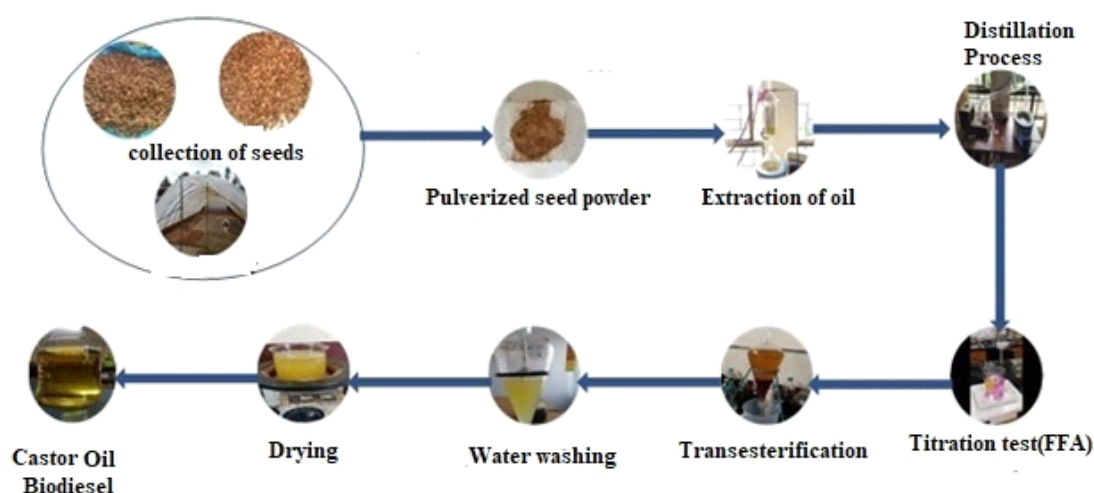


Figure 1. Production of castor ethyl ester.

## 2.2. Determining the Physical and Chemical Properties of Biodiesel

In this delving, based on the ASTM standard, castor biodiesel properties were calculated based on literature as mentioned in Table 1. Regarding the density, it was calculated regarding ASTM D4052 with the help of a density meter of DA-130N. It has an accuracy of  $\pm 0.001 \text{ g/cm}^3$ . HHV was determined using the standard ASTM D240 calorimeter [40]. It was found by noting the ASTM D5773 fuel's transparency, which had been cooled under few conditions regarding the point of cloud. It was obtained by DV-II Prime ASTM D445 Brookfield viscosity at the temperature of  $40 \text{ }^\circ\text{C}$  regarding viscosity. The flashpoint was calculated using the open-cup method based on ASTM D 93 standard [41]. A mass test of gas chromatography was used to determine the chemical components of the biodiesel. By this method, chemical components were dispatched by the point of boiling and components construction. The gas chromatography-mass of GC:7890A, MS:5975C, was used through this method, and while standard ASTM D6584, tests were taken [42].

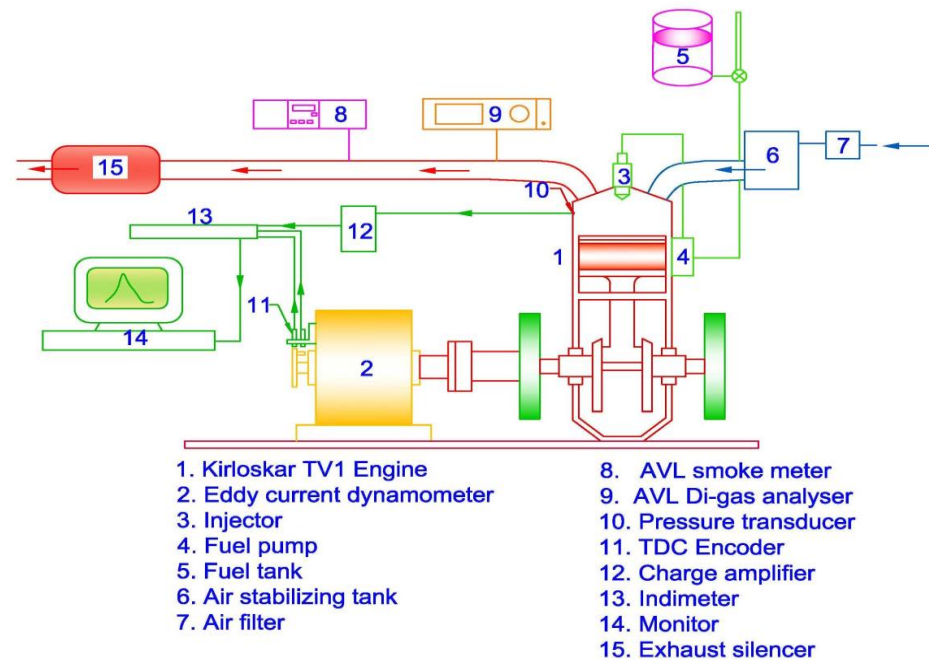
Table 1. Characteristics of various biodiesel.

Source of Biodiesel	Kinetic Viscosity at $40 \text{ }^\circ\text{C}$	Density ( $\text{g/cm}^3$ )	Flash Point ( $^\circ\text{C}$ )	References
Castor	3.5–5.6	0.853–0.870	161–236	[1,5]
Algal	2.41–4.3	0.841–0.937	114–243.5	[12,15,42]
Neem	2.93–4.90	0.840–0.896	133–257	[2,16]
Corn	4–4.7	0.871–0.883	73–111	[11,19,24]
Camalina sativa	4.04–4.94	0.882–0.893	65–142	[19,20,37,38]
Animal fat	4.3–5.7	0.875–0.880	83–176	[18,43]
Jatropha	4.1–4.3	0.835–0.884	92–181	[9,37,39,40]
Pure Diesel	2.3–5.5	0.814–0.844	76(Min)	[17,44,45]
ASTM Standard	1.7–5.8	0.830–0.890	122(Max)	[46,47]
(D-B100) Present Work	13.15	0.932	162	Present work

## 2.3. Engine Test

The engine tests were done regarding engine tests of a short time at standard ECE R-49. The engine, which was targeted, comprises four cylinders, with a direct-injected engine, shown in Figure 2.

Tests of the engines were done on four-engine loads such as 25%, 50%, 75%, and 100%. The engine's speed was 1500 rpm and 2000 rpm with three fuel sources: diesel, B20, and B5.



**Figure 2.** Diagram of the engine test setup.

This delving is to calculate the torque, power, and engine speed. Dicom 4000-AVL pollution gauge was used to calculate the CO<sub>2</sub>, NO<sub>x</sub>, HC, and CO. PT-100 was the temperature sensor. First, the engine started with diesel fuel over 15 min in a fully loaded condition for the engine test [48]. Next, one of the samples, prepared earlier, was added to the reservoir after turning off the engine. The engine was then restarted, and the speed data was logged in the engine. The exact process was repeated at the mentioned loads for every fuel sample. Specification of the tested engine is given in Table 2. The accuracy and error involved during the experimentation is provided in Table 3.

**Table 2.** Specification of the test engine.

Type	Vertical Single Cylinder DI Diesel Engine
Engine Speed	1500 rpm
Bore X Stroke	97 mm × 128 mm
Brake Power	5.2 kW
Compression Ratio	17:01
Standard Injection Timing	15° bTDC at full load condition
Standard Injection Pressure	200 bar

**Table 3.** Accuracy and errors in measuring equipment.

Parameters	Systematic Errors (±)	Measuring Range
Speed	±10 rpm	250–8000 rpm
Temperature	±1 °C	1–120 °C
Soot	±0.1%	0–100%
CO	±0.01 Vol.%	0–10 Vol.%
CO <sub>2</sub>	±0.1 Vol.%	0–20 Vol.%
HC	±1 ppm	0–20,000 ppm
NO	±1 ppm	1–4000 ppm

### 3. Biodiesel Properties

The created biodiesel properties had been evaluated considering the ASTM benchmarks. In December 1998, ASTM institute posted biodiesel magazine and EPA balanced; it



is measured based on ASTM reports. Based on this already specified standard values only all alternative fuels thermo-physical properties were calculated and compared with diesel fuel [49].

B20 and B5 and diesel fuel's properties and Free Fatty Acid composition of different biodiesels have been tried, detailed, and explained in Table 4. Density is one of the critical components which increases the fuel viscosity and impacts the atomization of the fuel at the cylinder and the combustion process [50]. The diesel fuel's density is lower compared to castor ethyl ester diesel; this includes castor biodiesel to regular diesel increments the fuel blend density. The measured density value of B10 is 0.93 g/cm<sup>3</sup> [51]. The density of numerous biodiesel values are extended between 0.86 g/cm<sup>3</sup> and 0.89 g/cm<sup>3</sup>. In this manner, the castor biodiesel density could be a little greater to some extent. The B20 density check was 0.87 g/cm<sup>3</sup> [52]. There is an increasing tendency in the viscosity of fuel due to the maximization of fuel components. This makes a lag within the discharge of power and decreases the highest temperature and pressure in the cylinder than regular diesel [53]. Besides, the regular diesel within the engine performs lubrication, including diesel fuel in biodiesel, which may be utilized as a valuable tool to cut down the parts' tear and wear. The castor oil viscosity is merely 14.79 cSt [54]. The general range for biodiesel viscosity is about 1.9–6 cSt, the viscosity of B20 and B5 is in this range. Moreover, the chemical composition of carbon, hydrogen and oxygen are lower than the diesel. Due to this the engine emission results will change.

**Table 4.** Properties of various blends of fuels.

PROPERTY	Diesel	B5	B20	B100	Unit
Flash point	42.6	42.8	48	166	deg cel.
Cloud point	−4	−5	−8	−24	deg cel.
Heating value	45.11	43.41	43.76	36.7	MJ/kg
Kinematic viscosity @ 40 °C	3.1	3.41	4.87	5.18	cSt
Calorific value	43,200	39,575	39,572	39,499	kJ/kg
Density at 15 °C	830	880.2	878	876	kg/m <sup>3</sup>
Cetane no.	51	51.4	51.7	52	-
Hydrogen content	13.34	11.73	11.79	11.80	(wt.%)
Oxygen content	16	11.37	11.61	11.28	(wt.%)
Sulfur content	26	6.3	6.5	6.9	(ppm)
Carbon content	85.92	76.36	75.9	75.1	(wt.%)

It is clear that including the fuel of diesel from biodiesel diminished the value of heating. An aromatic compound present in diesel fuel increases its thermal value. In contrast, biodiesel has no such compounds; due to this fact, including regular diesel in biodiesel decreases the amount of fuel of heating [55]. Value of heating of B10 was calculated 37.9 MJ/kg, however, the amount of heating of B20 was determined as 43.76 MJ/kg. The amount of heating of biodiesel was within the range of 36–44 MJ/kg. The flashpoint of the diesel fuel is lower than that of the biodiesel. Since biodiesel's flashpoint value is high, it is a good factor that reduces its storage and transportation rush.

The flashpoint for B100 was between 120–166 °C. B20 had a flashpoint of 55.3 °C as we got 48 °C in this delving. The minimum value of the standard range of the flashpoint is 130 °C. 157–182 °C is the range of biodiesel or various types. The delving results imply that the addition of biodiesel on regular diesel reduces fuel's cloud point. This means that fuel's lowest temperature is capable of using the engine. It causes fuel filter blockage when fuel consumption of temperatures lower than the cloud point is used to form wired networks [43]. Thus, cloud point ranges from −11 to 16 °C of various fuels obtained at −24 °C in this delving. Therefore, it can be stated that castor oil is viable for use in cold regions [56]. There are few major blends of the castor oil blend biodiesel, which was determined through the obtained product of gas chromatography. The highest fraction is linoleic acid, which is 41.30%. The lowest value is 2.99% for the theTridecacid. The

structural formula of the castor oil blend biodiesel is  $C_{18}H_{33}O_2$  and its molar mass is 0.281 kg/mol [57].

## 4. Result and Discussions

### 4.1. Engine Performance

The test results imply that B5 and B20 samples of 1500 rpm engine speed obtain the same power. And diesel fuel generated greater control. The power increased at 2000 rpm for B5 samples, but B20 samples, as well as diesel, are having almost the same values. It is considered the small values of castor biodiesel, which gave the same result as the diesel biodiesel having less value or calorific value. The higher cetane number of biodiesels and oxygen molecules helps to increase combustion efficiency. The engine's volumetric efficiency gets reduced in the natural aspirated IC engines due to the decrease of oxygen; the oxygen present in the biodiesel helps combustion in this situation, which tends to high brake power. The brake power is more significant at B5 sample and part load condition than diesel fuel [58]. Considering B20, the oxygen present in the energy is greater than the oxygen present in B5 fuel. Also, the calorific value of B20 fuel is lesser than the calorific value of B5 fuel. The oxygen content does complete combustion, but it reduces the fuel's heat value [59]. Thus, biodiesel in lesser portions, like B5, increases the brake power.

### 4.2. Brake Power of Biodiesel Blends with Diesel

The oxygen present in the fuel gets to be restrained since the engine comes to the smoke control (or critical restriction). In contrast, lower calorific value's influence gets to be a striking highlight, so multiplying the biodiesel component in the fuel-blends decreases the power [46]. While running at 1500 rpm and 75% load, the most developed power was associated with B5, and the least was associated with B20, shown in Figure 3. The inclusion of methyl ester up to B5 elevated the power, and the power diminished till B20, shown in Figure 4. While running at 75% load at 2000 rpm, the drift of power variety was diverse. The most extreme power was associated with B0 fuel, and the least power was associated with B20. While running at lower loads, the highest developed power was associated with B5, and also the least power was associated with B20. Thus the power used to be elevated from B0 to B5 and reduced about B5–B20. But while running at full load, the waft of power range was a small diverse. There was no contrast of power in B0 as well as B5; however, from B5–B20, BHP used to be improved, and it gets diminished from B5 to B20. The highest BHP was associated with B20, and the least power was associated with B0 and B5.

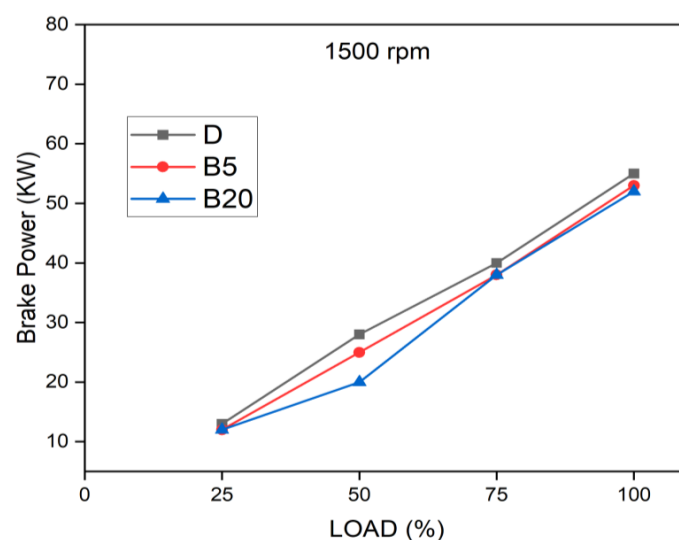


Figure 3. Load Vs. Brake Power at 1500 rpm.

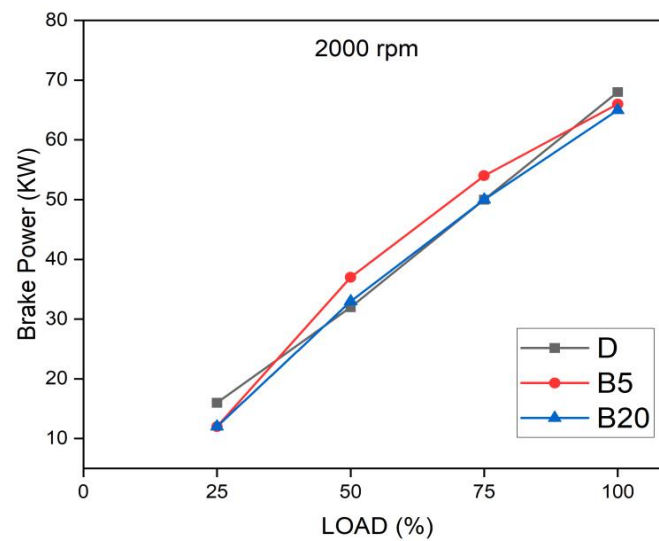


Figure 4. Load Vs. Brake Power at 2000 rpm.

#### 4.3. Brake Specific Fuel Consumption (BSFC)

BSFC is defined as the utilization of 1 kg of fuel for developing 1 kilowatt of energy in a time of 1hr. The increase in BSFC reduces the efficiency of the engine. According to the test results and Figures 5 and 6, B5 has the highest BSFC at 1500 rpm. While running at 2000 rpm, the most improved BSFC is associated with that of B20. While running at 1500 rpm on partial and complete loads, the BSFC of B5 and B20 are comparatively higher than diesel. However, at 2000 rpm, the outcomes are small and diverse. On 50 to 100% loads, BSFC is associated with that of standard diesel. BSFC is, in particular, related to the density of the fuel. However, combustion efficiency is also a fundamental factor because if the calorific value is excessive and the quality of combustion and the power development rate minimum, the BSFC will increase. So, the BSFC of Diesel and its blends are comparative. At lower load situations, while blending methyl ester in diesel fuel, the BSFC diminished from B5 to B20. But while running at full load, the inclusion of methyl ester has no substantial effect on the BSFC. Also, while applying a 75% load at 1500 and 2000 rpm, methyl ester increments BSFC. The glide of the BSFC range in current thinking can also be a little distinctive compared to the methyl ester, which can be due to differences within the variety of esters.

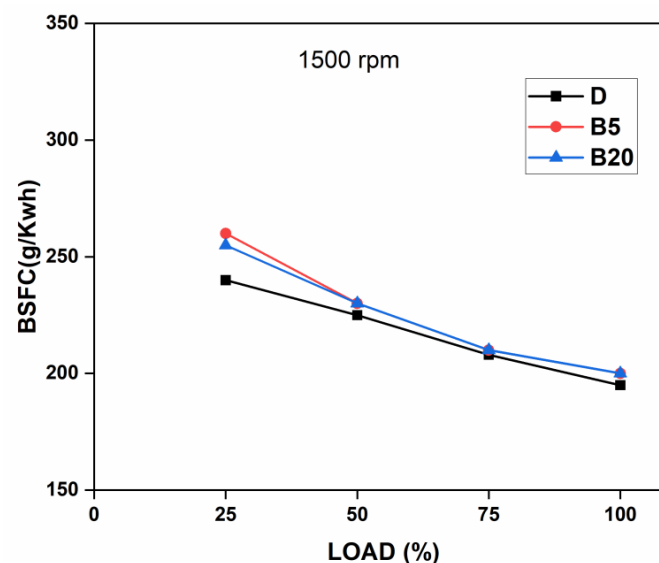


Figure 5. Load Vs. BSFC at 1500 rpm.



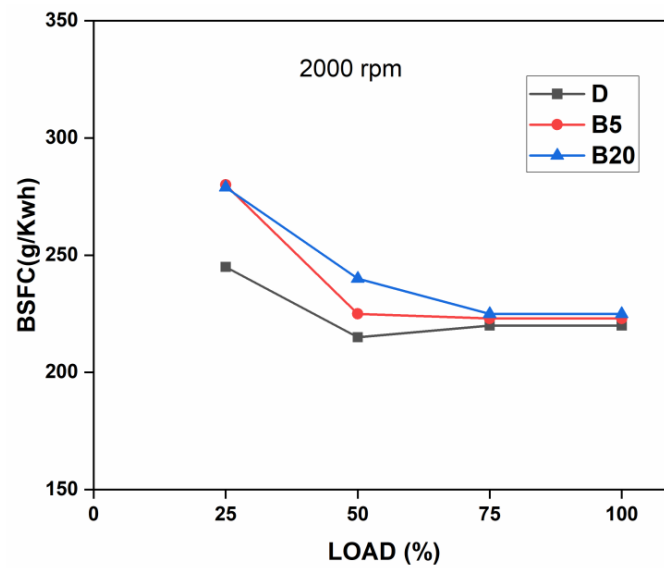


Figure 6. Load Vs. BSFC at 2000 rpm.

#### 4.4. Carbon Dioxide (CO<sub>2</sub>) Outflow

Carbon dioxide gas is the commonly emitted gas in Green House Gas emissions. In general, Carbon dioxide emission is directly proportional to the load and engine speed. As per the research, B5 emits comparatively less CO<sub>2</sub> than Diesel and B20 at 1500 rpm. At 50% and 75% load under 2000 rpm, B20 encompasses excessive CO<sub>2</sub> emission, shown in Figures 7 and 8. The degree of atomization of the fuel is reduced due to the higher viscosity and delays the power generation. Therefore, the maximum temperature and pressure of combustion will get reduced, resulting in low CO<sub>2</sub> emission. According to the types of factors, the liberation of Carbon dioxide will get higher or lower. Biodiesel has less carbon content than regular diesel, and the proportion of Hydro-carbon is even lower than the standard fuel. This may additionally cut down the CO<sub>2</sub> outflow.

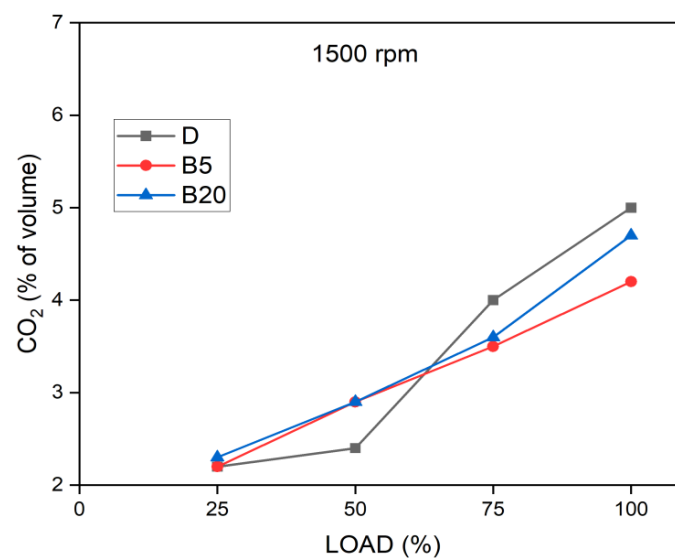


Figure 7. Load Vs. CO<sub>2</sub> at 1500 rpm.

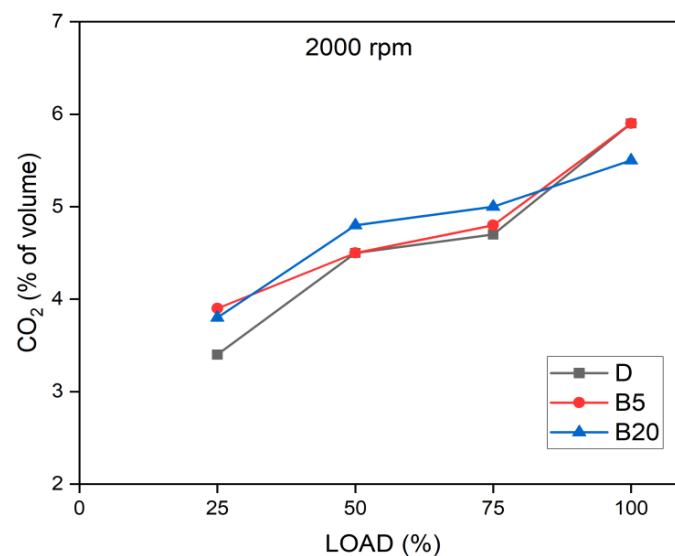


Figure 8. Load Vs. CO<sub>2</sub> at 2000 rpm.

#### 4.5. Emission of UHC (Unburned Hydrocarbon)

During the combustion process at the stage of engine power, when the combustion of fuel is incomplete, the unburned hydrocarbons are generated. There is not enough chance of comprehensive combustion in every period because of the high acceleration, and significantly less unburned fuel is obtained in the combustion chamber. Few amounts of fuel don't participate in combustion when the injected pressure is not required to dissipate the fuel molecules into the air, which is compressed. Those fuels remain without breaking. This reduces the efficiency of the engine and produces pollutants.

The most crucial factor of HC production is the design of the combustion chamber, injection posture, and pressure in these engines. The combustion chamber shape affects the combustion, and it either increases or decreases the outflow of HC [44,45,47,60]. The high-pressure injection turns fuel into tiny particles; thus, penetration of fuel particles in layers of compressed air decreases. That tends to cause incomplete combustion. Also, the low injection pressure increases the HC emission and gives the non-particulates fuel. From Figures 9 and 10 at 1500 rpm and 2000 rpm speed of the engine, B5 emits less UHC than diesel and B20. The chemical formula, C<sub>18</sub>H<sub>33</sub>O<sub>2</sub>, of the biodiesel, castor ethyl ester produced in the experiment into account, the oxygen content in it is almost 11.38% (O<sub>2</sub> mass-number/(C<sub>18</sub>H<sub>33</sub>O<sub>2</sub>) mass -number). The percentage of oxygen present in B5 and B20 is 0.57% and 2.27%, respectively. Fuel's oxygen content determines the combustion efficiency, and it also reduces the amount of UHC. Also, oxygen, which is present in the fuel, reduces the fuel's value of heating. It tends to significant fuel consumption, which can compensate for power loss during thermal devaluation. Thus, the oxygen that is present in fuel blends improves the combustion process and decreases UHC emission, and it also increases BSFC. These two phenomena meet at a point; that point is called the optimum point at that moment. Thus, a B5 sample with 0.57% oxygen content emits low UHC and implies that the primary drift's impact is higher than that of the second drift regarding B5. But, considering the B20 sample, the outcome of the second trend is higher, and it also increases the emission of UHC. In a delving using a 75% load at the engine speed of 1500 rpm, the highest emission of UHC is connected with the B20 sample, UHC emission for the B5 sample is less than that of B20. UHC's highest emission is connected with B20, For the lowest emission of UHC emission is associated with B5. Because of the findings of this investigation, the castor ethyl ester trend varies compared to the reports of castor methyl ester. These variations can be obtained by the variations of ethyl and methyl esters.

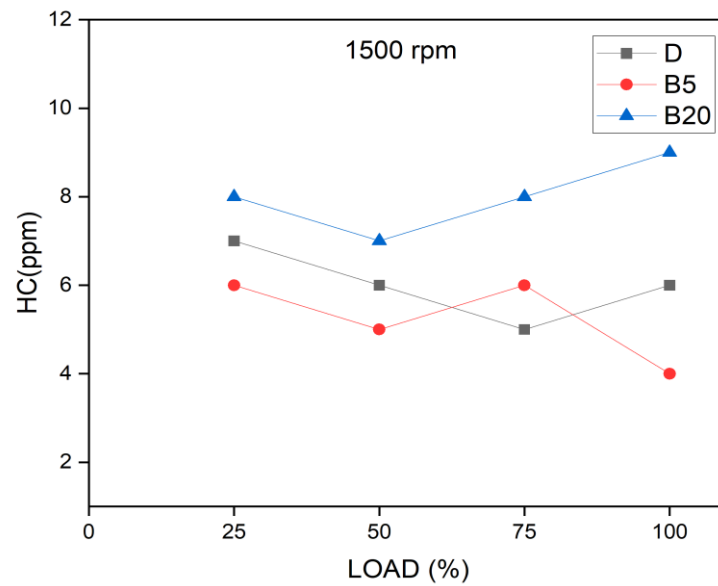


Figure 9. Load Vs. HC at 1500 rpm.

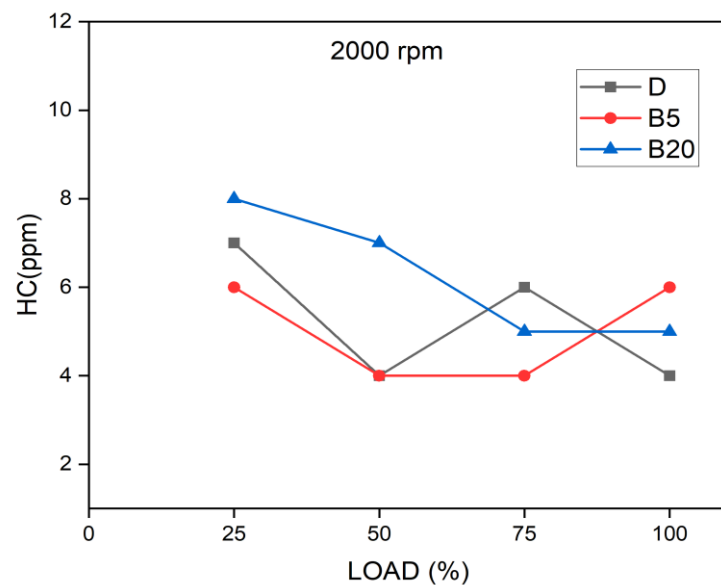


Figure 10. Load Vs. HC at 2000 rpm.

#### 4.6. Emission of Nitrous Oxide (NO<sub>x</sub>)

Nitrous oxide outflow happens at elevated temperatures. Expanding the percentage of biodiesel in the Diesel blends increments in fuel consistency, and the rise in viscosity diminishes the temperature of combustion; this decreases the nitrous oxide outflow. Similarly, the excessive cetane number of biodiesels increments the combustion temperature, which increments the nitrous oxide outflow [60–62].

As per the researchers, nitrous oxide emanation increments at 1500 and 2000 rpm while increasing the engine load. At a 25% load under 2000 rpm, Diesel fuel's nitrous oxide outflow is the least. However, at 1500 rpm under 50–100% load, NO<sub>x</sub> outflow of B5 is the least in contrast to these for B20 and Diesel fuels conjointly. At 2000 rpm on 75% load, the most negligible nitrous oxide outflow is seen as compared to the diesel fuel. The maximum nitrous oxide outflow is related to B5 to determine the chemical components of the biodiesel for these are shown in Figures 11 and 12. Therefore, including methyl ester in B5 increases nitrous oxide emission at that point from B5–B20. It is detailed that, under full load conditions, the inclusion of methyl ester increments the nitrous oxide emission from

B0–B5 and then diminishes the nitrous oxide outflow from B5–B10 and again increments the nitrous oxide outflow from B5–B20.

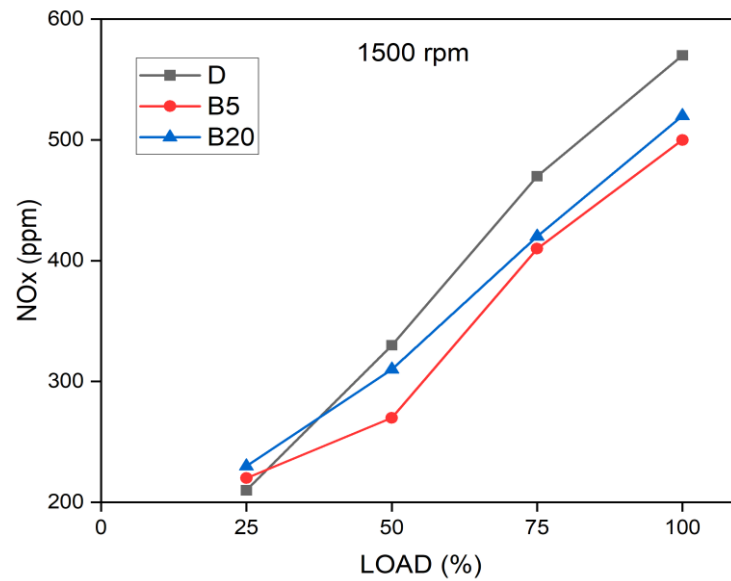


Figure 11. Load Vs. NO<sub>x</sub> at 1500 rpm.

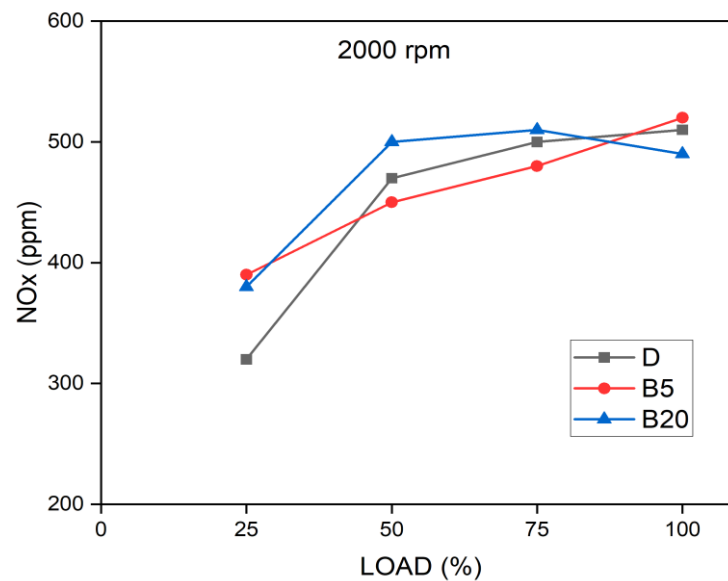


Figure 12. Load Vs. NO<sub>x</sub> at 2000 rpm.

#### 4.7. Soot Emission

Soot is formed as a result of incomplete combustion inside the cylinder. The common cause of soot formation is incomplete combustion, less oxygen, a poor blend of air/fuel, and lower thermal efficiency. From Figures 13 and 14 the amount of soot formation is almost the same for every fuel at 1500 rpm. However, B20 and B5 fuel's soot formation is less than diesel fuel at 2000 rpm under all load conditions loads.

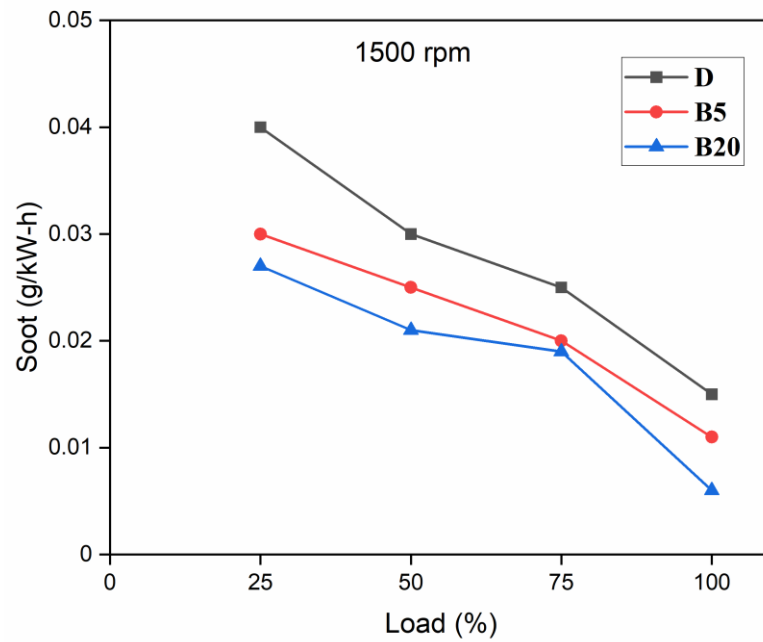


Figure 13. Load Vs. Soot emissions at 1500 rpm.

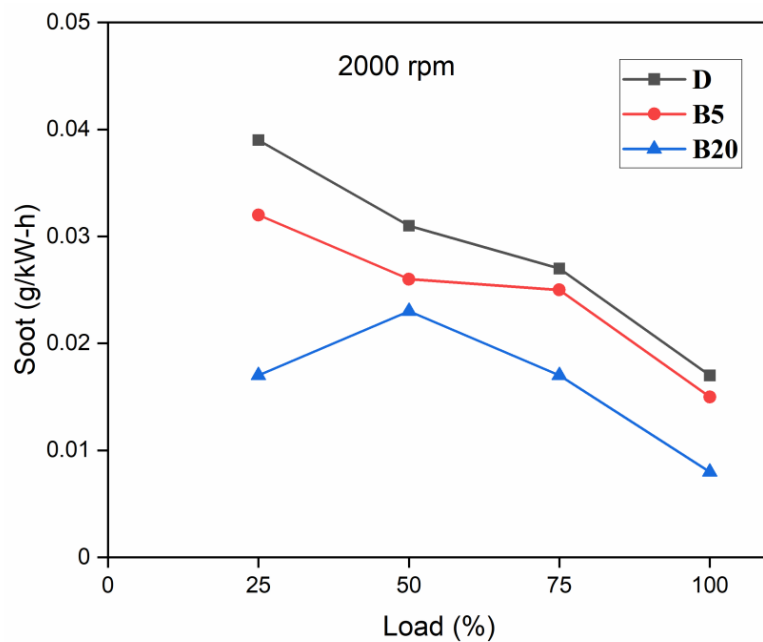


Figure 14. Load Vs. Soot emissions at 2000 rpm.

## 5. Conclusions

The performance and emission analysis of diesel engine with castor oil (*Ricinus Communis*) biodiesel have been conducted for two speeds, different loads and its values are compared with pure diesel. Based on the findings the following conclusions were drawn,

- According to engine performance, brake power reduced while increasing the biodiesel percentage in the blend at two different speeds. This may due to changes in the calorific value of different blending of biodiesels.
- While running at 1500 rpm and 2000 rpm on partial and complete loads, the BSFC of B5 and B20 are comparatively higher than diesel. This may due to various mixing ratios of esters.

- The outcomes of outflow demonstrate that B5 emits very low carbon dioxide (CO<sub>2</sub>), HC and nitrogen oxides (NO<sub>x</sub>) in comparison with B20 and Diesel in the case of the soot emissions, diesel fuel had the higher amount in comparison with B5 and B20. This occurred because of biodiesel has less carbon content than regular diesel, and the proportion of hydrocarbon is even lower than the standard fuel.

From the above observations, it was concluded that the performance of the B5 blend is better when compared with the B20 blend and conventional diesel at two speed conditions (1500 rpm and 2000 rpm). Hence, it is proved that castor oil (*Ricinus Communis*) biodiesel can be used as an alternative fuel for diesel engine.

**Author Contributions:** Conceptualization, M.A. (Munimathan Arunkumar); methodology, M.A. (Munimathan Arunkumar), A.A., N.A.A.; software, S.A.K., N.A.A.; formal analysis, M.A. (Munimathan Arunkumar), S.A.K., M.H.B.A.; investigation, V.M., S.A.K.; resources, A.A., T.S., S.A.K.; writing—original draft preparation, M.A. (Munimathan Arunkumar), A.A.; writing—review and editing, V.M., M.R., N.A.A., M.A. (Mohammad Asif); visualization, M.H.B.A., M.A. (Mohammad Asif); supervision, T.S., M.R.; project administration, V.M., T.S., M.H.B.A.; funding acquisition, M.R., M.A. (Mohammad Asif). All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** Authors would like to thank the Researchers Supporting Project, RSP-2021/42, King Saud University, Riyadh, Saudi Arabia for the financial support.

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

## Abbreviations

ASTM	American Society for Testing and Materials
bTDC	before Top Dead Center
Bd	Biodiesel
BSFC	Brake Specific Fuel Consumption
CO <sub>2</sub>	Carbon dioxide
CO	Carbon monoxide
cSt	Centistoke
CI	Compression Ignition
CR	Compression Ratio
cc	cubic centimeter
°C	Degree centigrade
HSU	Hatridge Smoke Unit
h	Hour
HC	Hydrocarbon
K	Kelvin
kJ	Kilo Joule
D	Diesel
kW	Kilo Watt
kg	Kilogram
mm	Millemeter
NOP	Nozzle Opening Pressure
NO <sub>x</sub>	Oxides of Nitrogen
ppm	Parts per Million
KOH	Potassium Hydroxide
P	Pressure (bar)
UHC	Unburned Hydro carbon
Rpm	Revolution per minute



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