

Article



A Parametric Study on a Diesel Engine Fuelled Using Waste Cooking Oil Blended with Al₂O₃ Nanoparticle—Performance, Emission, and Combustion Characteristics

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Abstract: As the environment is humiliated at a disturbing rate, most governments have persistent calls following global energy policies for the utilization of biofuels. This paper essentially examines the portrayal investigations of fatty acid methyl esters and fatty acid pentyl esters obtained from palm oil. The characterization studies such as gas chromatogram, mass spectrometry, and Fourier transformed infrared spectrometry have been performed to study biodiesel's chemical composition. This article likewise shows biodiesel's physiochemical properties and concentrates on biodiesel blends' hypothetical combustion properties with Al₂O₃ nanoparticles. The spectroscopic investigations demonstrate the contiguity of eight methyl esters and five pentyl esters prevalently of palmitic acid, oleic acid, octanoic acid, and stearic acid. The esters' nearness was additionally affirmed by the FTIR range, where the peaks in the scope of 1700 cm^{-1} to 1600 cm^{-1} can be observed. Looking at the thermophysical properties of the mixes with that of the base diesel fuel yielded the compromising results by giving the comparative density to that of the diesel fuel. The palm oil biodiesel's calorific value is, by all accounts, diminished by 10% when contrasted with diesel fuel. The addition of the nanoparticles up to 1 g has raised the calorific value most closely to the diesel's value. Correspondingly, the theoretical burning examinations have demonstrated the limit of biodiesel to go about as an option compared to consistent diesel in the conventional DI-CI engine. This article talks about the combustion attributes of the blend containing 60% diesel, 20% fatty acid methyl ester (FAME), and 20% fatty acid pentyl ester (FAPE) with aluminium oxide (Al_2O_3) nanoparticles at two distinctive concentrations. This article primarily concerns the inquiry of combustion criterion, such as in-chamber pressure variation, rate of heat release, start of combustion, end of combustion, and ignition delay for considered fuel blends when contrasted with neat diesel fuel in a four-stroke, direct-injection, single-cylinder diesel engine. The results showed a decrease in in-cylinder pressure at all loads of engine operation for biodiesel blends when compared with neat diesel, irrespective of the nanoparticle concentration. Biodiesel blends at all nanoparticle concentrations showed an increase in ignition delay compared with diesel fuels at all engine operation loads. The performance results show a slight deterioration in the engine's thermal efficiency using biodiesel blends, irrespective of the nanoparticle concentration. Additionally, the emissions show a considerable fall in trends for all loads in contrast with diesel fuel.

Keywords: fatty acid pentyl ester; used cooking oil; work done analysis; characterization

1. Introduction

The increasing fuel demands and stringent emission norms have led researchers to explore the word "alternate fuels". In the arena of alternate fuels for IC engines, biodiesels play a key role. Biodiesels are easily available and a powerful alternate to petrodiesel. Biodiesels are primarily prepared by transesterification of vegetable oils by employing light alcohols such as ethyl alcohol or methyl alcohol [1–4]. The usage of alternative alcohol



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). is still on the verge of exploration. The development of mankind has majorly relied on internal combustion engines for producing mechanical work by utilizing chemical energy from any hydrocarbon fuel. This energy is primarily utilized in the transportation and agriculture sector [5].

Sudhir et al. [6] analysed the realm of possibility on waste cooking oil for their agreement as to the best source of raw material for the production of biodiesel and contrasted the property of methyl esters derived from WCO with that of neat mineral diesel and fresh esters. Their results showed that the thermal performance of the engine closely resembled the performance of the engine powered with clean esters. It was noticed that, at the partial load of engine operation, WCO biodiesel languished in nearly 2% of brake thermal efficiency loss. On the other hand, the unburnt hydrocarbon emission was interestingly dropped down by 35% less than baseline diesel fuel's operation at all the operational loads of the engine.

Demirbas [7,8] performed a transesterification reaction on used cooling oil with KOH as the catalyst and supercritical methanol methods to produce biodiesel. The consequence of oil-to-alcohol ratio, temperature, and catalyst concentration on the yield of biodiesel was also probed. Further, they have also separated an increase in BSFC and BTE, while consecutively reducing HC and CO emissions. As a consequence of higher thermal efficiency, the NOx emission for the fuel has been reported to be high, even at higher engine operational loads. They showed a noticeable surge in smoke and particulate emission.

Kannan et al. [9] optimized the biodiesel extracted from waste cooking oil by employing the transesterification process and optimized the process. The optimal condition for biodiesel was determined, and the biodiesel was investigated in the engine for the combustion parameters by varying injection pressure and injection timing. They have reported improvement in brake power and heat release rates for elevated pressure and timings. Moreover, this result showed a reduction in smoke and NOx emission.

Berchmans and Hirata [10] proposed a method to formulate biodiesel from crude oil extracted from jatropha seed. They have materialized the two-step transesterification process for FFA reduction in CJS oil to a value of less than 1%. Initially, they carried out the acid pretreatment process by mixing 0.60% w/w methyl alcohol with oil in the acidic medium prepared by adding $1\% w/w H_2SO_4$ for 1 h at 50 °C. Finally, the pretreated sample was mixed with 0.24% w/w of methyl alcohol and reacted at 65 °C for 2 h under an alkali environment containing 1.4% w/w of NaOH. The above process yielded a biodiesel yield of 90% in the stipulated time.

Hwang et al. [11] studied the consequence of variation in injection timing and pressure on a CRDI engine fuelled with biodiesel obtained from waste cooking oil (WCO) and compared it with that of diesel fuel. From their results, it is evident that the fuel consumed to produce unit power was higher at elevated injection pressures for biodiesel under all operating circumstances. Biodiesel showed a slightly reduced peak in-cylinder pressure and rate of heat release while extending the ignition delay over the operational range of the engine. Their emission results seem to be compromising by showing reduced CO₂ and HC emission, while producing more NOx emissions when compared with diesel at all engine operating conditions.

Encinar et al. [12] characterized the ethyl ester for suitability to be utilized as biodiesel in a CI engine. The study has been conducted by varying the operating parameters such as oil/alcohol molar fraction, catalyst intensity, type of catalyst, and temperature. The convincible biodiesel yield with the finest properties was obtained at a molar ratio of 12:1 and 78 °C reaction temperature while using 1% KOH as a catalyst. It has been found that the cloud point, pour point, and cold filter plugging point for the biodiesel obtained is higher than base diesel. The higher flash point and combustion point make the ethyl ester derived from vegetable oil the best fuel for the CI engine.

While providing us with great convenience in expediting mobility and power, the engine also consumes a drastic amount of non-renewable fossil fuels, mostly petrol and diesel. The energy that can be obtained from the combustion of fuel in the engine comes with the cost of hazardous emissions. The emissions include greenhouse gasses such as

UBHC, NOx, CO, and PM [13]. Meher et al. [14] contrasted the combustion, emission, and performance characteristics of a single-cylinder diesel engine fuelled with biodiesel and diesel blends. The effect of compression rations on engine parameters has been elaborated and studied. Veritably, the dwindling crude oil reserves and accompanied environmental pollutants are the most astringing issues that are needed to be addressed in the current situation [15]. The work explores the capability of utilizing pentanol as alcohol for transesterifying UCO. The following context is inspired by numerous works that have been completed in the field of biodiesels. Some of the significant works are given below.

Raqeeb and Bhargavi [16] and Math et al. [17] applied base-promoted transesterification of UCO with methanol during a test trial in a small-scale research reactor. The consequences of methanol/UCO's quantitative relation, hydroxide concentration, and temperature on the biodiesel conversion rate were investigated. It was found from their trial that, at the methanol/oil ratios of 7:18:1, temperatures of 30 to 50 °C and 0.75% by weight of KOH, the biodiesel yield of 88% to 90% was obtained. The characterization results demonstrated that biodiesel encountered a higher, though much smaller, boiling point than traditional diesel.

Canakci [18], Kulkarni and Dalai [19], and Lam et al. [20] elaborated on a procedure to bring down the free fatty acid content of the feedstock by implementing acid-catalysed pretreatment to esterify FFA before performing actual transesterification reaction for obtaining biodiesel by converting triglycerides in the oil with the help of an alkali catalyst. Investigations on the process parameters that govern the transesterification reaction such as motor ratio catalyst concentration, reaction time, and FFA concentration were performed and determined the best proportion to obtain maximum conversion efficiency. The study also shows that the two-step transesterification process is effective in reducing FFA to less than 1%. Al-Widyan and Al-Shyoukh [21] and Singh and Singh [22] transesterified used cooking oil under various circumstances. From their results, it is clear that H₂SO₄ performed better than hydrochloric acid at a 2.25 M concentration. As a result, it lowered viscosity. Additionally, at 100% excess alcohol, the reaction time was significantly reduced, and viscosity was reduced drastically. They stated that 2.25 M of H₂SO₄, with 100% excess alcohol, will be the best process combination to effectively reduce the viscosity of the oil from 0.916 to 0.813 in about 3 h of reaction time.

Lapuerta et al. [23,24] obtained experimental results from biofuels derived from waste cooking oil by utilizing methanol and ethanol for the esterification process. The results showed a minor increase in fuel consumption in contrast with diesel. Moreover, a sharp decrease in CO, HC, and smoke opacity was found while keeping the NOx constant. Alcohols that have been used to process the fuel also have noticeable effects on the reduction of CO and PM emissions.

The emission characteristics of the Perkins engine that has been fuelled with methyl esters derived from olive oil have been studied by Dorado et al. [25], and their results revealed reduced exhaust emission for use of biodiesel and a considerable increase in NOx emission. The authors have also reported a slight increase in brake-specific fuel consumption, while constantly maintaining combustion efficiency for either diesel or biodiesel.

Pugazhvadivu and Jeyachandran [26] used waste cooking as fuel in a diesel engine. They showed improvement in engine performance, CO, and smoke emissions. Can [27] blended the mixture of biodiesel obtained from two different waste cooking oils at various proportions. The blends were tested for their performance and emission characteristics in a four-stroke engine at the naturally aspirated condition. Since the cetane number of biodiesels was elevated, despite the earlier start of combustion, the biodiesel was found to have reduced ignition delay for positive progression in engine operational loads. On the other hand, biodiesel addition with diesel deteriorated the in-cylinder pressure and peak heat release rate simultaneously. In addition, the emission characteristics showed a considerable rise in oxides of nitrogen while depicting a significant decrease in the hydrocarbon and smoke emissions for the entire range of engine operation. Moreover, it is found that CO_2 emissions at all the loads of engine operation have been significantly raised while using biodiesel blends. Valente et al. [28] focused on studying the emission characteristics of a diesel power generator fuelled with blends of diesel and biodiesel at different volume concentrations and variations in loads. The average increase in emission of CO₂, HC, and NOx was observed with various load ranges. It is evident from the results that usage of 50% blend concentrations increases the emission. Furthermore, the drastic increase in NOx was primarily found at a low load of engine operation. Meng et al. [29] performed experiments to find out the best parameters for the transesterification process to provide a maximum possible yield of biodiesel using orthogonal analysis of parameters in four-factor and three-level tests. The optimal parameters from the analysis were given as alcohol-to-oil volume ratio 9:1, along with 0.1% by wt. of sodium hydroxide and reaction temperature of 50 °C for 1 h and 30 min. The engine test results gave unsatisfactory emission parameters for higher biodiesel blends while keeping the dynamic performance of the engine constant. Lower blends of biodiesel showed a significant reduction in CO, HC, and particulate emissions. Di et al. [30] and Zhang et al. [31,32] critically studied the performance parameters of the engine and road performance of an automobile using biodiesel prepared by waste cooking oil. The results showed a 35% reduced torque and power output for biodiesel over diesel. As the result of winter conditions and insufficient combustion, carbonization of the injector was also observed for a reduction in viscosity of biodiesel, and there was no carbonization of the injector. The surfaces of the cylinder and piston head were also found clean. Wang et al. [33,34] mixed WCO samples having high acid value with alcohol to perform the methanolysis process under 95 °C for a range of reaction times. The conversion efficiency of the process was reported as 97.22% for 4 h of reaction time with methanol-to-oil ratio of 10:1 and used ferric sulfate as a catalyst. This new catalyst has been reported to have the advantage of having no acidic wastewater, high conversion efficiency, low cost, and tireless recovery of a catalyst over the traditional acid-catalysed process.

Utlu and Koçak [35] experimentally examined the performance characteristics of the waste cooking oil biodiesel in a turbocharged DI diesel engine. From the results of the trial and variation in the engine parameters, it was found that the basic attributes of the engine such as torque, power, and SFC remained nearly constant, whereas the emission components such as carbon oxides, nitrogen oxides, and smoke opacity were found to be reduced in contrast with diesel fuel. Results showed that using a heterogeneous catalyst, which was synthesized at 600 °C, produced maximum FAME conversion with reaction temperature, alcohol, oil, and catalyst loading of 65 °C, 25:1, and 1.5%, respectively. Bhatia et al. [36] used ethanol in waste cooking oil to reduce oxides of nitrogen and smoke density from RCCI engine in low temperature combustion. On an energy basis, ethanol was inducted through the intake manifold in the levels of 10 and 20% as low-reactivity fuel, whereas WCO biodiesel was injected into the cylinder as high-reactivity fuel. Results showed that the oxides of nitrogen and smoke were reduced up to 60 and 29%, respectively. Moreover, on operating the engine at peak load, the other emissions such as carbon monoxide and hydrocarbon increased to 2%. Khounani et al. [37] produced biodiesel from waste cooking oil by introducing walnut husk methanolic extract as an antioxidant in the place of propyl gallate. From the environmental perspective, it can be concluded that the walnut husk methanolic extract using solar photovoltaic process compared to propyl gallate. Chong et al. [38] analysed the soot volume fraction of biodiesel (WCO) and compared it with diesel fuel. Pool flame and diffusion jet flame methods were used to test the biodiesel blends and diesel. Results showed that, using diffusion jet flame, the soot particle diameter produced using WCO biodiesel reduced by 1.5 times compared to diesel. The mean particle diameter was higher using the pool flame technique by about 8% and 22% for WCO biodiesel and diesel fuel, respectively.

From the series of literature studies, it has been noted that the usage of used cooking oil as a source of biodiesel will effectively decrease carbon oxides and smoke emission while maintaining NOx and performance for an entire load range of engine operation. This current study is focused on studying the combustion, performance, and emission characteristics of Direct Injection Compression Ignition Diesel Engine fuelled with blends of fatty acid methyl & pentyl esters (FAME–FAPE) and diesel with two different concentrations of aluminium oxide nanoparticles. The idea of using metal oxides with the blends is to provide the oxygen required for the complete combustion of the pentyl ester, which has additional hydrocarbons that a normal diesel engine cannot handle. The production of FAPE from waste cooking oil is done by a typical two-step transesterification process.

2. Materials and Experimental Methodologies

2.1. Fuel Formulation

This current work is focused on the production of fatty acid methyl ester (FAME) and fatty acid pentyl ester (FAPE) from used palm oil. The palm oil was obtained from the restaurant and tested for its acid content and that was found to be 22.4 g/mL of NaOH. The oil was primarily treated with concentrated hydrochloric acid and further processed with a base-catalysed transesterification process with methanol and pentanol to obtain methyl esters and pentyl esters, respectively. The block diagram of the biodiesel production setup is shown in Figure 1. Initially, the oil is treated with alcohol and acid catalyst conc. H_2SO_4 to reduce the free fatty acid content in the oil below 2%. The treated used cooking oil is then taken to the transesterification stages where it is treated with alcohol and NaOH. In this stage of processing, the actual conversion happens, and the biodiesel is produced. After this stage, the crude biodiesel is taken and washed with warm water to get rid of the excess of the catalyst that is present in the biodiesel and dried at 100 °C to remove the water vapour that came as the result of washing. In similar ways, pentyl ester was also prepared and separated from glycerine. Both methyl ester and pentyl ester are mixed with diesel at different proportions to form different blends. Those blends are added with aluminium oxide nanopowder at two different proportions; esters are separated from the glycerine using a separator funnel.



Figure 1. Biodiesel production process.

2.2. Engine Test Rig

The experiments were conducted in a four-stroke, single-cylinder, compression ignition engine; the schematic of the engine is shown in Figure 2. The specification of the engine used is given in Table 1. The test fuel was a blend of FAME and FAPE obtained from the transesterification process of used cooking oil with methanol and pentanol, respectively. Additionally, the blends were mixed with aluminium oxide nanoparticles in two different proportions. The comparable physiochemical properties of the fuel blends are tabulated in the Table 2.



Figure 2. Engine test rig.

Table 1. Engine specification.

Name	Kirloskar
Number of cylinder	1
Displacement Volume	622 cc
Bore \times Stroke	$87.5~\mathrm{mm} imes110~\mathrm{mm}$
Compression ratio	17.4:1
Operating speed	1500 rpm
Injection Timing	23 deg BTDC
Injection Pressure	200 bar
Power	4.41 kW

Table 2. Fuel properties.

Property	Diesel	Palm Oil Biodiesel	D60 M20 P20 +50 ppm (Al ₂ O ₃)	D60 M20 P20 +100 ppm (Al ₂ O ₃)
Density (kg/m^3)	855	846	866	878
Kinematic Viscosity (Cst) (at 40 °C)	2.95	3.10	3.28	3.36
Flash Point (°C)	60-80	35	36	39
Fire Point (°C)	96	38	40	43
Calorific Value (MJ/Kg)	43.000	39.252	41.111	41.189

3. Results and Discussion

3.1. Fuel Characterization

Table 3 shows the details of the ester present in the sample (PB). It is clear from the table that, at the retention time of 18.140, 9-hexadecanoic acid and methyl esters, which is an ester of the name of acid palmitic acid, were found at the retention time of 18.407; hexadecanoic acid methyl ester was predominantly observed in the name of palmitic acid, with a retention time between 20.014 and 20.126; methyl esters of oleic acid were seen during the retention time of 20.33; the esters of stearic acids were seen at the retention of 21.661 and 21.784; and esters of octanic acids were seen (Figure 3). Table 3 also shows the details of the ester present in the sample (PB), and it is clear from the table that, at the retention time of 19.866, 4-methyl-terephthalic acid and 2-chloroethyl heptyl ester, which is an ester

of the name of acid octanoic acid and terephthalic acid, were found at the retention time of 21.506; the esters present in the form of palmitoleic acid, i-propyl 9-hexadecenoate, which is predominantly found in the name of palmitic acid, at the retention time of 21.697 esters of palmitic acid were seen; at the retention time of 23.106, the esters of decanoic acid were seen; and at the retention of 23.163, decyl oleate, butyl 9-octadecenoate, and esters of oleic acid were seen; and 23.334 esters of stearic acid, oleic acid, propionic acid were seen. Figures 4 and 5 show the presence of alkyl groups (traces of C-O and O-H stretch), aliphatic compounds, and esters.

Peak Retention **Description of** Name of the **Molecular Structure** No Time Esters Acid Tetradecanoic Methyl 1 16.215 tetradecanoate Acid 9-hexadecenoic acid, 2 18.140 Palmitic acid methyl ester Hexadecanolic acid, 3 18.407 Palmitic acid methyl ester 9,12-Linoleic acid 20.014 octadecadienoic 4 acid, methyl ester 11-octadecenoic 5 20.216 Oleic acid acid, methyl ester 6 20.303 Methyl stearate Stearic acid Oxlraneoctanoic 7 21.661 Octanoic acid acid, methyl ester Oxlraneoctanoic 8 21.784 Octanoic acid acid, methyl ester

Table 3. Description of the esters present in the fuel.



Figure 3. Mass spectrum of different esters at different retention timings.

XТ

10

5 0.0





Figure 4. Fourier transformed infrared spectrometry of fatty acid methyl ester.

1743



Figure 5. Fourier transformed infrared spectrometry of fatty acid pentyl ester.

The peaks at 2858 and 2956 cm^{-1} in the presence of O-H acid are found in Figures 4 and 5, while carboxylic acid is found in the peaks from 1780 cm⁻¹ to 1650 cm⁻¹. The peak in the region of 3344 cm⁻¹ represents the presence of a single bond between nitrogen and oxygen. The peak in the region of 1738 cm⁻¹ shows the presence of the double bond between carbon

Type of Bond	Transmittance (cm ⁻¹)	Intensity	
C-0	1054		
	1075	strong	
	1237		
C–N	1115		
	1186	medium	
C=O	1738	strong	
O-H (ACID)	2858		
	2956	strong, very broad	
N–H	3344	medium, broad	

and oxygen, which can be of esters of carboxylic acid. The data presented in Table 4 show

Table 4. FTIR spectrum of the fuel.

3.2. Variation in In-Cylinder Pressure with Respect to Crank Angle

the presence of different stretch in the palm oil biodiesel.

One of the major parameters in the analysis of the engine can be regarded as incylinder pressure variation with a crank angle. It can be argued that the pressure during the expansion stroke is very much valued since it is the pressure that forces the piston to move downwards and produce useful power. In this study, the pressure is measured by using Kreisler in-cylinder pressure sensor and incremental crank angle encoder coupled with a 3.5 GHz data acquisition system. The comparative results for the pressure are plotted for the full load operation of the engine that has been shown in Figure 6. From the figure, it is noted that the pressures of the blends are always lesser than that of diesel irrespective of the nanoparticle concentration. The above phenomenon occurs as a result of the comparative increase in densities of the biodiesel in relation to diesel.



Figure 6. Pressure theta curve.

Figure 7 depicts the instantaneous change of in-cylinder pressure with reference to the crank angle. The rate of pressure rise (RPR) gives the intensity of the combustion at all the instants of the crank angle. It can be noted that the RPR curve takes the positive slope for the increase in in-cylinder pressure, while it takes a negative slope for reducing pressure, depicting the movement of the piston in a downwards direction. From the figure, it is noted that the curves are not smooth for biodiesel when compared with diesel, which shows that the combustion is not smooth; this can be explained by rapid variation in combustion reactants species (due to the addition of Al_2O_3) that rapidly releases the oxygen after taking up the heat of combustion during the expansion stroke. This kind of phenomenon is not so

advisable in the engine, since it may cause potential damage to the internal parts of the engine and diminishes the mechanical efficiency of the engine.



Figure 7. Rate of pressure rise.

3.3. Variation of Heat Release Rate

It is mandatory to analyse the heat released from the engine to calculate the work done according to the first law of thermodynamics, which states the mutual relationship between work and heat for any thermodynamic system. The heat release rate of any system can be categorized into heat release rate, which is calculated as the rate at which the heat is released corresponding to the crank angle duration, and cumulative heat release rate, which is termed as the heat released per cycle.

Figure 8 shows the variation in heat release with respect to crank angle intervals. It is clear from the above figure that the heat release rate for biodiesel is comparatively less than that for diesel, irrespective of the blends. Biodiesels normally have high densities when compared with diesel; hence, the time for spray formation is prolonged. This phenomenon is responsible for increasing the ignition delay of the fuel blends, eventually making it fire during the expansion stroke. This can be avoided by advancing the injection. The figure shows the net heat release rate for the entire cycle, which also shows similar trends as the heat release rate. Biodiesel normally has a reduced calorific value than diesel that accounts for the reduction in the heat release rate of the biodiesel blends. From the analysis of the heat release and pressure characteristics of an engine, it is evident that the ignition delay of the biodiesels is higher than diesel; hence, the time for atomization of the fuel will be higher when compared to diesel, contributing predominantly to the physical delay period, eventually increasing the ignition delay of the blend.

3.4. Analysis of Work Done

One of the primary parameters that define the engine characteristics is work done. Work done can be used to determine the thermal conversion efficiency of the engine. In other terms, the work done will numerically define the amount of the heat supplied by the fuel that has been converted into useful work.

Work done on any engine operating on an air standard cycle can be calculated by using an indicator diagram that will be plotted between pressure and volume of the cycle. Figure 9 represents the indicator diagram for diesel and blended biodiesels, comparatively. It has been evident that the area of the PV plot of biodiesel blends is higher than that of diesel, which depicts that biodiesel provides higher work done when compared with diesel. Actually, the performance of biodiesel will be lesser than diesel. This is well depicted by the log PV curve plotted between the log of pressure and the corresponding volume, which denotes the change in the internal energy of the system. It can be seen that the curve has

the greatest decline in the expansion stroke for biodiesel blends, which represents the fact that the majority of the heat release from the biodiesel will happen only at the expansion stroke due to the late ignition of the fuel when compared with diesel, whereas the curve is found smooth for diesel.



Figure 8. Variations in heat release.



Figure 9. Work done by the engine.

3.5. Speed Torque Characteristics of the Engine

Figure 10 shows the speed and torque characteristics of the engine that has been used for the present study. The graph shows the decreasing trends for torque with increasing speeds; normally, the speed fluctuates between 1450 rpm and 1680 rpm. Hence, to maintain the standard torque range at all the loads, the engine was chosen to run at a constant speed of 1500 rpm, which was done by adjusting the governor screw of the engine. This assures the uniformity in the results obtained for various blends.

3.6. Performance Characteristics

Most of the literature reviews majorly focused on augmenting the thermal performance of the engine. This part of the study shows the variation in the thermal performance characteristics of the engine such as brake thermal efficiency and brake-specific energy consumption.



Figure 10. Speed torque characteristics of the engine.

3.6.1. Brake Thermal Efficiency

Figure 11 provides the performance characteristics of the test engine. It is evident that the thermal efficiency of the engine increases with an increase in the load of the engine operation, proving the fact that the compression ignition engines perform well at peak loads. It is also seen that the biodiesel blends with 0.5% nanoparticle concentration have shown better thermal efficiency than diesel, since the combustion is enhanced due to supply of the more oxygen by the nanoparticles. If the above context fits well to the picture then, nanoparticles with 1% nanoparticle should have exposed higher thermal efficiency; conversely, an increase in oxygen in the blends has negative effects on combustion. This additional oxygen not only promotes combustion but also enhances the formation of nitrogen oxides (NOx), therefore eventually reducing the oxygen available for combustion. From this observation, it can be concluded that the usage of metallic oxide nanoparticles to some smaller extent less than 0.5% will end up with increased thermal efficiency of the engine.

Figure 11. Performance characteristics.

3.6.2. Brake-Specific Energy Consumption

Figure 11 provides the variation in BSEC with load for various nanoparticle concentrations. It can be interpreted that the blends with minimal nanoparticle concentration will consume less energy. This makes the blends exhibit higher thermal efficiency than diesel fuel. It also is seen that the BSEC for low loads is higher, and for high loads is lower; these trends are seen in all the blends of the biodiesel.

3.7. Emission Characteristics

3.7.1. Variation in Carbon Emissions

The total carbon emission from the engine will be considered as a cumulative accord of carbon monoxide (CO) and carbon dioxide (CO₂). Generally, there will be a trade-off between CO and CO₂; while the former increases the latter decreases. This trend of CO and CO₂ variation with load for different blends is plotted in Figure 12. The figure shows an increase in CO₂ for the increase in loads. Conversely, it demands the formation of CO. While discussing emission, it is noted that biodiesel blends show more increased emission than diesel at all loads. The actual combustion process theoretically yields CO₂ and water as products. Hence, the higher formation of CO₂ indicates complete combustion. From the graph, it is evident that, at higher loads, the combustion of all the fuels is better when compared with the low load operation of the engine.

Figure 12. Total carbon emission of the engine.

3.7.2. Variation in Oxides of Nitrogen

NO and NO₂ cordially correspond to NOx emission of the engine. The NOx will be separated as a consequence of two phenomena, thermal NO and prompt NO. The thermal NO is produced due to the oxidation of N₂ in the air at a higher temperature. This kind of NOx is most predominately found in the case of the engine. The NOx is formed primarily due to the high temperature of the combustion. Figure 13 shows the variation in NOx for different blends over the entire operations of the engine. The results show elevated emission in NOx for biodiesel blends for all the loads. Generally, there is an engine trade-off between thermal efficiency and NOx. If the efficiency of the engine increases, then there will be a subsequent increase in NOx. Since biodiesel has high thermal efficiency, they are exhibiting higher NOx.

Figure 13. UBHC and oxides of nitrogen emission.

3.7.3. Variation in Unburnt Hydrocarbon Emissions

Figure 13 shows the UBHC emission of the blends for engine loads. The graph shows a decrease in HC for the increase in loads for diesel fuel alone on contradicting the biodiesel blends shows an increase in emission of HC for the increase in loads range of engine operation.

4. Conclusions

The current work speaks about the rapidly depleting fossil fuels and the method to utilize the UCO for the production of biodiesels. Studies have analysed the usage of alcohol for the alcoholysis process and have concluded that the pentanol can also be used for the transesterification of the fatty acids to produce biodiesel. It has also been proved that biodiesel from UCO will be a major breakthrough in the field of alternate fuels. On analysing the results obtained from testing the biodiesel from waste cooking oil in a compression ignition engine with two distinct blends of nanoparticles, it can be concluded that:

- Usage of the oxygenator in the form of nanoparticles will considerably increase the performance when compared with pure biodiesel blends.
- The biodiesel will increase the ignition delay of the fuel.
- The work done from biodiesel will be more when compared with diesel, but the restriction in internal energy of the system reduces the work done in biodiesel.
- The addition of metal oxides such as nanoparticles in smaller extents can achieve better performance.
- The emission for the blends with nanoparticles has been found to be increased.
- The addition of metallic oxides nanoparticle will also account for nanometals emission, which is unregulated.

5. Future Research

Given the present global energy demand, it is critical to diversify into various alternative energy sources. The only solution to the present energy issues is to commercialize FAME manufacturing to fulfil global energy demand. Because of their biodegradability, lower toxicity, and similar performance to fossil fuels, renewable energy sources such as biofuels are currently regarded as the greatest alternative to traditional fossil fuels. However, due to the higher production cost, the present FAME manufacturing appears to be an unsustainable one. By improving the catalytic system and reducing the cost of manufacturing, this higher production could be solved. **Author Contributions:** Conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft preparation, writing—review and editing, M.P., B.R. and R.S. All authors have read and agreed to the published version of the manuscript.

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