Experimental Study on Biodiesel Production Parameter Optimization of Jatropha–Algae Oil Mixtures and Performance and Emission Analysis of a Diesel Engine Coupled with a Generator Fueled with Diesel/Biodiesel Blends

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ABSTRACT: Methyl ester production from jatropha–alga oil is conducted through a transesterification process. Consequences of four parameters, the molar ratio (oil:methanol), the reaction temperature, the amount of catalyst, and the reaction time for obtaining a higher yield of biodiesel, are derived, and the process was optimized using the response surface methodology based on the Box–Behnken Design. An optimized biodiesel yield of 96% is achieved at a molar ratio of 1:10, a reaction temperature of 53°C, a 0.3 wt% catalyst, and a reaction time of 172 min. The predicted optimal conditions were experimentally validated with a relative error of 4% of the experimental result (96%). The P value of ANOVA is <0.0001, which shows that the model is significant. Finally, the performance and emissions in a diesel engine coupled with an electricity generator powered by biodiesel blends (B0, B5, B10, and B20% vol.) were investigated, concluding a significant reduction of exhaust gases. The engine was run with numerous blends of biodiesel by changing the brake power from 0 load to 0.5, 1, 1.5, and 2 kW.

1. INTRODUCTION

With global concerns about oil cost and atmospheric changes, scientists around the world have been looking for renewable energy resources. This forced researchers to identify an alternative source for petroleum products. Biodiesel showed promising results when compared with other renewable and alternative sources for diesel. Recently, several research studies were conducted to analyze the use of biofuels obtained based on macroorganisms and microorganisms, as they are a sustainable and renewable energy source and also environmentally friendly.

There are different methods used to improve the properties of fuels and further decrease viscosity and density of biodiesel, such as mixing with the petroleum diesel fuel, microemulsification with alcohols, and preheating. Among these, mixing with diesel is widely adopted. 20% biodiesel with 80% diesel mixture by volume is a common biodiesel blend. 20% biodiesel is prevalent because it provides good balance of low-temperature performance, low emissions, low cost, material compatibility, and the ability to act as a solvent.1 Biodiesel was generated from the jatropha–alga oil with a transesterification process along with the response surface methodology (RSM).2 Biodiesel was also generated from inedible food materials, like Mahua and Karanja, with 50:50 by v/v mixing of two. A double-pass reaction with acid esterification that decreased the quantity of free fatty acid (FFA) to a required limit followed by an alkaline transesterification method were carried out to convert the oils to fatty acids of methyl esters. To conduct the esterification reaction, sulfuric acid was employed as a catalyst. Transesterification method involves mixing of KOH and methanol. Methanol can be used as alcohol that reduces the reaction time, while being cheap.1 Catalytic and noncatalytic techniques were used to generate biodiesel from jatropha. It was found that an alkaline catalyst and a two-step transesterification are perfect for biodiesel production if the FFA content of the jatropha oil is less than 1% and greater than 1%, respectively.4 Production of biodiesel from raw Jatropha Curcas by transesterification using a single-pass alkaline catalyst was examined.5 Biodiesel yields were examined at numerous molar ratios such as 5.5:1, 6:1, 6.75:1, 7.5:1, and 8. They found a changeable response temperature of 50 to 70 °C,

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maximum of 80. It was found that yield was less because of a heavy content of fatty acids in the Jatropha Curcas crude oil. It was also found that kinematic viscosity decreased after the transesterification and that different properties are found to be in accordance with specifications of American Society for Test Materials. In recent decades, microalgae have attracted renewed attention as biodiesel feedstock for various reasons, including the lack of competition with food crops for land and their potential for economic and social development in rural areas.\(^6\) A combined closed-plane bioreactor and a direct transesterification process with supercritical methanol resulted in lower water consumption and a reduction of greenhouse gas emissions by 86% compared to single-base technology.\(^8\) Biodiesel can be generated from numerous sources and from different resources. Only a few biodiesels were used directly in engines without any changes, and some with slight changes, such as cylinder lining, injection, etc. Furthermore, internal combustion engines show an increase in emission of exhaust gases like carbon monoxide (CO), hydrocarbons (HC), NO\(_x\), smoke, and so forth, which cause environmental damage. Several researchers have studied engine performance in terms of mechanical efficiency, power, CFS, thermal efficiency, and exhaust temperature using the biodiesel discussed. Mofijur et al.\(^9\) reported on production of biodiesel based on raw moringa oil (CMOO) and the effect of its 10 and 20% volume mixtures on diesel engines. In their experiment, biodiesel production was carried out in two steps. In an acid-catalyzed process, CMOO is reacted with a 12:1 molar ratio (methanol: CMOO) and 1% (v/v oil) of H\(_2\)SO\(_4\) for 3 h at 60 °C and 600 rpm to minimize free fatty acids. Thereafter, an alkaline-catalyzed process with a molar ratio of 6:1 and 1% (w/w oil) of KOH was conducted at 60°C and 600 rpm for 2 h, producing 90% of biodiesel. Additionally, the engine test results revealed that the CMOO B10 and B20 biodiesel blends have high brake-specific fuel consumptions (BSFCs) than those of the diesel fuel. In the same way, a decrease in CO and an increase in NO emission were found for the B10 and B20 mixtures. Finally, the researchers summarized that CMOO is a probable source of biodiesel and that its blends (B10 and B20) can be used as a substitute for diesel. Bora et al.\(^10\) found that combustion in a diesel engine was easier than that in a dual fuel engine. Ignition delay in a dual fuel engine is lower, while the maximum pressure of the cylinder and the heat release rate are greater than those of a diesel engine, when CR was increased. For the diesel mode, PCP was found to be 62.93 bar compared to 45.66, 43.36, 42.47, and 38.13 bar in the dual fuel mode at CR 18, 17.5, 17, and 16 at 100% load, respectively. The carbon dioxide percentage reduced to 20.84% for B20. HC reduced up to 50% for B20. Nitrogen oxides reduced to 22.1% for B10. Residual oxygen reduced to 24.58% for B20. B10 and B20 have less emission compared with those of diesel and B30 fuels.\(^11\) Naik and Balakrishna used Balnitesageytiaca (L.) from seed oil and produced 89% biodiesel using base-catalyzed esterification in a molar ratio of 8:1, 1.26% by weight KOH, at 65 °C in 2.5 h. In addition, they carried out experiments on engines with biodiesel blends in 10 and 20% ranges that improved engine performance and decreased emissions of carbon monoxide (CO), HCs, and nitrogen oxides (NO\(_x\)) with a maximum load compared to those of diesel fuel.\(^12\) Biodiesel combines up to 20% with diesel and can be conceived as an alternative fuel for CI engines. A test on a single cylinder four-stroke VCR diesel engine at 1500 rpm with biodiesel blends ranging from B10 to B100 was conducted. For B100, biodiesel generated from Jatropha had the highest level of consumption that was 15% higher than that of diesel. Thermal efficiency of brakes for biodiesel blends was found to be little higher than that of diesel under different loads. Consumption of fuel increased from 2.75 to 15% for fuels B10 to B100.\(^13\) Exhaust gas temperature (EGT) increased with a higher biodiesel blend. Highest observed temperature in the exhaust gases was 430 °C with biodiesel under the loading conditions of 1.5–3.5 kW, while for diesel the maximum exhaust gas leakage temperature is 440 °C. An improvement in BSFC and BTE was found in CR 19.5 compared to CR 17.5 in all mixes. Using Tamanu oil and defined diesel under conditions of loads such as 0 to 12 kg with an engine speed of 1500 rpm varyingCR from 14:1 to 18:1, it was found that BTE of the esterified Tamanu oil in a VCR engine increased slightly at a high CR, and SFC reduced under the same conditions. Highest BP achieved in CR 18 is 3.51 kW and SFC is 0.24 kg/kW h. It was found that BMEP for the esterified Tamanu oil is high at a high CR. BTE of biodiesel for CR 18 is 30.57% at a maximum weight of 12 kg.\(^14\) Thermal efficiencies of the brakes are found to increase for all CR values. Microalgae oil (10%) is mixed with ethanol (10%) and MEO20 petroleum diesel (80%) and tested in a single-cylinder engine resulting in a NO\(_x\) reduction of 13.85%.\(^15\) Emission of CO and HC for the mahua ester was reduced by 26 and 20%, respectively, compared to diesel. Researchers concluded that NO\(_x\) emission is 4% lower for Mahua methyl ester compared to diesel.\(^16\) The highest yield of methyl ester of 94.50% is reached when the reaction is carried out under the conditions of (4% by weight, g cat./g oil), a reaction period of 2 h, a reaction temperature of 60°C, and a molar ratio 8/1 of methanol/oil, while a catalyst dose of (4% by weight, g cat./g.oil), a molar ratio of the methanol/ethanol mixture of 9/1, 65°C, and 2 h were found to be the optimal reaction conditions, under which a higher yield of methyl/ethyl esters (93.12%) was obtained.\(^17\) The C. inophyllum—palm biodiesel was first produced by mixing the crude oils at an equal ratio of 50:50 vol %, followed by degumming, acid-catalyzed esterification, purification, and, finally, alkaline-catalyzed transesterification. With this systematic procedure, the acid value of the CPME is 0.4 mg KOH/g, resulting in a significant enhancement of oxidation stability (114.21 h).\(^18\) The best conversion of the RO—AKO blend to MBD (96.12 ± 1.25%) and MEBD (94.23 ± 2.22) was achieved at a KOH concentration of 0.75% w/w of oil, an alcohol/oil molar ratio of 6/1, a mixing intensity of 600 rpm, a reaction temperature of 60°C, and a reaction period of 45 min, whereas the best conditions that produced the highest yield of EBD (95.19 ± 2.0%) were a KOH concentration of 1.0 KOH % w/w of oil, an ethanol/oil molar ratio of 8/1, a mixing intensity of 600 rpm, a reaction temperature of 65°C, and a reaction period of 75 min.\(^19\) Thus, the main aim of the present work is to provide a full detailed study on the production of biodiesel from the jatropha—algae oil including process optimization and practical implementation on a diesel engine to analyze the performance and emissions of biodiesel/petrodiesel blends. RSM based on Box—Behnken Design (BBD) has been used for designing of experiments, modeling, and optimization of the most significant variables affecting the biodiesel yield; molar ratio, catalyst concentration, temperature, and reaction time, and for maximizing the production of biodiesel from the jatropha—algae oil. Finally, diesel engine performance was investigated.
and exhaust emission analysis was carried out using different blends of biodiesel/petrodiesel, to figure out the performance.

2. EXPERIMENTAL METHODOLOGY

2.1. Materials and Chemicals. JCO (Jatropha Cruces oil) was purchased from JatrophaVikas Sansthan in India. They produce a large quantity of JCO oil and export globally. Algae oil was obtained from M/s Soley Biotechnology Institute, Turkey. Chemicals such as KOH and methanol were of analytical grade chemical reagents and 99% pure. Potassium hydroxide was utilized in the shape of granules as the base catalyst.

2.2. Biodiesel Preparation. In the biodiesel generation process, a transesterification reaction is used. For carrying out the reaction, the catalyst was added to the mixture. A general process is a combination of three steps. In the first step, triglycerides are converted to diglycerides, diglycerides are converted to monoglycerides in the second step, and in the final step, esters and glycerine are generated. The ratio between alcohol and oil is 3:1. To conduct the transesterification process, a glass reactor with a stirrer and a thermometer is utilized. The glass reactor is initially topped up with a desired quantity of oil, and then placed on a hot plate stirrer. After reaching the oil phase at a selected temperature, the catalyst and methanol are added to the reaction vessel. The transesterification reaction was carried out under the conditions of the necessary molar ratio (6−12), potassium hydroxide (0–2% by weight of the oil), reaction time (60−180 min), and temperature (35−55 °C). The mixture is poured into a separating funnel, and glycerol was separated by gravity in one day. After removing glycerol, the methyl ester layer is washed three times, with two time volumes of hot distilled water to remove the catalyst and the glycerol residues.

Biodiesel yield can be calculated using eq 1.

Yield = \frac{\text{weight of methyl ester produced}}{\text{weight of oil used}} \times 100 \quad (1)

2.3. Statistical and Design Analysis. BBD was used to analyze the reaction variables. In the current research, four independent variables are the reaction temperature, the molar ratio, the catalyst concentration, and the reaction time. Output was biodiesel yields, which were obtained by transesterification of the jatropha−algae oil. Three-level-four-factor BBD is implemented. Table 1 shows the ranges and levels of the predefined independent variables. Table 2 depicts the experimental design matrix with 29 runs. Experiments are carried out and the results are shown in Table 2. Experimental outcomes collected from BBD are statistically examined using Design Expert Software 10.0.

2.4. Engine Setup and Experimental Procedures. The experiments are performed on a diesel engine (model Kirloskar AA3S). The engine is coupled with a generator (KBM-102) with the highest rating of 2 kW to load the engine. Table 3 depicts engine specifications. Figure 1 shows the diagram of the engine setup. Emissions including carbon dioxide (CO2), carbon monoxide (CO), HC, nitrogen oxides (NOx), oxygen (O2), and EGT were analyzed using a Testo-340 and MRU vario plus emission meter. Biodiesel blends of 0, S, 10, and 20 vol. % were used, which are coded as Diesel, B5, B10, and B20, respectively. Experiments are conducted at a constant speed of 1500 RPM.

3. RESULTS AND DISCUSSION

3.1. Model-Fitting Summary. Based on the experimental values shown in Table 2, Design Expert software was used to design the regression equation representing the relationship between the response variable (biodiesel yield) and the reaction parameters (X1 is the catalyst concentration, X2 is the temperature, X3 is the time of reaction, and X4 is the methanol/oil ratio). The developed quadratic model is shown in eq 2.

\[ \ln(\text{yield}) = +7.78758 + 0.33308 \times X_1 - 0.10125 \times X_2 - 6.27034 \times 10^{-3} \times X_3 - 0.19875 \times X_4 - 9.08171 \times 10^{-3} \times X_1 \times X_2 + 2.74690 \times 10^{-4} \times X_1 \times X_3 - 7.10692 \times 10^{-3} \times X_1 \times X_4 + 2.73170 \times 10^{-5} \times X_2 \times X_3 + 2.99339 \times 10^{3} \times X_2 \times X_4 + 5.09878 \times 10^{-4} \times X_3 \times X_4 - 0.065152 \times X_1^2 + 6.86911 \times 10^{-4} \times X_2^2 + 6.04019 \times 10^{-6} \times X_3^2 + 6.98471 \times 10^{4} \times X_4^2 \]

(2)

where X1 is the catalyst concentration, X2 is the temperature, X3 is the time of reaction, and X4 is the methanol/oil ratio. The proposed model has been evaluated to identify any errors related to normality assumptions. The positive notation of each term indicates a synergetic effect while the negative notation indicates an antagonistic effect. Table 4 shows ANOVA for the jatropha−algae biodiesel experiment. The model is significant. There is only 0.01% chance that the F value becomes high because of noise. Value of prb > F and less than 0.05000 describes that the model is significant. Determination coefficients, R2 and R2 adj, from which reliability of model fitting can be derived, have been evaluated to be 0.98 and 0.97, respectively. These values show that approximately 98% of variance has been attributed to variables. A graph plotted between the predicted values and the actual values of the yield is shown in Figure 2.

The model F-value of 74.42 defines that the model is significant. There is only 0.01% chance that an F-value this large could occur because of noise. Values of “Prob > F” and less than 0.05000 indicate that the model terms are significant. In this case, X1, X2, X1X2, X1X3, X1X4, X2X4, X32, X42, and X1X2 are significant model terms. Values higher than 0.1000 imply that the model is not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction improves the model. A “Lack of Fit F-value” of 1.08 implies that the Lack of Fit is nonsignificant.

A “Pred R-Squared” of 0.9246 is in agreement with an “Adj R-Squared” of 0.9735, that is, the difference is less than 0.2.
“Adeq Precision” measures the signal/noise ratio. A ratio greater than 4 is desirable. Here, the ratio is 32.026, which is an adequate ratio.

3.2. Effect of Parameters on Yield. Figure 3a–f shows a three-dimensional plot for interpretation of the relation between the response factor and the variables. Figure 3a shows the effect of temperature and the catalyst on the production performance of jatropha–algae methyl ester. With a lower quantity of the catalyst and at a low temperature, the biodiesel yield increases extremely. Furthermore, the yield decreases substantially with a high quantity of the catalyst and at a high reaction temperature. This is true because a larger amount of catalyst with increased temperature support the triglyceride saponification side reaction.24 The response graph of the interaction effect between the reaction time and the amount of catalyst is shown in Figure 3b. Conversion performance of jatropha–algae biodiesel is increased to an optimal level, and it is subsequently discovered that there is no significant increase in performance. In any case, an increase in time does not illustrate considerable response in transformation performance. Figure 3c illustrates the combined effect of the catalyst amount and the molar ratio on conversion performance, while keeping other variables constant. From the graphical representation, it is understood that the biodiesel yield does not have a significant effect upon increasing the amount of KOH.25 As found in Figure 3d, increasing the temperature has a direct effect on biodiesel performance in the range of 350–550 °C, where other variables are kept constant, that is, the molar ratio, KOH concentration, and weather. Increasing the time has a positive response on the biodiesel yield, the time range between 60 and 180 min, where other variables were kept constant. Barbosa et al.26 investigated the effect of the reaction time on the reaction performance of transesterification of castor oil/soybean oil mixtures. The above facts are correlated with the graphs of Figure 3e,f. When methanol is used for transesterification, the yield at first increases with the increase of the molar ratio. The effect of temperature is small on a better reaction time because a longer reaction period allows the reaction to show a better performance even at a low reaction temperature.

3.3. Optimization of Variables. Design Expert-10 software was implemented to optimize each independent variable and search for optimal values for response targets. Biodiesel yield has been intend to be maximized. A molar ratio of catalyst is shown in Figure 3b. Conversion performance of jatropha–algae biodiesel is increased to an optimal level, and it is subsequently discovered that there is no significant increase in performance. In any case, an increase in time does not illustrate considerable response in transformation performance. Figure 3c illustrates the combined effect of the catalyst amount and the molar ratio on conversion performance, while keeping other variables constant. From the graphical representation, it is understood that the biodiesel yield does not have a significant effect upon increasing the amount of KOH.25 As found in Figure 3d, increasing the temperature has a direct effect on biodiesel performance in the range of 350–550 °C, where other variables are kept constant, that is, the molar ratio, KOH concentration, and weather. Increasing the time has a positive response on the biodiesel yield, the time range between 60 and 180 min, where other variables were kept constant. Barbosa et al.26 investigated the effect of the reaction time on the reaction performance of transesterification of castor oil/soybean oil mixtures. The above facts are correlated with the graphs of Figure 3e,f. When methanol is used for transesterification, the yield at first increases with the increase of the molar ratio. The effect of temperature is small on a better reaction time because a longer reaction period allows the reaction to show a better performance even at a low reaction temperature.

Table 2. Statistics of Independent Variables with Experimental and RSM Responses

| s. no. | X₁: catalyst amount | X₂: temperature | X₃: reaction time | X₄: methanol/oil ratio | blend biodiesel yield (%) |
|--------|---------------------|----------------|------------------|------------------------|----------------------------|
| 1      | 2                   | 45             | 120              | 12                     | 54.82                       |
| 2      | 1                   | 55             | 180              | 9                      | 94.12                       |
| 3      | 1                   | 55             | 120              | 12                     | 92.21                       |
| 4      | 0                   | 45             | 120              | 6                      | 91.57                       |
| 5      | 1                   | 35             | 120              | 12                     | 77.11                       |
| 6      | 1                   | 55             | 60               | 9                      | 77.76                       |
| 7      | 1                   | 45             | 120              | 9                      | 76.57                       |
| 8      | 0                   | 45             | 60               | 9                      | 87.57                       |
| 9      | 1                   | 35             | 60               | 9                      | 80.4                        |
| 10     | 1                   | 55             | 120              | 6                      | 75.28                       |
| 11     | 1                   | 45             | 180              | 12                     | 93.26                       |
| 12     | 1                   | 45             | 120              | 9                      | 76.62                       |
| 13     | 1                   | 45             | 120              | 9                      | 75.82                       |
| 14     | 2                   | 45             | 180              | 9                      | 63.29                       |
| 15     | 1                   | 35             | 120              | 6                      | 90.16                       |
| 16     | 2                   | 35             | 120              | 9                      | 72.32                       |
| 17     | 2                   | 45             | 120              | 6                      | 56.37                       |
| 18     | 1                   | 45             | 60               | 12                     | 65.36                       |
| 19     | 2                   | 55             | 120              | 9                      | 53.84                       |
| 20     | 1                   | 45             | 120              | 9                      | 75.28                       |
| 21     | 0                   | 45             | 120              | 12                     | 96.98                       |
| 22     | 0                   | 35             | 120              | 9                      | 92.4                        |
| 23     | 0                   | 55             | 120              | 9                      | 98.92                       |
| 24     | 1                   | 45             | 120              | 9                      | 76.17                       |
| 25     | 1                   | 45             | 60               | 9                      | 77.83                       |
| 26     | 1                   | 35             | 180              | 9                      | 91.14                       |
| 27     | 1                   | 45             | 180              | 6                      | 76.93                       |
| 28     | 2                   | 45             | 60               | 9                      | 53.12                       |
| 29     | 0                   | 45             | 180              | 9                      | 96.29                       |

Table 3. Diesel Engine Specification

| sr. no. | parameters     | details                                                                 |
|---------|----------------|-------------------------------------------------------------------------|
| 1       | company name   | Kirloskar, AA35                                                          |
| 2       | engine         | vertical, 4-stroke, single-acting high-speed compression ignition diesel engine |
| 3       | number of cylinder | single                                                                |
| 4       | rating         | 2.6 KW (3.5 bhp)                                                        |
| 5       | compression ratio | 15.6:1                                                                |
| 6       | RPM            | 1500                                                                   |
| 7       | fuel oil tank capacity | 3.75 L                                                                |
of 1:10, a KOH concentration of 0.3%, a reaction temperature of 53 °C, a reaction time of 172 min resulted in a biodiesel yield of 100%. Predicted optimal conditions were examined using experimental validation. Experiments resulted an average yield of biodiesel of 96%. The experimental response output and the predicted optimal output were compared and the accuracy and adequacy of the results of the predicted quadratic model were verified. Table 5 shows the limiting conditions/constraints of obtaining the optimum results:

3.4. Properties of Produced Biodiesel. Properties of the Jatropha–algae biodiesel samples are investigated. Table 6 shows the properties of jatropha–algae biodiesel, most of the physicochemical properties matched with the standard properties.

3.5. Engine Performance. Effects of blending of biodiesel on engine performance parameters are determined and compared with those of diesel. Figure 4 outlines the discrepancy of BSFC over brake power for fuels mixed with diesel and jatropha–algae. From the graphical representation, it is clear that BSFC goes up with an increase in the proportion of the blending ratio. This is because of high viscosity, density, and a lower calorific value of the fuel. In the case of diesel, BSFC was reduced from 1036.8 to 340.2 g/Kw h upon increasing the no-load load to 2 kw. The graph shows the highest BSFC for blend B5 (1417.84 g/Kw h), indicating that fuel was consumed most for the same level of power. The lower value for B20 mix is 588.12 g/Kw h. Variations in engine BTE for numerous blends at different loads are depicted in Figure 5. It was found that at all engine brake powers, BTE is less when the engine is fed with jatropha blends with algae. Efficiency of any engine depends on the physical processes involved, such as combustion, atomization, evaporation, and so
forth. Thermal efficiency of brakes increased with increasing load. These outputs are in agreement with those of the relative works reported by other researchers. In the case of diesel, the BTE was higher (23.11%) under full-load conditions. This may be because of the complete combustion of fuel. The same result has been obtained for B5 and B20. B10 shows an

Table 5. Conditions of Optimization

| s. no. | parameters       | constraint/optimization conditions |
|--------|------------------|------------------------------------|
| 1      | catalyst amount, $X_1$ | in range                           |
| 2      | temperature, $X_2$    | in range                           |
| 3      | reaction time, $X_3$  | in range                           |
| 4      | methanol/oil ratio, $X_4$ | in range                        |
| 5      | biodiesel yield     | maximize                           |

Table 6. Properties of Jatropha–Algae Oil Blend Biodiesel

| s. no. | properties       | value | standard               |
|--------|------------------|-------|------------------------|
| 1      | flash point (°C) | 115   | ISI448                 |
| 2      | FFA (%)          | <1%   | ASTM-D5555-95          |
| 3      | viscosity@40 °C | 4.1   | ISI448                 |
| 4      | density (Kg/m$^3$) | 886   | ASTM-D1298             |
| 5      | cloud point °C   | −2    | ASTM 2500              |
| 6      | acid number mg KOH/g | 0.5   | ASTM D664              |
| 7      | calorific value MJ/kg | 46    | ASTM-D4809             |
exceptional result at 1.5 KW, the thermal efficiency of the brake decreases instead of increasing.

3.6. Engine Exhaust Emissions. Impact of biodiesel-mixed fuels on engine exhaust compared to diesel fuel was analyzed and the testing responses are given below:

A HC emission is produced by incomplete combustion and extinguishing of the flame in the regions of cracks in cylinder walls. Figure 6 represents disparity of HC emissions from the diesel fuel and Jatropha blends and algae at different loads. HC emissions for biodiesel blends are perceived to be lesser than those for diesel. It was shown that increasing the amount of biodiesel in diesel blends greatly minimizes HC emissions because of the mixing of the oxygen content incorporated into fuels with biodiesel, resulting in complete combustion. These results are in agreement with those of the existing research in which the reduction of HC was attributed a high oxygen content in biodiesel that leads to full combustion.37,32

Maximum concentrations of HC emissions are 90, 84, 64, and 53 ppm for diesel, B5, B10, and B20 biodiesel blends, respectively.

Carbon monoxide (CO) is one of the arbitrary compounds developed during the intermediate combustion level of HC fuels. CO formation depends on the air/fuel atomization rate, equivalency ratio, fuel type, start of the injection time, combustion chamber design, load, injection pressure, and engine speed.33 Variations in CO emission upon varying the load are shown in Figure 7. CO emissions decreased upon increasing the engine load from lower loads to higher loads. The decrease in CO emissions for blends is because there are more oxygen molecules in blends compared to those in diesel fuel. Minimum CO emissions from jatropha—algae biodiesel mix B5 were obtained at 1.5 kW loads.

In the current study, NOx emissions increased as the percentage of biodiesel in the mixture increases, as shown in Figure 8. Main factors that affect NOx emissions are the oxygen level and combustion temperature.34 Biodiesel is an oxygen-rich fuel that consequently increases the level of oxygen in the combustion environment. As seen in the graph above, B20 has the highest value for NOx emission (799 ppm) at full loads. Diesel (104 ppm) has lower NOx values at lower loads.

Figure 4. Variations of BSFC V/S brake power.

Figure 5. Variations of brake thermal efficiency V/S brake power.

Figure 6. Variations of HC V/S brake power.

Figure 7. Variations of carbon monoxide V/S brake power.

Figure 8. Variations of nitrogen oxides V/S brake power.
9 shows $O_2$ values plotted against the loads for different mixtures of variable ratios. As seen in the figure, $O_2$ values in exhaust are directly related to the $CO$, $C$, $O_2$, and $NO_x$ concentrations. The highest $O_2$ value for pure diesel is 17.75% with no load and B20 has 9.05% with full load. The lower $O_2$ values in the graph imply that $O_2$ was used in combustion. Almost all oxygen readings are lower than those of diesel, because it has a high $NO_x$ content in the exact ratio.

4. CONCLUSIONS

In the current study, biodiesel was extracted from the jatropha–algae oil. Homogeneous alkali (KOH)-catalyzed transesterification of the oil was used for the production of jatropha–algae methyl ester. An optimized biodiesel yield of 100% is obtained under a 1:10 molar ratio with 0.3 wt % catalyst at a temperature of $53 \degree C$ in 172 min. Predicted optimum values are validated experimentally with a 4% relative error of the experimental result (96%). The P-value from ANOVA is <0.0001, which depicts that the model is significant. Engine tests are carried out to examine the effect of biodiesel blends on performance and emission characteristics. Principal conclusions made from the engine test are given as below.

- BSFC decreases with load. Diesel has lowest 340.2 g/Kw h BSFC at full load.
- Brake thermal efficiency increases with load. Diesel has higher a BTE of 23.11%.
- Reduction in HC emissions is identified for jatropha–algae biodiesel blends. The maximum concentrations of HC emissions were 90, 84, 64, and 53 ppm for diesel, B5, B10, and B20 biodiesel, respectively.
- Carbon monoxide emission can be decreased by using biodiesel blends, and the jatropha–algae biodiesel blend B5 has minimum CO emissions at 1.5 Kw loads.
- Constituents of $NO_x$ for the fuel tested (blends of biodiesel) are little higher than those of the base line diesel fuel. B20 has the highest value for $NO_x$ emission (799 ppm) for full loads. Diesel (104 ppm) has lower $NO_x$ values at lower loads.
- The highest value of $O_2$ of 17.75% is obtained for pure diesel with no load and B20 has 9.05% with full load.

These results prove that biodiesel can be used in engines as an alternative fuel. Using the jatropha–algae oil as the feedstock for biodiesel production, biodiesel blends with diesel give optimal engine test characteristics for $NO_x$, $O_2$, $CO$, and HC concentrations.

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Notes

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