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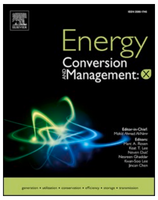

Study of performance, combustion, and emissions parameters of DI-diesel engine fueled with algae biodiesel/diesel/n-pentane blends

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ABSTRACT

Biodiesel extracted from *Scenedesmus obliquus* algae through transesterification was used in the current study. Due to the disadvantages of using pure biodiesel in engines, it was used as B50 (a blend of 50% diesel and 50% biodiesel). To enhance engine performance, n-pentane was used in different extents of 5, 10, and 15 ml per liter as an enhancer additive. Through performance tests, it was found that 15 ml of n-pentane per liter was the best addition as it caused an increase in the brake thermal efficiency of 7.1% and a decrease in brake specific fuel consumption of 6.4% compared to the elegant B50. Whereas for exhaust gases, there was an increase in nitrogen oxides, which was associated with the significant increase in exhaust temperature and the high oxygen content present in B50. In comparison, hydrocarbons emission decreased by 7.2% compared to B50 in contrast to carbon dioxide which increased by 22.3% over B50. The carbon monoxide and oxygen concentrations of the exhaust gases also decreased by 17.35% and 9.5%, respectively compared to B50. The results obtained indicated that there are a significant improvements in pressure evolution and heat release data, which depend on the role of the mixed fuel addition of n-pentane.

1. Introduction

Most life applications nowadays rely on these sources of non-renewable energy from coal and oil and so forth [1]. The use of fossil fuels has increased the rate of air pollution due to the multiple combustion waste produced by combustion [2]. Many pollutants are resulting from the burning of fossil fuels, including carbon dioxide, carbon monoxide, sulfur oxides, and nitrogen oxides, as well as fumes and unburned hydrocarbons [3,4]. Diesel engines are one of the most important and widely used ways of turning fossil fuels into energy. Diesel engines are used in many industrial applications such as cars, ships, and trains. Due to an increase in population growth and continued industrial development has become very difficult to keep pace with the demand for fossil fuels. As world oil consumption has been recorded at about 100.3 million barrels/day in the first quarter of 2020 [5]. Non-renewable fossil fuel supplies have prompted researchers to try to explore renewable energy sources. Biofuels are of major renewable energy sources. fossil fuel value stems from the similarities between Biofuels combustion properties and fossil fuels combustion properties and therefore does not require alteration of the combustion systems [6,7].

Based on biofuels production sources, biofuels are classified into three generations: first generation, second generation, and third generation [8]. The first generation of biofuel is based on food crops. As for biodiesel, there are many feedstocks including soybean [9], coconut [10], vegetable oils [11], and sunflowers [12]. The main source of production of the second generation of biofuel is non-food products. These sources include agricultural residues, cooking oil waste, and wood slats [13]. Agricultural residues such as rice straw, wheat straw, and edible plant sticks. Third generation biofuels are produced from entirely new sources. These sources include algae and fast-growing trees. Microalgae are microscopic photosynthetic organisms growing in water [14]. Algae are important among other sources of biodiesel as it not dependent on food crops but also, it's growth depends on the absorption of harmful emissions of carbon dioxide [15,16]. But for the biodiesel production from algae passes through four consequent stages which are

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the cultivation, harvesting, lipid extraction, and transesterification and fermentation. Algae have a higher conversion of solar energy to chemical energy due to higher photon conversion efficiency. The conversion efficiency of 3: 8% versus 0.5% for other terrestrial planets. In addition to the faster growth rate of other plants. It can be cultivated on non-arable land like a desert and coastal lands. Thus, the lands suitable for the cultivation of foodstuffs are not used. Algae production is non-seasonal where it is produced throughout the year and in any weather conditions due to the variety of types to suit different weather conditions. It processes wastewater bioremediation by absorbing nitrogen and phosphorus on which it feeds. Removal of nitrogen and phosphorus is one of the most difficult stages of wastewater treatment. All previous advantages made algae biodiesel production a promising area for researchers to enhance cultivation and production processes [17,18]

One of the drawbacks of biodiesel is its high viscosity relative to pure diesel, resulting in lower atomization and lower energy content to weight due to high oxygen [19]. The results of performance tests for diesel and *Scenedesmus obliquus* algae biodiesel blends showed an increase in the values of thermal efficiency with increasing the load due to the low heat loss [20]. These results are in great agreement with the results from these references [21,22]. There also had been a decrease in the values of B.S.F.C with the increase in load [20]. This decrease was due to the convergence of density and heating values for diesel and algae biodiesel blends from the values of pure diesel [21,23].

Consequently, pure biodiesel is not preferred in internal combustion engines, as it causes corrosion of rubber rings, clogged pipes and nozzles, and increased carbon deposition [24]. It is also desirable to use biodiesel in blends with diesel to achieve the necessary physical and chemical

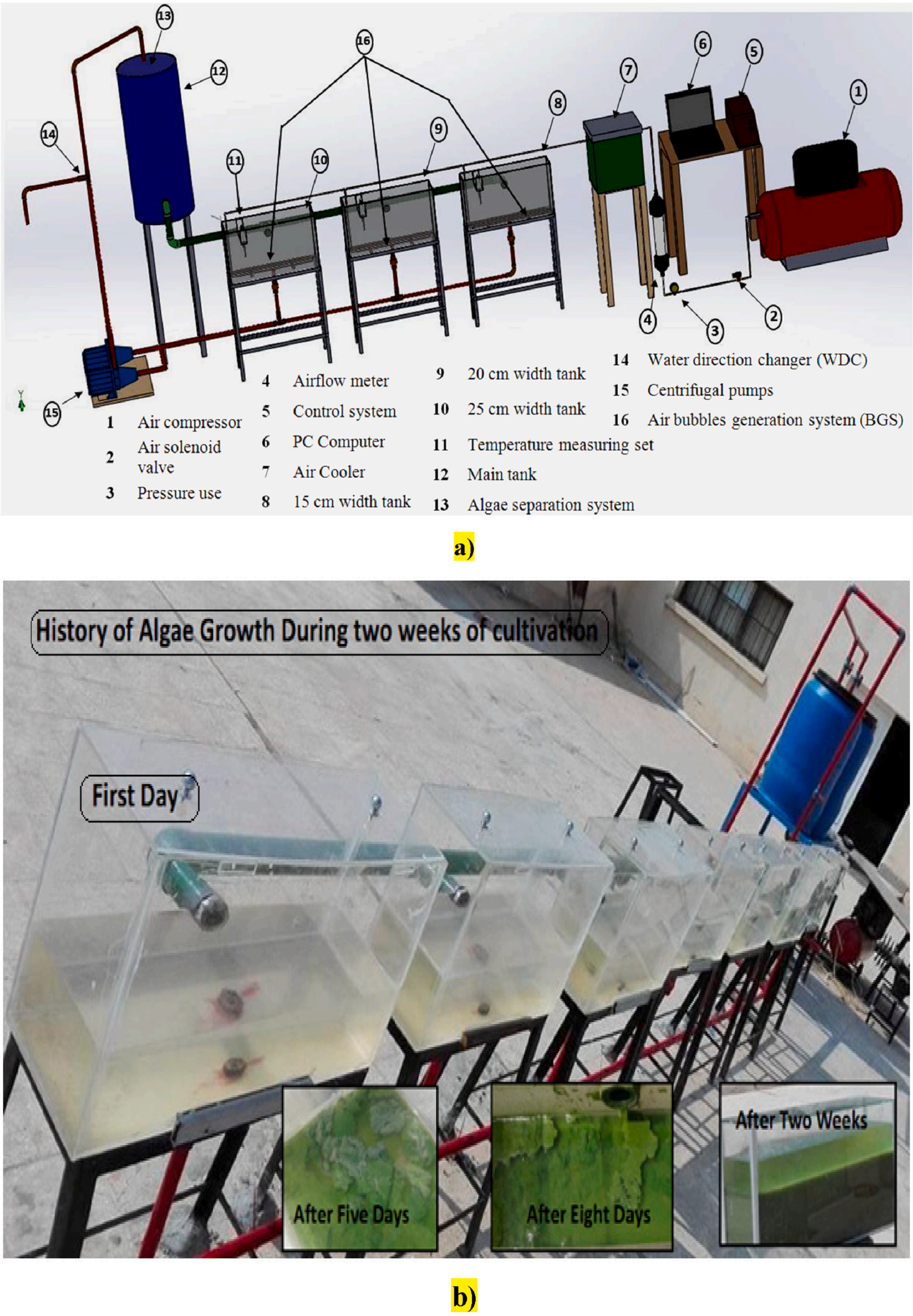

Fig. 1. *Scenedesmus Obliquus* Algae cultivation system: a) the system layout, and b) the boxes photo bio-reactor during the system growth history [38].

properties and to enhance efficiency and pollution characteristics [25,26]. There are a variety of additives that can be used to enhance the efficiency of CI engines running on biodiesel blends, such as oxidizing additives [27–29] and Metallic and non-metallic based additives [30,31]. The number and quality of mineral-based additives created in laboratories increase every day more than its predecessor [32,33]. The use of oxygenated additives also affects the properties of the fuel itself, such as density, viscosity, and cetane number [34,35]. Oxygenated additives allow complete combustion and reduce harmful pollutants because of high oxygen content [36]. There are several trials in using biodiesel organic additives. The effect of using alcohol additives such as butanol, methane, and ethanol on biodiesel blends was studied [37]. Related to additives having five carbon, Pentanol was also studied as an alcoholic additive that has the same carbon atoms number of n-pentane that will be used in the current work.

The current study aims to investigate the addition of three different ratios of n-pentane of 5 ml, 10 ml, and 15 ml per liter of *Scenedesmus obliquus* algae biodiesel/diesel blend. The investigation is done through engine performance, combustion characteristics, and emissions characteristics study and to determine the best ratio of the used n-pentane.

2. Production of algae

The algae cultivation process was carried out in Boxes photo-bioreactor as shown in Fig. 1 [38]. *Scenedesmus Obliquus* algae were used in the cultivation process.

Boxes photo bio-reactor is a new cultivation technique that combines the advantages of both tubular photo bio-reactor [39] and the raceway pond system [40,41]. The used system consists of acrylic boxes with pumps and an air system used to flip algae, cool the system, and supply the system with more carbon dioxide. Cooling the system and increasing the supplied CO_2 will enhance the cultivation process of algae [41].

2.1. Lipids extraction process

Grown algae were gathered and then sifted through a 45 μm filter. After collecting the algae, they are dried by heating it at 105℃ and keeping it overnight, after which it is cooled. To extract the lipids from the dried algae, Bligh and Dyer's method is used, which states that for every 100 ml of dry algae, 250 ml of methanol is added in addition to 125 ml chloroform and stirred well. After stirring the mixture another 125 ml of methanol are added and vortex well for 30 s. At the end of the process, 125 ml of distilled water is added, and the mixture is left to separate the lipids.

2.2. Transesterification of lipids into biodiesel

200 ml of pre-prepared methoxide (5 gm NaOH and 200 ml methanol) was mixed with one liter of preheated filtered lipids oil. The mixing process takes place for an hour at a constant temperature of 60° C and a mixing speed of 500 rpm. The mixture is placed in a separating funnel for 24 h to complete the separation process, which results in two layers of biodiesel and glycerol arranged according to their density. After extracting the biodiesel, it was washed with hot water at a temperature of 80° C, at a ratio of 1/1 each, and the used water is separated after the washing process. The washing process is repeated more than once until the water PH after washing is equal to 7 then biodiesel is heated at a temperature of 100° C to remove the remaining moisture in the biodiesel. Finally, biodiesel yield was calculated to be 34%, where it was stored in a clean and dry container. Lipids Extraction and transesterification processes are illustrated in Fig. 2.

2.3. Fuels and used additives properties

Owing to its high flammability, n-pentane was chosen solely from organic materials to increase the combustion starting properties of biodiesel blends. In addition to its low viscosity that decreases the final average viscosity of the mixture leading to improved atomization and penetration of biodiesel blends. The most important advantage of

Table 1
N-Pentane physical properties.

Properties	Diesel	Algae biodiesel	n-Pentane	ASTM
Density at 40℃ (kg/m^3)	830	880	626	–
Viscosity at 40℃ (mm^2/s)	3.28	4.15	0.36	D-445
Heating value	43,100	38,000	48,600	–
Cetane number	54	62	36	D-613

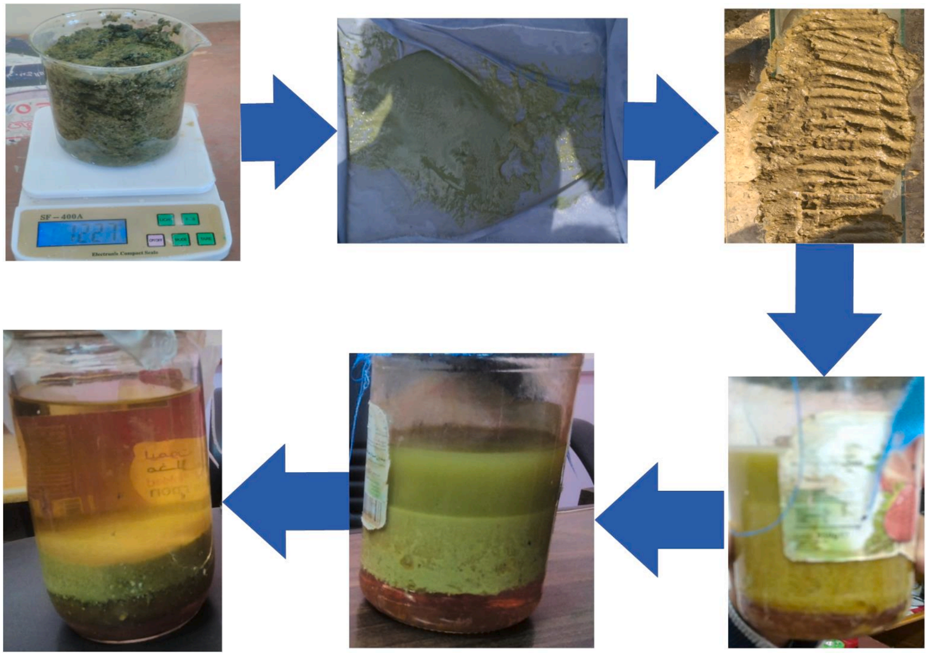

Fig. 2. Lipids extraction and transesterification step.

pentane is its availability and low price. Table 1 is presenting some properties of used diesel, algae biodiesel, and n-Pentane. Measured values were measured based on the ASTM standard. N-pentane was used as B50 additive because of its' low viscosity and better mixing properties.

3. Experimental setup and procedures

(S1100A2) the diesel engine was used to perform experiments and engine specifications are shown in Table 2. A hydraulic dynamometer (ATE-160 LC) having specifications shown in Table 3 was used to measure the power of the engine. Properties and concentrations of exhaust gases emitted during various experiments were measured using HPC500/400 Automotive emission analyzer was used. It can measure the following emissions (CO, CO2, HC, O2, and NOx). Accuracies and uncertainties of gas analyzer measurements are shown in Table 4. Engine speed is set to 1400 rpm and all previous components were gathered to be test system as shown in Figs. 3 and 4.

Measurements uncertainties have been calculated for each measured parameters in this work. The estimated error for each measured parameters were recorded and the accuracy of the instrument were listed in Table 4. The accuracy of the instruments were established from the minimum reading value of the estimated error. However, if the established value of the error R, depends on the independent parameters such as (Z1, Z2, Z3,….., Zn), so, the error for the R value is computed from the Eq. (1) as the following:

$$\frac{\partial R}{R} = \left(\left[\frac{\partial Z1}{Z1}\right]^2 + \left[\left[\frac{\partial Z2}{Z2}\right]\right]^2 + \ldots\ldots + \left[\frac{\partial Zn}{Zn}\right]^2 \right)^{\frac{1}{2}} \quad (1)$$

Where $(\frac{\partial Z1}{Z1})$, $(\frac{\partial Z2}{Z2})$, and ….$(\frac{\partial Zn}{Zn})$ are the error in the measured parameters. While, $\partial Z1$ is the system accuracy and $Z1$ is calculated during the experimental from the minimum reading value.

The error connected with the BTE of the engine can be computed by applying the following Eq. (2), which is dependent on the engine fuel consumption and measured engine torque.

$$\left(\frac{\partial BTE}{BTE}\right) = \left(\left(\frac{\partial RPM}{RPM}\right)^2 + \left(\frac{\partial TORQUE}{TORQUE}\right)^2 + \left(\frac{\partial TIME}{TIME}\right)^2 \right)^{\frac{1}{2}} - - - - (2)$$

(2)

4. Results and discussions

4.1. *Performance analysis*

Performance tests included an analysis of brake thermal efficiency, brake specific fuel consumption, and temperature of exhaust gases. These variables were studied at different engine loads.

4.1.1. *Brake specific fuel consumption*

Rate of fuel consumption to the brake Power output is defined as Brake specific fuel consumption. Fig. 5 showing the change of brake specific fuel consumption against the load.

Fig. 5 shows that B.S.F.C decreases for each case by increasing engine load. The highest value of B.S.F.C was recorded for B50 due to increased viscosity and lower calorific value of biodiesel. The value of B.S.F.C decreases as the percentage of additives increased due to improved viscosity and good atomization of the fuel mixture. The values of B.S.F.C continued to decrease until reaching a lower value than pure diesel when using 15% n-pentane as additive. The results shows an average change in B.S.F.C by 14.55% ,12.24% , 3.88% and −2% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane with respect to pure diesel as shown in Fig. 14 and Table 5.

Table 2
Diesel engine specifications.

Type of the engine	Engine model “A1100A2” Single cylinder, four strokes, horizontal and swirl Combustion chamber, Water cooling
Bore * Stroke* Displacement	100 mm * 115 mm* 0.903 L
Compression ratio	20
Power of the engine	11 kW /2200 r.p.m

Table 3
Hydraulic dynamometer specifications.

Dynamometer Model	ATE-160 LC
Type of Weighing Mechanism	Load Cell with Digital Torque Indicator
The capacity of Load Cell	0 to 350 Kg. (0 to 1050 N-m)
Calibration Lever Arm Length	0.7645 m
Speed Sensing	60 Tooth Wheel and Sensor
Drive Attachment	Half Coupling Attached to Shaft
Type of Absorption	Water/Hydraulic

Table 4
Accuracies and uncertainties of gas analyzer measurements.

Parameters	Measurement range	Accuracy	Uncertainties (%)
Humidity	3–99%	±0.5%	±0.5
Temperatures	0–1000 °C	±1 °C	±0.1
Ambient pressure	700–1100 M bar	±1 M bar	±0.09
Carbon monoxide	0–15.0 volumetric percentage	±0.01 volumetric percentage	±0.07
Carbon dioxide	0–20.0 volumetric percentage	±0.01 volumetric percentage	±0.05
Oxygen	0–25.0 volumetric percentage	±0.01 volumetric percentage	±0.04
Unburnt hydrocarbons	0–30000 ppm vol.	±1 ppm vol.	±0.003
Nitrogen oxides	0–1000 ppm vol.	±1 ppm vol.	±0.1

4.1.2. *Brake thermal efficiency*

Brake thermal efficiency refers to how much chemical energy in the fuel is converted into useful energy. Different results of thermal efficiency values concerning engine load are shown in Fig. 6.

It is obvious from Fig. 6 that the least efficiency was for the B50 due to the high BSFC. The BTE starts to increase with the increase of the additives until reaching value greater than pure diesel when using 15% n-pentane as additive. The differences in the average values of B.T.E for all cases compared to diesel were as follows: −4.75%, −4.4%, 0.7% and 3% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.1.3. *Exhaust gas temperature (EGT)*

Exhaust gas temperature variations for engine loads are shown in Fig. 7. Exhaust temperature is a preliminary indicator of the quality and efficiency of the combustion process.

Fig. 7 demonstrates that; exhaust gas temperature increases with the increase of engine load for all different cases. We note that the lowest exhaust gas temperature was for the B50 due to the low combustion quality compared to other fuel. Exhaust gas temperatures start to rise when adding an n-pentane due to improved fuel properties and improved combustion. When using 15% N pentane, the exhaust gas temperature reaches a value greater than the exhaust gas temperature when using pure diesel fuel. The differences in the average values of B.T.E for all cases compared to diesel were as follows: −5.21%, −1.36%, 3.64% and 6.22% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.2. *Emission analysis*

The second part of the results includes the analysis of combustion

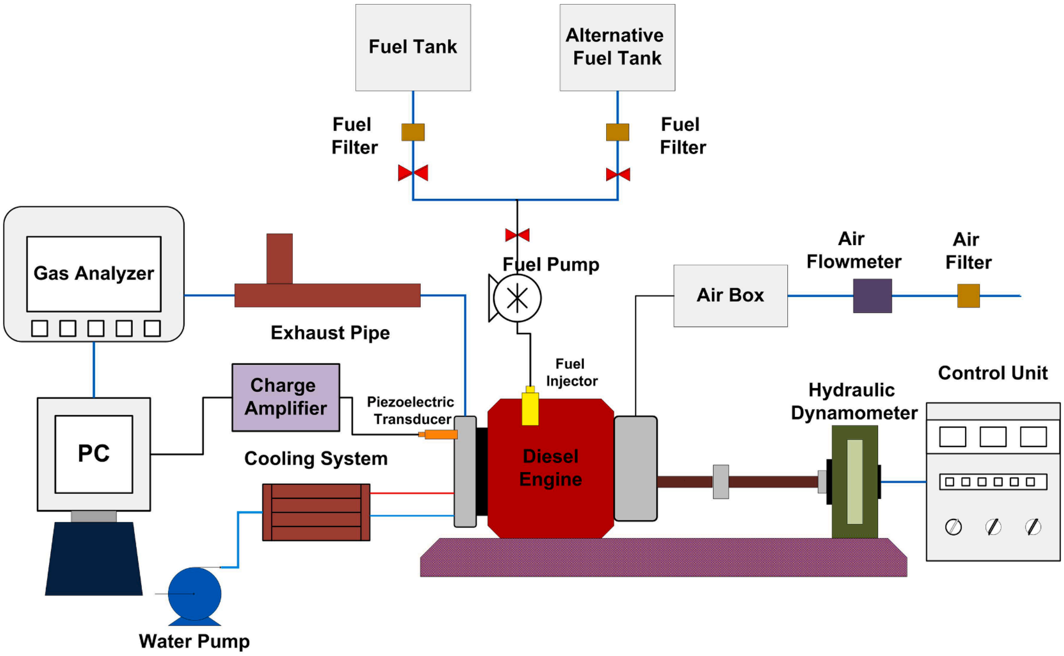

Fig. 3. Combustion system components schematic diagram.

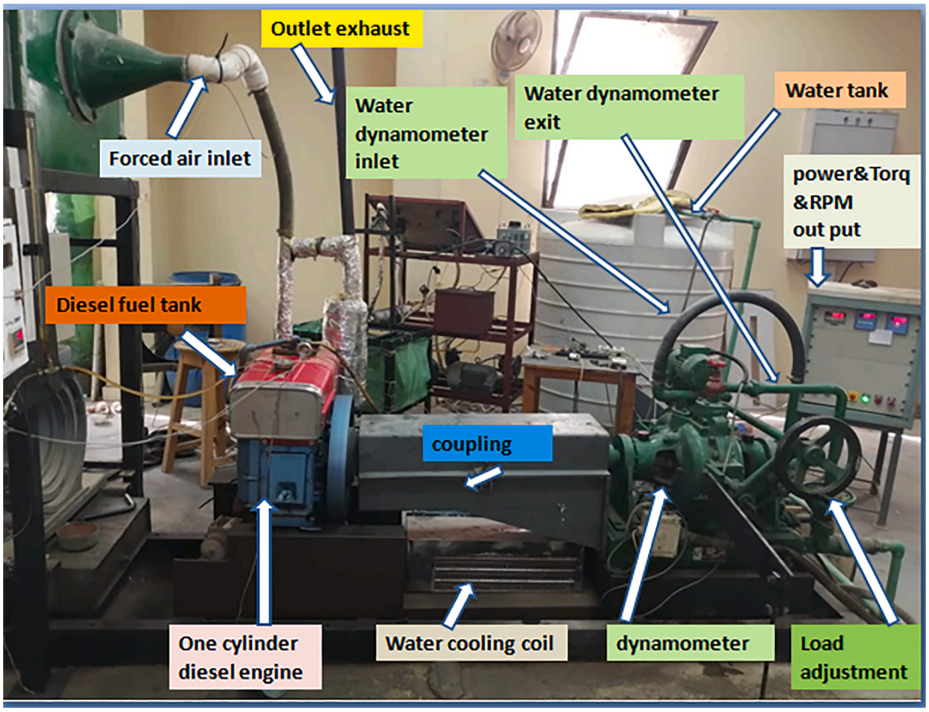

Fig. 4. Combustion system components.

exhaust gases, which are among the most important factors governing the process of improving internal combustion engines. The results were analyzed for unburnt hydrocarbons (HC), carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), and oxygen emissions (O2) for all different fuel cases.

4.2.1. *Hydrocarbon emissions (HC)*

HC emissions are mainly formed due to incomplete combustion of fuel. It is one of the most important parameters in defining the nature of combustion. HC emissions variation of different types of fuels is shown in Fig. 8.

Fig. 7 shows that HC emissions increase with increasing load for different studied cases due to insufficient time for combustion as the combustion time gets shorter. We also note that the highest HC values were for pure diesel fuel. Despite the incomplete combustion of B50, HC emissions are lower than diesel due to the increased oxygen content in biodiesel. HC emissions continue to decrease with the increase in the percentage of additives. HC decrease may be due to improved combustion due to the presence of oxygen from biodiesel and improved fuel properties of atomization and viscosity by additives. The differences in

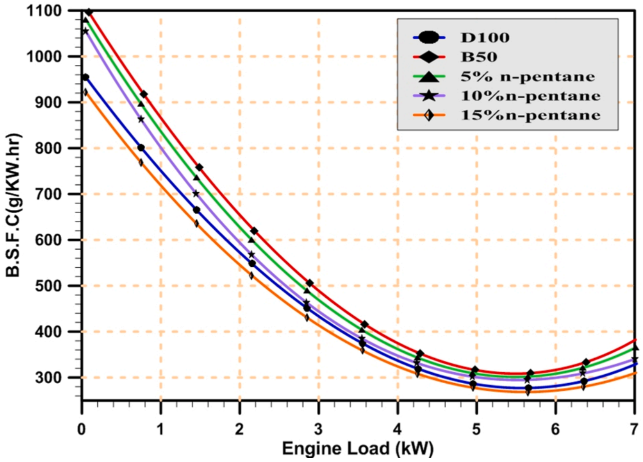

Fig. 5. Brake specific fuel consumption for pure diesel, different fuel blends, and N-pentane additives.

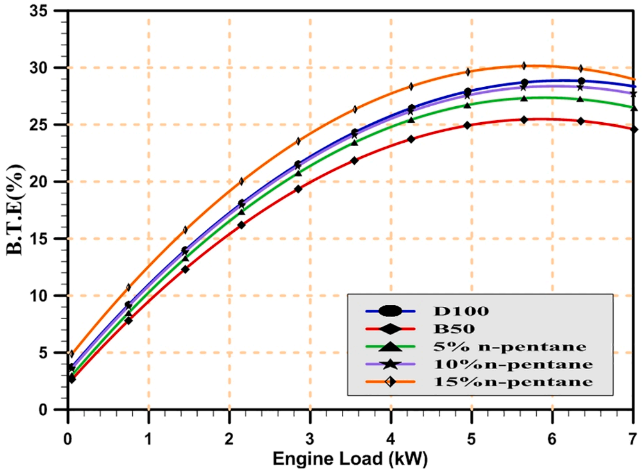

Fig. 6. Brake thermal efficiency for pure diesel, different fuel blends, and N-pentane additives.

Table 5
Rate of change of measured parameters concerning pure diesel for different fuel blends and additives.

Measured parameter	Rate of change in measured values (%)			
	B50	B50 + 5% n-pentane	B50 + 10% n-pentane	B50 + 15% n-pentane
BSFC	14.55	12.24	3.88	−2
BTE	−4.75	−4.4	0.7	3
CO_2	−4.46	0.9	9.9	16.92
CO	−4.63	−9.32	−14.74	−21.19
HC	−2.84	−5.23	−8.33	−9.82
NOx	12.53	10	28.27	36
Texh	−5.21	−1.36	3.64	6.22
O_2	2.29	−2.04	−5.81	−7.52

the average values of HC emissions for all cases compared to diesel were as follows: −2.84%, −5.23%, −8.33% and −9.82% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.2.2. *Carbon monoxide (CO) emission*

The emissions of carbon monoxide are mainly caused by incomplete combustion of fuels through the combustion chamber. Variations in CO emissions of all fuel types tested are shown in Fig. 9.

Fig. 9 shows that CO emissions increase with increasing load for all different fuel cases due to shorter time for combustion that leads to incomplete combustion of carbon. It is also observed that the highest CO

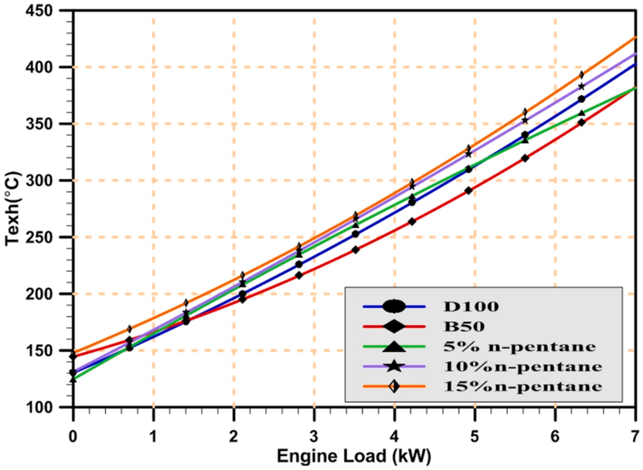

Fig. 7. Exhaust gas temperature for pure diesel, different fuel blends, and N-pentane additives.

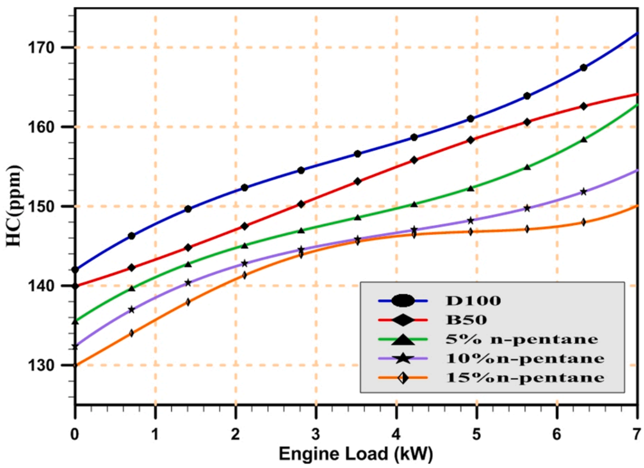

Fig. 8. Hydrocarbon emissions (HC) for pure diesel, different fuel blends, and N-pentane additives.

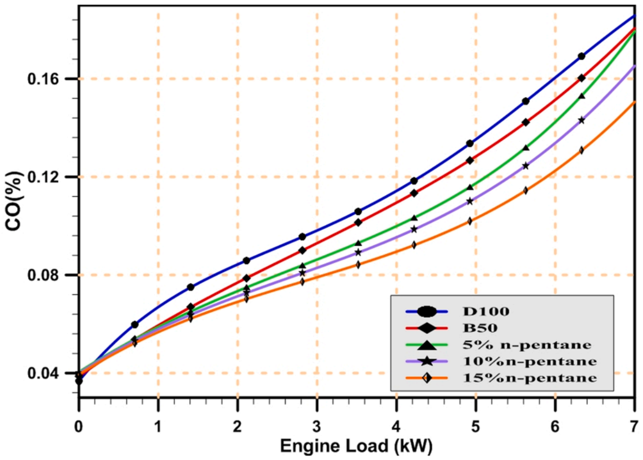

Fig. 9. Carbon monoxide (CO) emission for pure diesel, different fuel blends, and N-pentane additives.

emissions value was for pure diesel fuel. CO for B50 fuel is lower than pure diesel due to increased oxygen from biodiesel. The values of CO will continue to decrease for n-pentane additives due to increased oxygen from biodiesel and enhanced fuel properties due to n-pentane additives. The differences in the average values of CO emissions for all cases compared to diesel were as follows: −4.63%, −9.32%, −14.74% and −21.19% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.2.3. Oxides of nitrogen (NOx) emissions

Oxides of nitrogen are formed mainly due to the abundance of oxygen and the high temperature of the combustion chamber. Nitrogen oxides are very harmful emissions to the environment, which hinders the improvement of engines. The higher the combustion quality, the higher the temperature, and the greater the NOx formation. Fig. 10 shows the different NOx concentrations in the exhaust gases for different fuel cases.

It is recognized that as the load increases, the combustion chamber temperature increases. Therefore, we noted from the previous figure that NOx emissions increase as load increases for all different fuel conditions. Fig. 10 shows that the least NOx emissions were for pure diesel fuel. When using B50, NOx emissions increase due to increased oxygen as a result of biodiesel presence. The figure also shows an increase in NOx emissions when using n-pentane additives due to the increased oxygen from mixed biodiesel and improved combustion due to improved fuel properties as a result of additives which in turn improves the combustion of fuel. The differences in the average values of CO emissions for all cases compared to diesel were as follows: −4.63%, −9.32%, −14.74% and −21.19% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.2.4. Carbon dioxide emission

Carbon dioxide emissions are the inevitable result of the complete combustion of carbon in the fuel. Fig. 11 shows the different concentrations of CO2 emissions for all different fuel states at different loads.

Fig. 11 shows that CO2 emissions increase with increasing load for all different fuel cases. Also, the least CO2 emissions were for B50 due to incomplete combustion of biodiesel blends. CO2 emissions also increased for n-pentane additives due to increased oxygen from biodiesel, increased carbon to hydrogen ratio, and enhanced combustion due to additives. The differences in the average values of CO2 emissions for all cases compared to diesel were as follows: −4.46%, 0.9%, 9.9% and 16.92% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

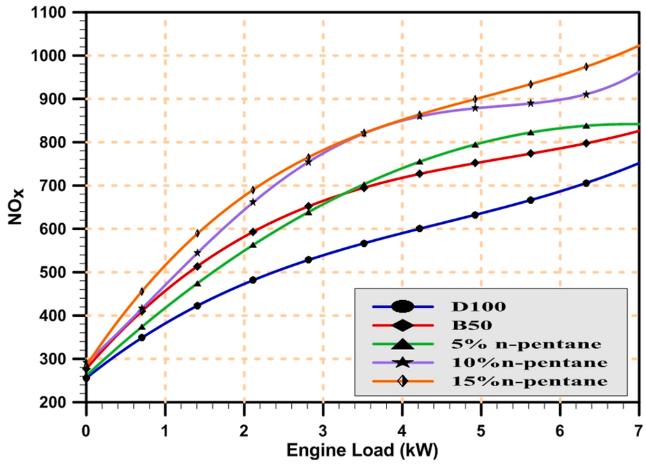

Fig. 10. Oxides of nitrogen (NOx) emissions for pure diesel, different fuel blends, and N-pentane additives.

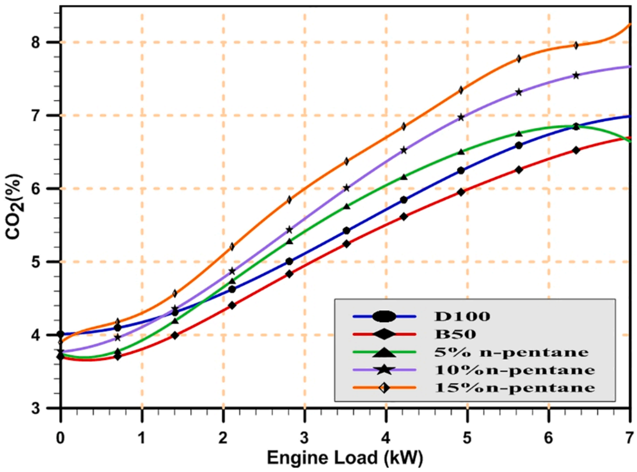

Fig. 11. Carbon dioxide (CO2) emission for pure diesel, different fuel blends, and N-pentane additives.

4.2.5. Oxygen emissions

Oxygen emissions are the amount of oxygen remaining without combustion. Fig. 12 shows the different oxygen concentrations in the exhaust gases for different fuel conditions.

Fig. 12 shows a decrease in the oxygen concentration in the exhaust gases with increasing the load due to the increase in the amount of fuel added, which in turn needs more oxygen to complete the combustion. It is also noted that the highest oxygen concentration in the exhaust gases was for B50 due to incomplete fuel combustion. Oxygen emissions begin to decrease when n-pentane additives are used. This decrease is the result of improved combustion, which increases the amount of oxygen needed to complete the combustion and therefore less oxygen concentration in the exhaust gases. The differences in the average values of O_2 emissions for all cases compared to diesel were as follows: 2.29%, −2.04%, −5.81% and −7.52% for B50, B50 + 5% n-Pentane, B50 + 10% n-Pentane and B50 + 15% n-pentane as shown in Fig. 14 and Table 5.

4.3. Combustion analysis

The third part in the analysis of the results includes the performance analysis inside the combustion chamber by presenting the results of pressure development and heat release rate. The results were presented in three percentages of maximum load, 10%, 30%, and 60%.

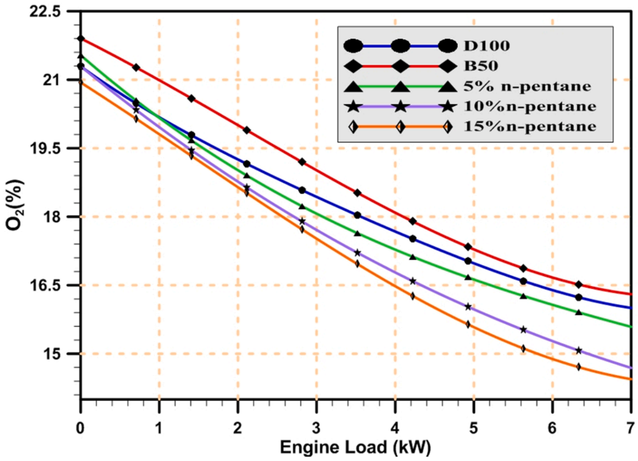

Fig. 12. Oxygen emissions for pure diesel, different fuel blends, and N-pentane additives.

4.3.1. Pressure development

The pressure inside the combustion chamber is one of the most important factors to be studied to infer the combustion quality and engine efficiency.

Fig. 13 [a, b, and c] shows the general shape of the pressure curve inside the combustion chamber at three ratios of maximum load. We noted that all curves for all fuels at different load ratios had almost the same trend. The maximum pressure recorded in the combustion chamber was 60.6, 70.6, and 80 bar for 10%, 30%, and 60% of the maximum load. Figures also showed that the lowest pressure value was for B50 due to low calorific value and incomplete combustion. Start of combustion for B50 advances before diesel due to high cetane number. When using n-pentane additives, the start of combustion retarded from B50 due to the low cetane number until it reaches a very close value to diesel when using 15% pentane.

4.3.2. Heat release rate

The heat release rate is the basic indication of fuel chemical energy conversion into useful thermal energy. Fig. 13 [a, b, and c] shows the differences in heat release rate for used types of fuel at different ratios of maximum engine load.

Figures show that the less heat release rate was for B50 due to incomplete combustion and a shorter delay period that does not allow good premixing. The heat release rate for diesel was larger than biodiesel due to a longer delay period that enhances premixing in addition to the good properties of diesel than B50. When using B50 + 15% n-pentane it had nearly the same delay period of diesel but enhanced properties than diesel resulting in a higher heat release rate. The maximum heat release rate recorded in the combustion chamber was 58.7, 71, and 81.5 J/deg for 10%, 30%, and 60% of the maximum load

4.4. Rate of change of engine parameters and gas emissions concerning pure diesel

The rate of change in engine parameters and gas emissions was measured to demonstrate the overall effect on the engine performance of each type of fuel used. Fig. 14 shows the rate of decrease and increase in emission parameters and engine performance concerning pure diesel.

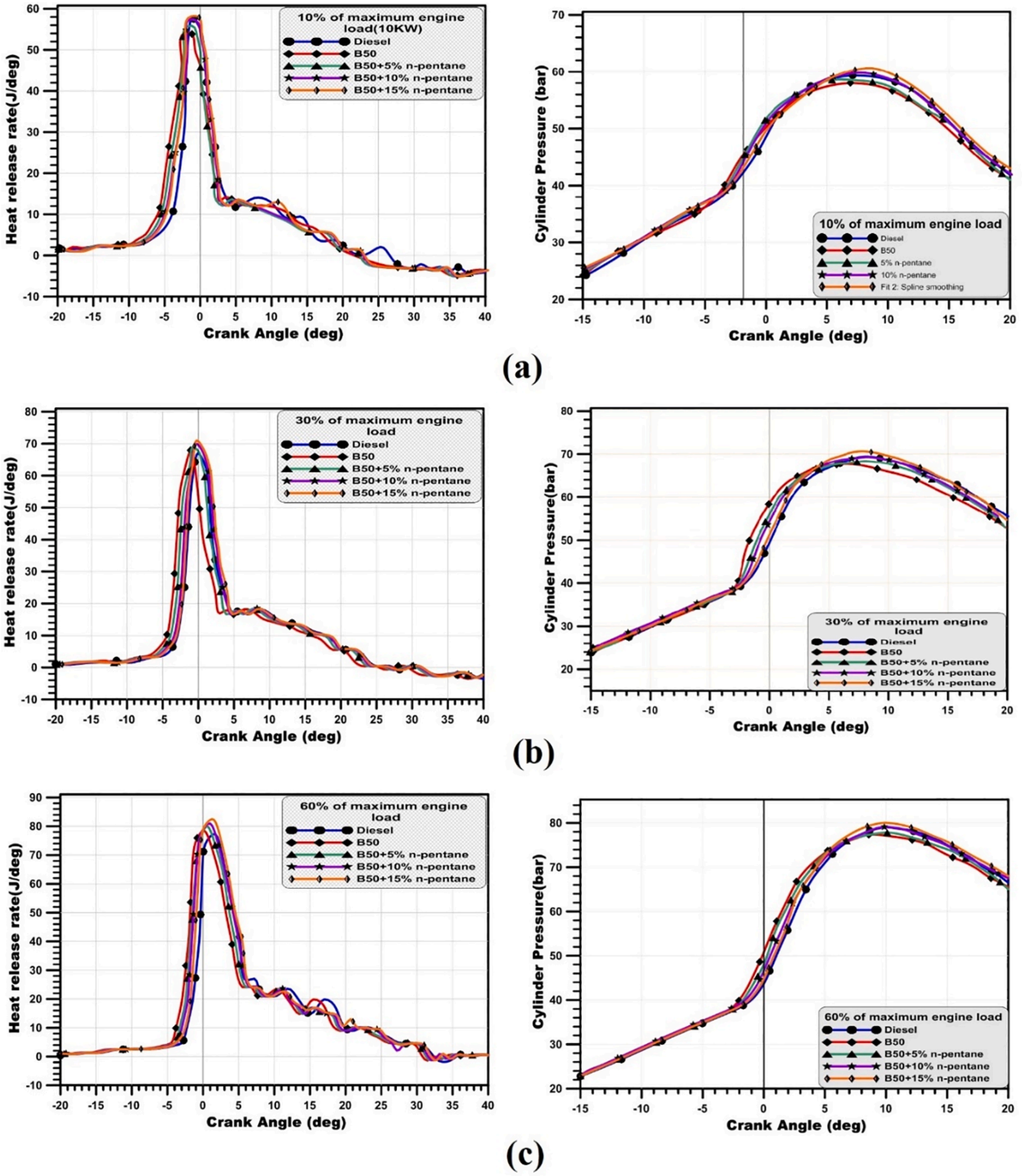

Fig. 13. Heat release rate and pressure development [(a) 10% of maximum engine load, (b)30% of maximum engine load and (c) 10% of maximum engine load]

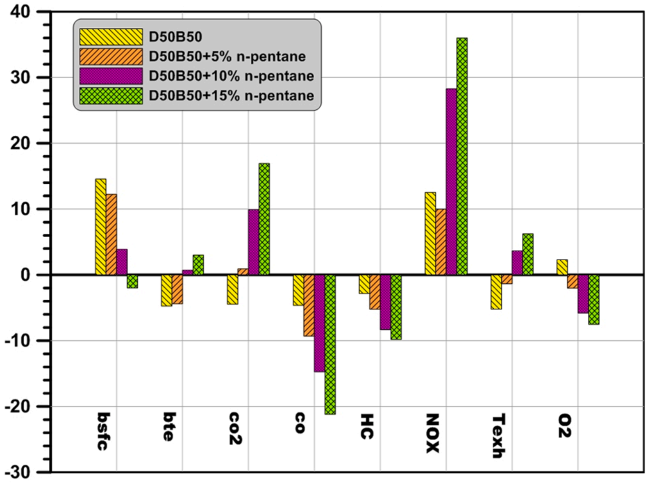

Fig. 14. Rate of change of measured parameters concerning pure diesel for different fuel blends and additives.

Table 5 shows the calculated rate of change for four different types of fuels of B50, B50 + 5% n-pentane, B50 + 10% n-pentane and B50 + 15% n-pentane.

Weighted mean average values of measured parameters were calculated using the following formula $= \frac{x_1y_1+x_2y_2+\cdots+x_ny_n}{x_1+x_2+\cdots+x_n}$ where x_n represents engine load and y_n represent the measured value related to loading value. The rate of change of each measured parameter for each fuel is calculated as follows:

$$\text{rateofchange} = \frac{\text{parameterofeachfuel} - \text{parameterofpurediesel}}{\text{parameterofpurediesel}}$$

5. Conclusion

The experimental study was performed to evaluate the effect of n-pentane addition to the blend of diesel / algal biodiesel with mix ratios of 5, 10, 15 ml/liter. The tests were conducted in a single-cylinder diesel engine with a constant speed of 1400 rpm and the main results are summarized below.

- The addition of biodiesel to the diesel will adversely affect the performance of the engine Despite the quality of biodiesel produced from algae, which distinguishes it from other different types of biodiesel.
- Performance wise, n-pentane addition in algae biodiesel blend resulted in a decrease in BSFC, an increase in BTE, increase in heat release rate, exhaust temperature, peak pressure rise, cylinder pressure, and combustion duration along with longer ignition delay compared to the elegant biodiesel blend.
- Emission wise, an increase in CO_2, NOx with lowered HC, CO, O_2 in comparison with elegant biodiesel blend were observed.
- In general, the use of pentane as an addition to biodiesel blend significantly improved engine performance, surpassing that of pure diesel

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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