Journal of Mines, Metals and Fuels, *71(12B): 193-208; 2023. DOI: 10.18311/jmmf/2023/45585*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Combustion Characteristics of a Variable Compression Ratio Diesel Engine Using Hibiscus *Cocos nucifera* Biodiesel and Taguchi Optimization

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Abstract

Biodiesel is a sustainable and renewable fuel to replace the conventional diesel. Biodiesel produced from hibiscus cocos nucifera oil was employed in a variable compression ratio diesel engine. The combustion characteristics of an engine were studied with different blends at various compression ratios 15, 16, 17 and 18. Experimental outcomes are compared with diesel fuel. The cylinder pressure is improved for blend B20 at compression ratio 18. The cumulative heat release is improved for blend B5 at compression ratio 17. Net heat release is highest for B10 at CR15. The mean gas temperature for B5 blend at compression ratio 17 has a maximum. To optimise combustion parameters, the Taguchi method was applied. The optimal values of the combustion parameters are 65.65 bar cylinder pressure, 7.26 bar/deg rate of pressure rise, 75.46 J/deg net heat release, 0.96 KJ cumulative heat release and 1424.54°C mean gas temperature respectively, at maximum load, 16:1 compression ratio, and B20 blend using the Taguchi technique.

Keywords: *Biodiesel, Combustion, Compression Ratio, Hibiscus cocos nucifera Oil*

1.0 Introduction

Diesel engines are generally utilised in agriculture, industry and transportation sectors due to their increased efficiency in the conversion of fuel[1]. The transportation sector is a large user of diesel. Crude oil consumption is increasing, and crude oil reserves are decreasing and may soon be depleted[2]. Diesel engines have contributed to air pollution. Nitrogen oxides, particulate particles, and smoke are produced during combustion of fuel. Pollutants in the air are harmful to human health. Alternative fuels are being researched to reduce the impact. Furthermore, the world's energy demands are rising. Biodiesel is a sustainable energy source that can help to reduce the depletion of fossil diesel fuel[3]. Vegetable oils, waste oil, animal fat and other ingredients can all be used to make biodiesel. Waste oil and solar biodiesel are the four generations of biodiesel[4]. The biofuels made from agricultural crops like sugar cane, corn and vegetable oils are the first generation of biofuels. Methanol, diethyl ether, and butanol are second-generation fuels. Photosynthetic microorganisms, such as microalgae and bacteria, are typically used to make third generation biofuels. Methane, bioethanol, biobutanol, biodiesel, and biohydrogen are

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some examples of third-generation biofuels[5]. Biodiesel is a renewable fuel with a higher viscosity, higher oxygen content, reduced volatility, and a higher cetane number. It is also non-toxic and biodegradable[6]. When using biodiesel, engine emissions are reduced. However, nitrogen oxide (NO_x) emissions are higher when compared with diesel fuel[7]. Biodiesel is produced from the transesterification process by using vegetable oils, and animal fats. Biodiesel has an oxygen content of about 11% by weight. Biodiesel has the same heating value as diesel and it is safer to transport. It is more dependable than diesel fuel because of these qualities[8]. Singh *et al.*[9] considered the combustion of argemone biodiesel in a 4 cylinder, turbocharged, common rail diesel injection (CRDI) engine at moderate, part, and peak load conditions at 2000 rpm. At high load, blend B20 improved its brake thermal efficiency (BTE) and brake specific fuel consumption (BSFC) by 5.58% and 7.88%, respectively. NO_x emissions were reduced by 30% for a blend of argemone biodiesel at all loads. Emissions carbon monoxide (CO) and hydrocarbon (HC) are increased for all blends. In comparison to other blends, 30% and 50% blends had greater igniting delay. The blend B20 had maximum heat release rates and in-cylinder pressure in all experiments except low load. Mohamed *et al.*[10] used the pyrolysis process to produce waste cooking oil biodiesel. In the pyrolysis process, sodium hydroxide (NaOH) and potassium hydroxide (KOH) catalysts are used in different concentrations. With 1% NaOH, a biodiesel yield of over 70% was achieved. The biodiesel was mixed with diesel fuel at various proportions. At higher loads, emissions of NO_x and CO decreased with increasing blend ratios. Mubarak *et al.*,[11] studied the performance of a low heat rejection (LHR) diesel engine with waste cooking oil (WCO) biodiesel. The LHR engine brake thermal efficiency with diesel and WCO biodiesel is found to be 26.5% and 26% at peak load. A LHR engine consumes less brake specific energy than a diesel engine. The maximum cylinder pressure (CP) for diesel fuel and biodiesel at peak load is 55 bar and 53 bar. The cumulative heat release (CHR) is greater for a LHR engine with waste cooking oil biodiesel. The emissions got reduced with the LHR compared to the diesel and waste cooking oil. Ahamad Shaik *et al.*,[12] tested a 20% waste mango seed biodiesel on a Kirloskar engine at various compression ratio (CR) of 18, 20, and 22 along with 5% and 10% of exhaust gas recirculation (EGR). The findings were compared to diesel fuel at CR18. Cylinder pressure and BTE and cylinder pressure increased by 6.91% and 7.4% respectively. BSFC was decreased by 5.7% at CR 22. The emissions smoke, CO, and HC was reduced by 33.3%, 7.1% and 40% and nitrogen oxide were reduced by 40.5% at CR 22 at the addition of 5% EGR. The cylinder pressure was increased by 6.91% at CR 22. The maximum heat release rate of 62.4 J/^{0}CA was reported at compression ratios of 22. More *et al.*[13] considered the effect of CR on diesel engine by using diethyl ether to re-purpose used cooking oil biodiesel. 0.8% diethyl ether (DEE) with 19.2% biodiesel fuel improves efficiency as 16.06%, reduces BSFC as 4.12%, and emissions were decreased when compared with diesel fuel at a CR 15. Kumaran *et al.*,[14] employed Hibiscus rosa sinensis based hydroxy apatite nano particles in waste cooking oil biodiesel emulsion fuel to minimise NOx emissions by 30% and maximize BTE on diesel engines. Alenezi *et al.*[15] examined the combustion and emission phenomena of a diesel engine at 1800 rpm at peak load. In experiments, blend 10%, 20%, 30%, and 40% with different carbon nanotubes were used in experiments. The cylinder pressure increased by 4.64% compared with diesel fuel at sample B10 with 50 ppm of carbon nano tubes. At 150 degrees crank angle, the maximum cylinder temperatures were observed in all samples. The blend B20 produces a higher carbon dioxide (CO_2) for 50 ppm of nanotubes. B20 and B40 blends have a reduction in NOx. Babji *et al.*[16] studied the optimization parameters of a variable compression ratio (VCR) engine by using the Taguchi technique and discussed the mass fraction burned.

According to the review of literature, it is found that much research work has been conducted to analyse the combustion of various blends at various compression ratios, but no research work has been done to evaluate the combustion of hibiscus *cocos nucifera* methyl ester. It has not been examined how compression ratio impacts combustion parameters of hibiscus cocos nucifera methyl ester. There is a chance that biodiesel will replace traditional diesel oil. Hence, it is imperative to analyse the combustion characteristics of hibiscus *cocos nucifera* (HCN) biodiesel in the diesel engine. The current research investigates the combustion analysis of HCN biodiesel and compares them with diesel. The CP, CHR, mass fraction

burned (MFB), rate of pressure rise (RPR), net heat release rate (NHR) and mean gas temperature (MGT) are studied for various blends and compression ratios at different load conditions. It was revealed that hibiscus *cocos nucifera* biodiesel and its blends improve combustion properties of diesel engine with no modifications. The Taguchi L18 approach is used to optimize the combustion parameters.

2.0 Materials and Methodology

2.1 Extraction of Oil

Hibiscus Rosa sinensis (both flowers and leaves), coconut oil, and curry leaves also known as *Murraya koenigii* were selected for making HCN oil. Hibiscus is a member of the Malvaceae family of flowering plants. It is available worldwide. Curry leaves, known as Murraya koenigii, have properties like antioxidants, antibacterial, carotene, minerals, nicotinic acid and other compounds. Heat the coconut oil in a bigger pan. Add the curry leaves, hibiscus flowers and leaves to the coconut oil. Boil the mixture over medium heat until the colour changes to brown. Stop the heating and keep the pan to cool for about twenty-four hours. After straining the oil through the filter, pour it into a jar or bottle.

2.2 Biodiesel Production

Transesterification is one of the processes of turning the oil triglycerides into biodiesel in the presence of a catalyst and alcohol. The biodiesel is obtained from hibiscus *cocos nucifera* oil by the process of transesterification. The HCN oil, methanol in a 6:1 molar ratio, and catalyst KOH at 1% w/w is placed in a three-necked reactor chamber equipped with a condenser and thermometer. The entire mixture is heated in the reactor for two hours at 60°C while being constantly stirred stirrer.

After that, the composition was transferred to a conduit for separation. After cooling, there are two layers visible, with the top layer being methyl ester and the bottom layer being glycerin. Separate the glycerin and HCN methyl ester from the conduit. Hot water should be used to abolish soap impurities, and heat it to evaporate leftover moisture content. Finally, biodiesel manufactured from HCN is ready for usage. Figure 1 depicts a biodiesel preparation by transesterification process.

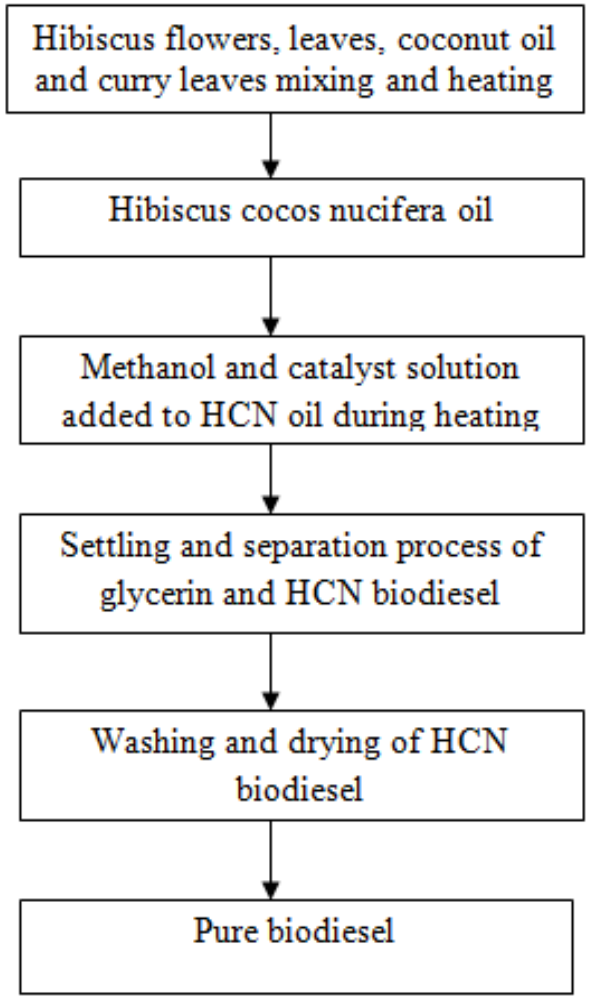


Figure 1. Biodiesel preparation by transesterification process.

2.3 Fuel Properties

The properties of hibiscus *cocos nucifera* methyl ester are shown in Table 1. All properties are measured according to the American society for testing and materials (ASTM) standards. Various equipments are used to find out the fuel properties. The density is measured using a hydrometer. At 15 °C, the density of hibiscus *cocos nucifera* methyl ester is tested using ASTM D287 standards. The measured density of biodiesel is 863 Kg/m^3 whereas for diesel is 830 Kg/m^3. The flash point and fire points were measured by the Pensky Martens apparatus. Bomb calorimeter was utilised to calculate the calorific value of the fuel. The viscosity was determined by utilising a Redwood viscometer.

Table 1. The properties of biodiesel and diesel

Parameter	Unit	Biodiesel	Diesel	Methods	ASTM standards
Density	kg/m^3	863	830	D287	860-900
Flash point	°C	96	53	D93-58T	130-170
Fire point	°C	105	56	D93-58T	130-185
Calorific value	kJ/kg°C	9578	42786	D4809	>33000
Viscosity	cSt	2.96	2.09	D445	2.5 - 6

2.4 Experimental Setup and Methodology

At constant speed, the tests were performed on a 4-stroke, 1-cylinder, water-cooled variable compression ratio diesel engine. Figure 2 depicts the experimental setup schematically. An eddy current dynamometer along with a load cell is connected to the engine. For combustion analysis, a crank angle encoder and a pressure sensor are utilised. Test engine details are shown in Table 2. The studies were conducted with a fixed injection timing of 23^0 before top dead centre and 200 bar injection pressure.

The engine is operated at 1500 rpm at different load conditions. The tests were carried out with blends of 5% biodiesel with 95% diesel (B5), 10% biodiesel with 90% diesel (B10), 15% biodiesel with 85% diesel (B15), 20% biodiesel with 80% diesel (B20) and diesel at compression ratios of 15, 16, 17 and 18. The experiments conducted were conducted to inspect the combustion parameters.

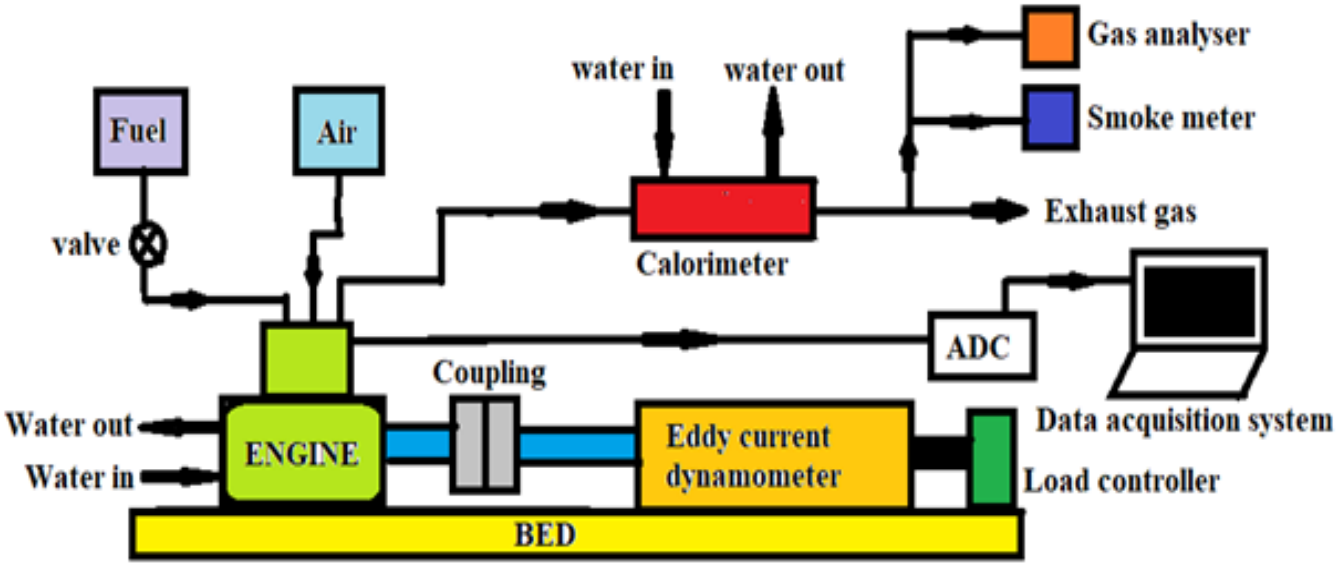


Figure 2. Experimental setup Schematic diagram.

Table 2. Test engine details

Parameter	Description
Type	VCR diesel engine
Make and model	Kirloskar TV1
Power	3.5 kW
Speed	1500 rpm
Cylinder	I
Number of strokes	4
Loading device	Eddy current dynamometer
Cooling	Water cooling
Compression ratio (CR)	12: to 18:1
Bore diameter	87.5 mm
Stroke length	110 mm
Stroke volume	661.45 cm^3
Injection pressure	200 bar
Injection timing	23^0 before top dead centre

3.0 Results and Discussions

3.1 Combustion Parameters

3.1.1 Cylinder Pressure (CP)

The CP variation with crank angle (CA) for blends B5, B10, B15, and B20 at compression ratios CR15, CR16, CR17 and CR18 is shown in Figures 3 and 4. The CP values for diesel, B5, B10, B15 and B20 at CR15 are 54.75 bar, 53.08 bar, 49.66 bar, 49.55 bar and 52.55 bar. The CP values for diesel, B5, B10, B15 and B20 at CR16 are 60.38 bar, 53.71 bar, 54.4 bar, 53.82 bar and 55.82 bar. The CP values for diesel, B5, B10, B15 and B20 at CR17 are 63.35 bar, 63.72 bar, 60.64 bar, 58.66 bar and 60.61 bar. The CP values for diesel, B5, B10, B15 and B20 at CR18 are 64.31 bar, 65.43 bar, 65.17 bar, 65.45 bar and 65.65 bar. The cylinder pressure improved as the CR increases for all

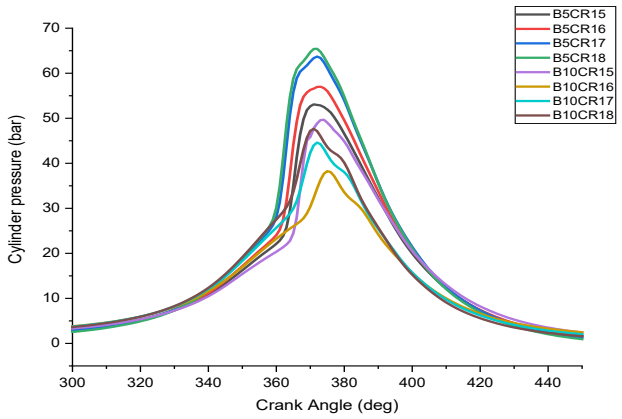


Figure 3. CP variation with crank angle for blends B5 and B10.

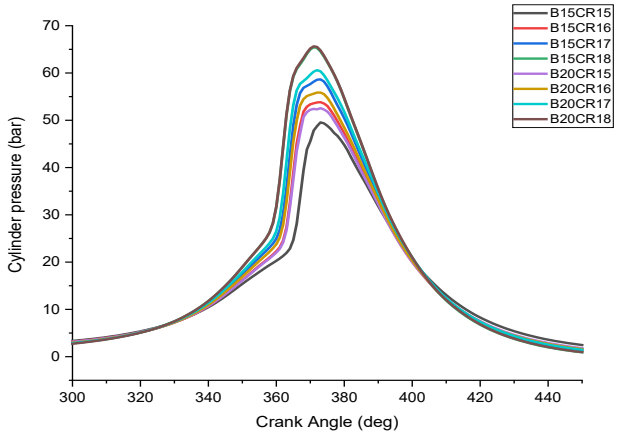


Figure 4. CP variation with crank angle for blends B15 and B20.

blends. B20 at CR 18 has the highest cylinder pressure of 65.65 bar out of all of the blends at peak load.

3.1.2 Cumulative Heat Release (CHR)

Figures 5 and 6 demonstrate the variation in CHR with CA for blends B5, B10, B15, and B20 at compression ratios CR15, CR16, CR17, and CR18. The CHR value for diesel is 0.91 KJ, and for B5, B10, B15, and B20, it is 0.9 KJ at CR15. The CHR values for diesel, B5, B10, B15, and B20 at CR16 are 0.96 KJ, 0.93 KJ, 0.92 KJ, 0.9 KJ, and 0.92 KJ. The CHR values for diesel, B5, B10, B15, and B20 at CR17 are 0.95 KJ, 0.98 KJ, 0.96 KJ, 0.93 KJ, and 0.95 KJ. The CHR values for diesel, B5, B10, B15, and B20 at CR18 are 0.94 KJ, 0.97 KJ, and 0.96 KJ. The CHR increases

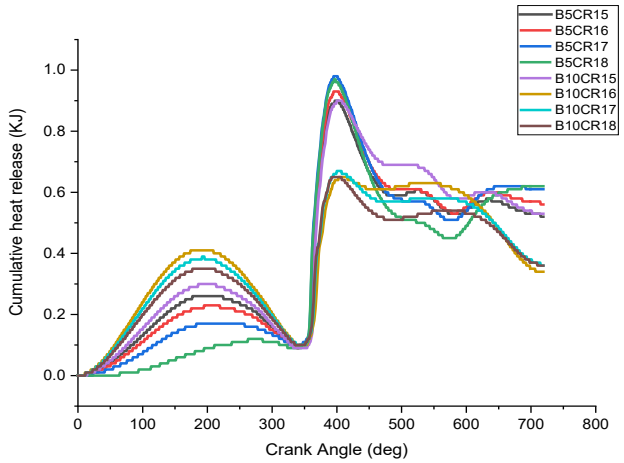


Figure 5. CHR variation with crank angle for blends B5 and B10.

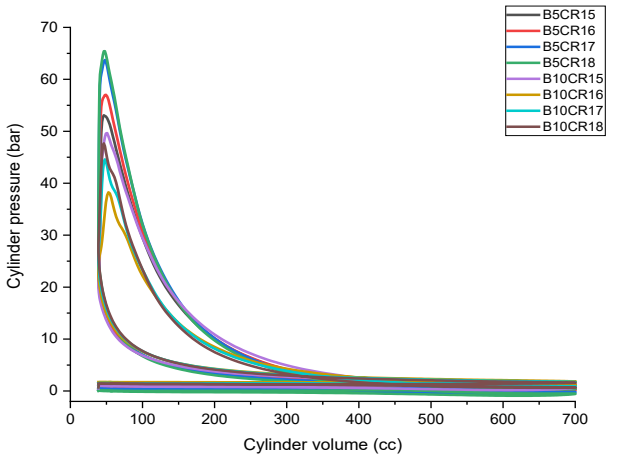


Figure 7. Cylinder pressure variation with cylinder volume for blends B5 and B10.

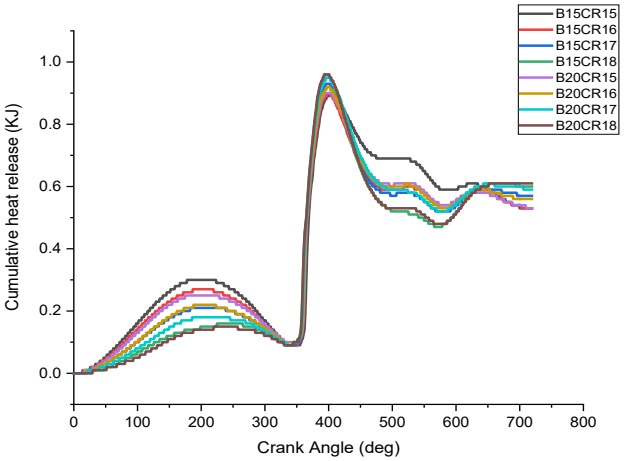


Figure 6. CHR variation with crank angle for blends B15 and B20.

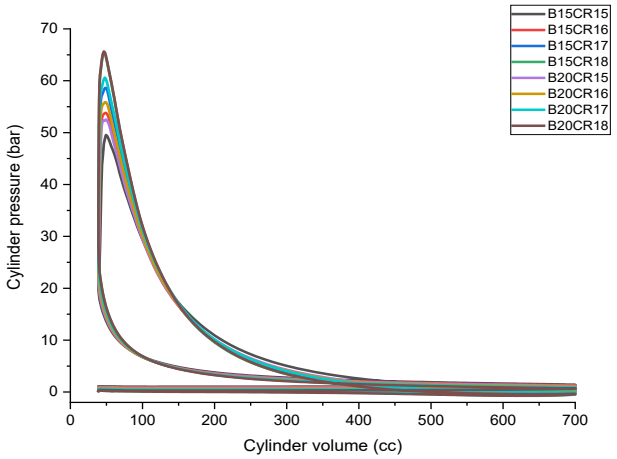


Figure 8. Cylinder pressure variation with cylinder volume for blends B15 and B20.

when the CR increases for all blends. The maximum CHR for the blends B5 at CR17 is 0.98 KJ, respectively. When compared with diesel, the CHR of B5 fuel was higher.

3.1.3 Pressure – Volume (P-V)

Figures 7 and 8 show the change in CP as a result of its volume during a complete cycle. The engine output is directly proportional to the variation in cylinder pressure and volume. At CR 18, B20 biodiesel blend produced the best result. During the expansion stroke, higher pressures were achieved, and the positive work area increased. The pressure increases because biodiesel has a higher density than diesel.

3.1.4 Mass Fraction Burned (MFB)

Figures 9 and 10 show the change in MFB with CA for blends B5, B10, B15 and B20 at compression ratio CR15, CR16, CR17 and CR18. It has been noted that the compression ratio increases as MFB decreases. The maximum mass fraction burnt for blend B5 at CR 15 is 100.64%. The start of combustion (SOC) and end of combustion (EOC) for blend B5 at CR15 is 27^0CA before top dead centre (TDC) and 32^0CA after TDC. The MFB for blend B15 at CR 16 is 100.56%. The start and end of combustion for blend B15 at CR16 is 27^0CA before TDC and 32^0CA after TDC. 10%, 50%, and 90% of MFB are allocated to the beginning combustion,

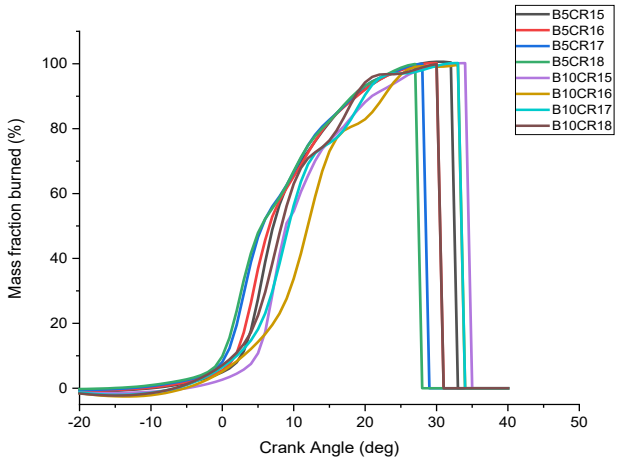


Figure 9 Mass fraction burned for blends B5 and B10.

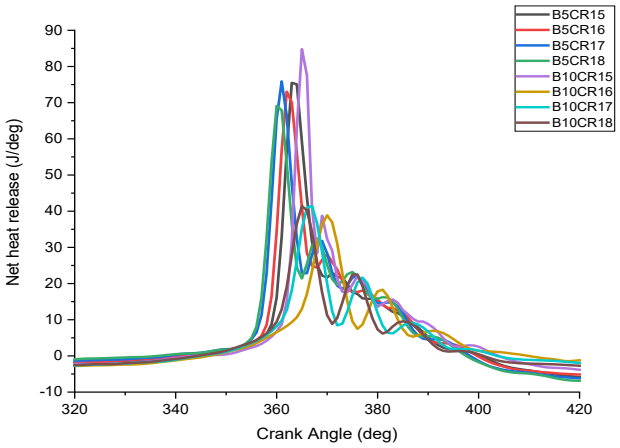


Figure 11. NHR with crank angle for blends B5 and B10.

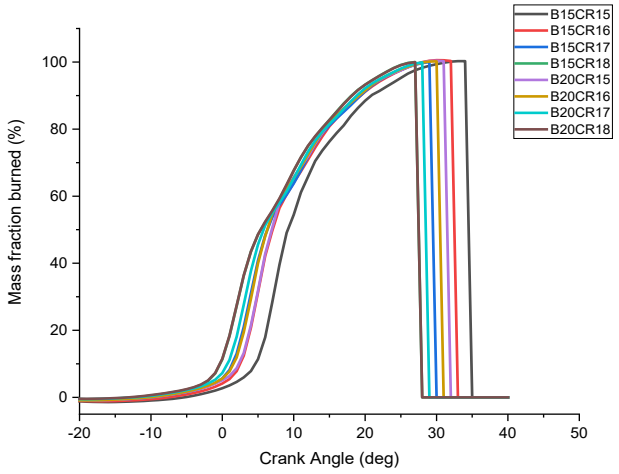


Figure 10. Mass fraction burned for blends B15 and B20.

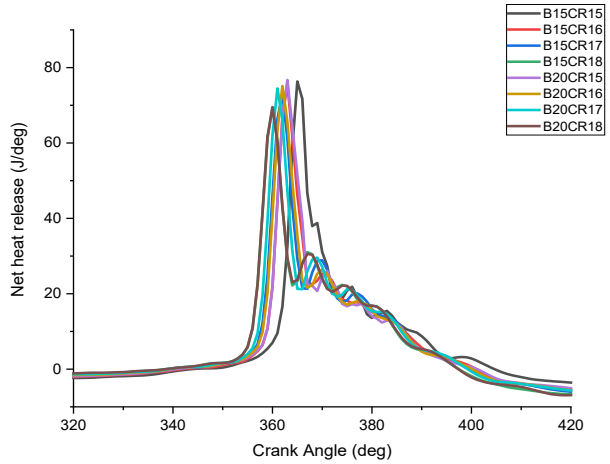


Figure 12. NHR with crank angle for blends B15 and B20.

centre of combustion, and main combustion stages, respectively.

3.1.5 Net Heat Release (NHR)

The change of NHR with CA for blends B5, B10, B15, and B20 at compression ratios CR15, CR16, CR17 and CR18 is shown in Figure 11 and Figure 12. The NHR value for diesel, B5, B10, B15 and B20 are 76.16 J/deg, 75.5 J/deg, 84.78 J/deg, 76.33 J/deg and 76.73 J/deg at CR15. The NHR values for diesel, B5, B10, B15, and B20 at CR16 are 81.39 J/deg, 73.04 J/deg, 72.48 J/deg, 75.7 J/deg and 75.11 J/deg. The NHR values for diesel, B5, B10, B15, and B20 at CR17 are 76.36 J/deg, 75.88 J/deg, 71.57 J/deg, 72.98 J/deg and 74.48 J/deg. The NHR values for diesel, B5, B10, B15, and B20 at CR18 are 66.39 J/deg, 69.09 J/deg, 68.96 J/deg, 69.41 J/deg and 69.53 J/deg. The blend B10 at CR 15 has the highest NHR out of all of the blends and diesel.

3.1.6 Rate of Pressure Rise (RPR)

The change of the RPR with CA for blends B5, B10, B15, and B20 at compression ratios CR15, CR16, CR17 and CR18 is shown in Figure 13 and Figure 14. The RPR value for diesel, B5, B10, B15 and B20 are 6.18 bar/deg, 6.14 bar/deg, 6.64 bar/deg, 5.93 bar/deg and 6.24 bar/deg at CR15. The RPR values for diesel, B5, B10, B15, and B20 at CR16 are 7.23 bar /deg, 6.48 bar/deg, 6.28 bar/deg, 6.57

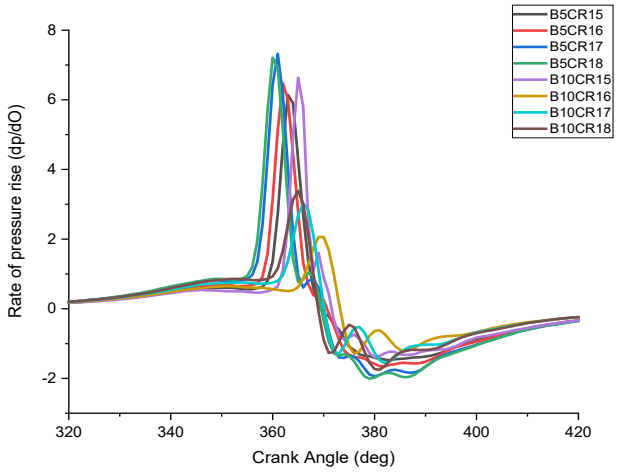


Figure 13. RPR with crank angle for blends B5 and B10.

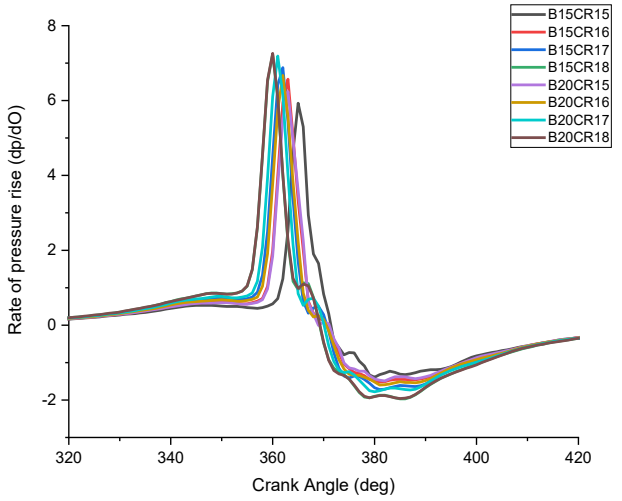


Figure 14. RPR with crank angle for blends B15 and B20.

bar/deg and 6.67 bar /deg. The RPR values for diesel, B5, B10, B15, and B20 at CR17 are 7.37 bar/deg, 7.32 bar / deg, 6.91 bar/deg, 6.88 bar/deg and 7.19 bar/deg. The RPR values for diesel, B5, B10, B15, and B20 at CR18 are 6.93 bar/deg, 7.21 bar/deg, 7.2 bar/deg, 7.24 bar/deg and 7.26 bar/deg. The blend B5 at CR17 has the highest value of 7.32 bar at 361^{0}CA out of all of the blends.

3.1.7 Mean Gas Temperature (MGT)

The combustion efficiency of the combustion chamber is measured by the MGT. Figure 15 and Figure 16 shows how mean gas temperatures vary with crank angle at various blends and compression ratios. The MGT value for diesel, B5, B10, B15 and B20 are 1402.55^{0}C, 1363.54^{0}C, 1328^{0}C, 1322.21^{0}C and 1357.52^{0}C at CR15. The MGT values for diesel, B5, B10, B15, and B20 at CR16 are 1453.91^{0}C, 1393.21^{0}C, 1350.55^{0}C, 1328.69^{0}C and 1365.02^{0}C. The MGT values for diesel, B5, B10, B15, and B20 at CR17 are 1436.2^{0}C, 1453.94^{0}C, 1407.81^{0}C, 1369.02^{0}C and 1396.87^{0}C. The MGT values for diesel, B5, B10, B15, and B20 at CR18 are 1402.25^{0}C, 1424.08^{0}C, 1426.32^{0}C, 1421.53^{0}C and 1425.22^{0}C. From results, the blend B5 at

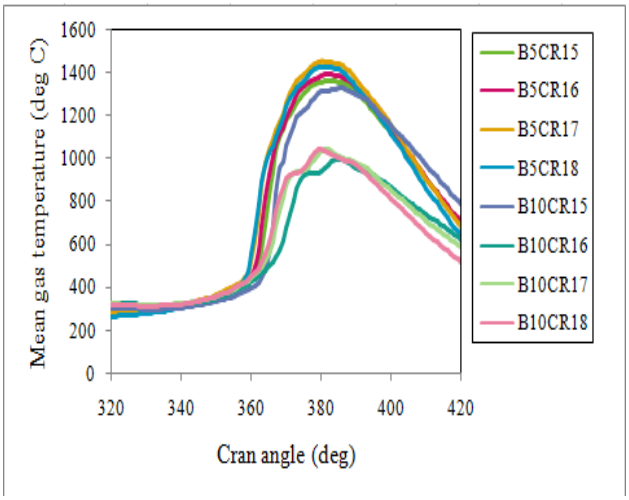


Figure 15. MGT with crank angle for blends B5 and B10.

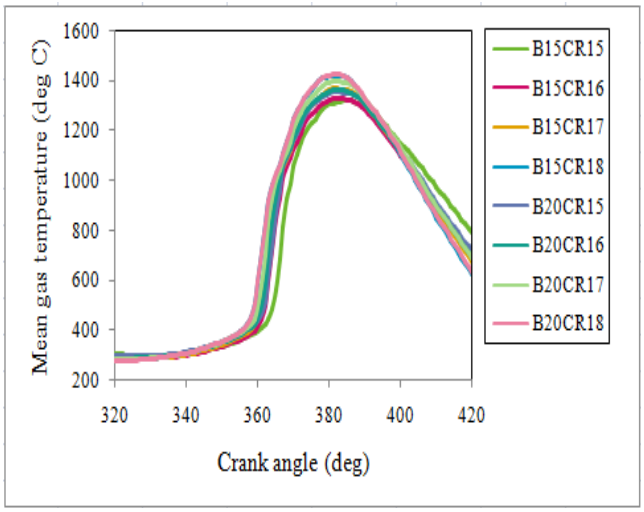


Figure 16. MGT variation with crank angle for blends B15 and B20.

CR17 has the highest mean gas temperature of 1453.94^{0}C out of all of the blends and diesel.

4.0 Discussion

4.1 Cylinder Pressure (CP)

The cylinder pressure improved as the compression ratio increases for all blends. Because of the shorter ignition delay, B20 CR18 had a higher cylinder pressure than remaining compression ratios. High cylinder temperatures with high compression ratios were caused by improved fuel atomization and the burning of more fuel in premixed combustion[17]. With a high compression ratio, increased cylinder pressure was found for all test fuels.

4.2 Cumulative Heat Release (CHR)

The cumulative heat release increases when the compression ratio increases for all blends. The maximum cumulative heat release for the blends B5 at CR17 is 0.98 KJ, respectively. When compared with diesel, the cumulative heat release of B5 fuel was higher. The increased cumulative heat release is due to the concentration of oxygen molecules within the fuel, which results in good fuel combustion[18].

4.3 Pressure – Volume (P-V)

Area of the P-V diagram indicates the work done during the cycle. The pressure increases because biodiesel has a higher density than diesel. The more oxygen in biodiesel fuel is the reason for the pressure increase in biodiesel. For biodiesel blend B20, the maximum pressure was 11^0 after top dead centre. The peak pressure for fig seed biodiesel fuel is found to occur at 12^0 after dead centre[19].

4.4 Mass Fraction Burned (MFB)

The stages of combustion are beginning combustion, centre of combustion, and main combustion stages, respectively. The mass fraction burnt at the centre of combustion was somewhat earlier due to a shorter ignition delay since biodiesel blends have a greater oxygen content and cetane number[20].

4.5 Net Heat Release (NHR)

At compression ratio 15 the blend B10 has the highest NHR out of all of the blends and diesel. The blends have a lower NHR than diesel. As a result of the rapid burning of injected fuel, there is less fuel accumulation. Diesel has a larger ignition delay than biodiesel due to its high volatility and interaction with air. A higher rate of pre-mixed combustion results in peak rate of heat release for diesel[21].

4.6 Rate of Pressure Rise (RPR)

The blend B5 at CR 17 has the highest value of 7.32 bar at 361^{0}CA out of all of the blends and it has less value compared to diesel at CR17. All biodiesel blends have a slower RPR than diesel. Biodiesel has a less ignition delay due to its greater cetane number[22].

4.7 Mean Gas Temperature (MGT)

The blend B5 at CR17 has the highest mean gas temperature of 1453.94^{0}C out of all of the blends and diesel. The diesel fuel at compression ratio 16 has the mean gas temperature of 1453.91^{0}C. Diesel fuel has a higher calorific value than biodiesel, which causes the mean gas temperature to be at its highest level. Based on the results, it is evident that biodiesel combustion characteristics may be good at greater compression ratios[23].

5.0 Taguchi Method for Optimization

The Taguchi approach is the most basic approach for optimising parameters with the fewest number of attempts. The total attempts for the tests are found out by the total parameters involved. More parameters resulted in more trails, which took longer to finish the experiment. As a result, a Taguchi approach is utilised to optimise the experimental levels involved. With a minimal number of experiments, this approach studies the full parameter space by using an orthogonal array. To choose the proper orthogonal array the total degree of freedom requires being calculation. The degree of freedom refers to the number of comparisons that must be made between design parameters. The current investigation employs mixed levels and thus, an L18 orthogonal array was used to construct the experimental pattern is shown in Table 3. The L18 is made up of three columns and eighteen rows, as well as factors including mixes, compression ratio, and load.

Table 3. Orthogonal array L18

Experiment	Fuel	CR	load
1	Diesel	16	6
2		17	9
3		18	12
4	B5	16	6
5		17	9
6		18	12
7	B10	16	9
8		17	12
9		18	6
10	B15	16	12
11		17	6
12		18	9
13	B20	16	9
14		17	12
15		18	6
16	B25	16	12
17		17	6
18		18	9

5.1 Control Parameter Selection

Table 4 contains the parameters that were chosen for the study because they have an effect on increasing the goals. More parameters are there out of which; these parameters were found to be best suitable with engine configuration. For this study, mixed levels were chosen.

This experiment has 3 factors at mixed levels. A full factorial design would require at least 3^3 =27 tests. Taguchi method with a L18 (3^3) orthogonal array were tested. Table 5 depicts the experiment design.

Table 4. Levels for design parameters

Control factor	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Blend	Diesel	B5	B10	B15	B20	B25
CR	16	17	18	---	---	---
Loads	6	9	12	---	---	---

Table 5. Design of experiments

Experiment	Blend	Compression ratio	Load	Cylinder Pressure (bar)	RPR (dp/dO)	NHR (J/deg)	Cumulative Heat Release (KJ)	Mean Gas Temperature (^{0}C)	SNR	Mean
1	Diesel	16	6	54.11	5.69	68.78	0.8	1273.27	4.964975	166.986
2	Diesel	17	9	59.31	6.64	68.9	0.88	1343.43	5.802093	167.704
3	Diesel	18	12	64.31	6.93	66.39	0.94	1402.25	6.371305	167.786
4	B5	16	6	51.36	5.17	62.39	0.79	1226.65	4.840314	165.052
5	B5	17	9	59.47	6.42	68.71	0.9	1359.77	5.988316	167.658
6	B5	18	12	65.43	7.21	69.09	0.97	1424.08	6.645445	168.612
7	B10	16	9	51.29	5.75	68.61	0.85	1263.89	5.482371	166.41
8	B10	17	12	60.64	6.91	71.57	0.96	1407.81	6.550257	168.574
9	B10	18	6	30.37	1.03	32.31	0.7	960.62	2.239593	154.622
10	B15	16	12	53.82	6.57	75.7	0.9	1328.69	5.992008	168.508
11	B15	17	6	51.81	5.35	59.09	0.77	1171.67	4.628805	163.962
12	B15	18	9	61.64	6.68	64.04	0.88	1329.97	5.802948	166.72
13	B20	16	9	62.53	6.12	71.11	0.85	1287.77	5.493698	169.232
14	B20	17	12	67.21	7.19	74.48	0.96	1415.87	6.656797	170.926
15	B20	18	6	60.72	6.52	59.5	0.81	1316.09	5.091325	165.582
16	B25	16	12	58.53	6.92	73.27	0.93	1395.32	6.279847	168.232
17	B25	17	6	52.36	6.22	66.42	0.86	1311.25	5.595559	166.036
18	B25	18	9	54.23	6.51	69.71	0.88	1359.88	5.798903	166.892

Eighteen experiments were conducted on the engine and the results were shown in Table 5 and the Analysis Of Variance (ANOVA) of CP, RPR, NHR, CHR and MGT are shown in Table 6.

Table 6. ANOVA of combustion parameters

	Source	DF	Adj SS	Adj MS	F-Value	P-Value
Cylinder pressure	Blends	5	277.56	55.51	1.37	0.33
	Compression Ratio	2	39.98	19.99	0.49	0.63
	Load	2	369.19	184.6	4.55	0.04
	Error	8	324.81	40.6	---	---
	Total	17	1011.53	---	---	---
Rate of pressure rise	Blends	5	8.476	1.6952	1.38	0.325
	Compression Ratio	2	1.569	0.7844	0.64	0.552
	Load	2	13.138	6.5692	5.36	0.033
	Error	8	9.803	1.2254	---	---
	Total	17	32.986	---	---	---
Net heat release	Blends	5	290.9	58.17	1.36	0.331
	Compression Ratio	2	327.3	163.63	3.84	0.068
	Load	2	612.2	306.12	7.18	0.016
	Error	8	341.2	42.65	---	---
	Total	17	1571.6	---	---	---
Cumulative heat release	Blends	5	0.0065	0.0013	1.17	0.399
	CR	2	0.0035	0.0018	1.58	0.264
	Load	2	0.0708	0.0354	31.9	0
	Error	8	0.0088	0.0011	---	---
	Total	17	0.0897	---	---	---
Mean gas temperature	Blends	5	43396	8679	1.66	0.25
	Compression Ratio	2	6715	3357	0.64	0.552
	Load	2	116497	58248	11.12	0.005
	Error	8	41887	5236	---	---
	Total	17	208495	---	---	---

Table 6 shows that the P value for load is 0.04 which is less than or equal to 0.05. As a result, the load is the most influential parameter for cylinder pressure. The P value load is 0.033, is less than 0.05. As a result, the load has the greatest impact on RPR. The value of P for load is 0.016, which is less than or equal to 0.05. As a result, the load is the most influential parameter for net heat release. The P value of for load is 0.000, which is less than or equal to 0.05. As a result, the load is the most influential parameter for cumulative heat release. The value of P for load is 0.005, which is less than or equal to 0.05. As a result, the load is the most influential parameter for mean gas temperature. Finally, the load is the most important response parameter.

5.2 Main Effects Plot for SN ratios

Figure 17 depicts the main effects plot for SN ratio, which is drawn for the larger is better type. From the Figure 18, it is noticed that the optimum values of CP, RPR, NHR, CHR and MGT are at B20 blend, 17 compression ratio and 12 kg load.

5.3 Main Effects Plot for Means

Figure 18 depicts the main effects plot for means, which is drawn in the larger is better style. From Figure 19, it is noticed that the optimum values of CP, RPR, NHR, CHR and MGT are at B20 blend, 17 compression ratio and 12 kg load.

Table 7 shows the optimal parameters for CP, RPR, NHR, CHR and MGT, with the desirability approach used for optimization analysis. Table 7 clearly demonstrates that global solution one has achieved the composite desirability approaches 0.81, which is near to 1.

6.0 Conclusion

The combustion parameters of an engine running on HCN biodiesel are investigated under different blends and compression ratios at peak load and constant speed of the engine. The experimental investigation gave the following conclusions:

- The cylinder pressure increases with an increase in compression ratio for all fuel blends. Blend B20 at

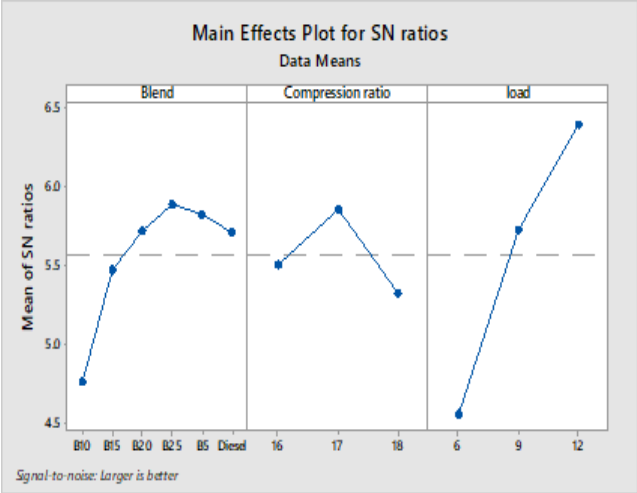


Figure 17. Main effects plot for SN ratio.



Figure 18. Main effects plot for Means

Table 7. Optimum parameters

Solution	CR	Load (kg)	Blend	CP (bar)	RPR Rise (dp/dO)	NHR (J/deg)	CHR (KJ)	MGT (°C)	Composite desirability
1	16	12	B20	65.65	7.26	75.46	0.96	1424.54	0.81

CR 18 has a maximum cylinder pressure of 65.65 bar at 371^{0}CA, which is 2.08% higher than the diesel fuel.

- Cumulative heat release increases when the compression ratio increases for all blends. The maximum cumulative heat release for the blends B5 at CR17 is 0.98 KJ which is 3.16% higher than diesel fuel.
- The mass fraction burned decreases with an increase in compression ratio. The maximum mass fraction burnt for blend B5 at CR 15 is 100.64%, which is 0.39% less compared to diesel. Blend B15 at CR17 has a mass fraction burned of 100.56%, which is 0.35% higher than diesel fuel.
- With increasing biodiesel content in blends, net heat release rises, but it falls with increasing compression ratio. The blend B10 at CR 15 has the highest value of net heat release 84.78 KJ at 365^{0}CA which is 11.32% higher than diesel fuel.
- When the compression ratio increases, the rate of pressure rises for all blends. The blend B5 at CR17 has the highest rate of pressure rise of 7.32 bar at 361^{0}CA out of all of the blends, but it has 0.68% less compared to diesel fuel.
- The mean gas temperature increases with an increase in compression ratio for all fuel blends and it has a maximum value of 1453.94^{0}C at 380^{0}CA with CR17 for the B5 blend, which is 1.24% higher than diesel fuel.
- The Taguchi process is a simple, practical, and quick way for developing a dependable and high quality engine.
- The Taguchi technique optimization results are quite similar to the experimental results.

Based on the findings and conclusions, it is observed and suggested that HCN biodiesel blend B20 can be used effectively at a compression ratio of 16:1 without requiring any engine modification.

7.0 Author's Contribution Statement

Alapati Babji developed the presented concept, performed the experiments, observations, graphs and preparation of the manuscript. Rambabu Govada supervised the process of concept, experiments, results and draught of the manuscript. Balaji Naik D contributed to the investigation into difficulties, results, interpretation of the findings, and draught of the manuscript. Sowmya Jonnagiri documented and developed results and experimentation.

8.0 Data Availability Statement

The authors affirm that the data behind the study's conclusions are included in the article.

9.0 Acknowledgment

The authors would like to thank K. Satya Bharati and Mr. G. Venkateswararao for their valuable suggestions to do the test on the engine for carrying out performance and emission analysis and fuel testing.

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Abbreviations

S. No	*Abbreviations*	*Description*
1	ANOVA	Analysis of variance
2	ASTM	American society for testing and materials
3	CA	Crank angle
4	CHR	Cumulative heat release
5	CP	Cylinder pressure
6	CR	Compression ratio
7	EOC	End of combustion
8	HCN	Hibiscus cocos nucifera
9	MFB	Mass fraction burned
10	MGT	Mean gas temperature
11	NHR	Net heat release rate
12	RPR	Rate of pressure rise
13	SNR	Signal to nose ratio
14	SOC	Start of combustion
15	VCR	Variable compression ratio