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Experimental investigations into engine characteristics fuelled with hibiscus coconut biodiesel and its blends

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Abstract
The world's fossil fuel sources are decreasing rapidly. Rising population growth needs alternative fuels. Biodiesel is an alternate and sustainable fuel obtained from different feedstocks. In this work, biodiesel was made from hibiscus-coconut oil by the transesterification technique. The aim of the present research is to investigate the emissions, combustion and performance characteristics of a single-cylinder variable compression ratio diesel engine fuelled with hibiscus-coconut biodiesel blends. The blends of B05 (5% biodiesel and 95% diesel), B10 (10% biodiesel and 90% diesel), and B15 (15% biodiesel and 85% diesel) were prepared with hibiscus-coconut biodiesel and diesel. The engine is running at a speed of 1500 rpm and a compression ratio of 17.5:1 at various loads. The experimental findings are compared with those of diesel fuel. The brake thermal efficiency (BTE) and brake power (BP) were improved by 2.48% and 1.78% for blend B15 at peak load. The brake specific fuel consumption is the same as that of diesel. The maximum cylinder pressure is 63.82 bar. Carbon monoxide, hydrocarbon emissions and smoke have decreased by 18.03%, 13.79% and 52.71%, respectively. There is a marginal increment in nitrogen oxides of 14.37%. The blend B15 is acceptable for diesel engines as a renewable fuel. Thus, the findings show that, without any modification to the engine, the blend B15 can be utilized as an alternate fuel for diesel engines.

Keywords
Diesel, Hibiscus coconut biodiesel, Blends, Performance, Emissions, Combustion.

1.Introduction
The requirement for energy on the globe is enormous. Fossil fuels are the primary source of energy. Fossil fuel plays a leading role in the global energy scenario [1]. Crude oil is expected to become extremely scarce and expensive [2]. Petroleum based fuels are used in industries, transportation, power plants and agricultural sectors, respectively [3]. Fossil fuels are finite and the use of fossil fuels results in pollution and global warming too. Carbon dioxide, nitrogen oxide, volatile compounds, and hydrocarbons (HC) are produced by fossil fuels during combustion. There has been a surge in demand for alternate energy sources [4]. Vegetable oils create engine problems like injector blockage, piston rings sticking and deposits because of high level viscosity and less volatility.

Edible oils like rapeseed [5], olive [6], sunflower and corn oil [7], as well as non-edible oils like Jatropha [8], linseed [9], castor [10], jojoba [11], mahua [12], neem [13] and waste cooking oil [14], are all examples of vegetable oils. To reduce its higher viscosity, it is blended, transesterified with alcohol, and converted to biodiesel, as well as thermal cracking and preheating [15]. When Rudolf Diesel originally developed a diesel engine, he experimented with peanut oil, demonstrating that vegetable oils are suited for future needs [16]. In the transportation industry, agriculture field, and power generating industries, diesel engines are frequently used due to their high compression ratio (CR), which make them very efficient and durable. Apart from their renewable nature, biodiesel has low sulphur content, a greater cetane number, flash point, lubricity, non-toxicity, and better biodegradability. Biodiesel fuels are preferred up to 20% [17]. The motive of this study is to employ the appropriate kind of sustainable energy to reduce greenhouse gas emissions, enhance

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people's living conditions, and supply sustainable fuel for energy production. The objective of the research is to look at how biodiesel blends of B05, B10 and B15 affect the emission, combustion, and performance of a variable compression ratio (VCR) engine at CR and various loads. Performance parameters of brake power (BP), brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), combustion parameter cylinder pressure (CP), emission parameters of carbon monoxide (CO), oxides of nitrogen (NOx), HC, and smoke level are studied.

This paper is organized into six sections. Section 1 provides an introduction of the work background, motivation, and research objectives. Section 2 reveals the literature survey on related work. Section 3 shows the materials and methods used in the biodiesel production, as well as the experimentation procedure and uncertainty analysis. Section 4 reveals the results of the work. Section 5 represents the discussion in the analysis of the obtained results and the limitations related with them. Section 6 gives the conclusions and future scope.

2.Literature review

Biodiesel was produced from coconut oil using the catalyst as a hydroxide impregnated calcium oxide in the transesterification process. Biodiesel conversion increased from 66.36% to 81.70% by adding co-solvent such as tetrahydrofuran [18]. A transesterification process using calcium oxide as a heterogeneous catalyst produced Jatropha biodiesel. The response surface method was applied to optimise the engine performance parameters working with a B20 blend [19]. The pyrolysis waste cooking biodiesel is fuelled in a diesel engine to find out the performance, emissions, and combustion parameters. Two catalysts such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) are used in various proportions to prepare biodiesel. NaOH and KOH are given 70% and 25% yields. Tests are conducted using different blends and different loads at constant speed. BSFC decreased from 20% to 75% load and increased as the biodiesel percentage increased. BTE and NOx levels rise with increasing load and fall with increasing biodiesel percentage. HC emissions rise as the load and the proportion of biodiesel increases. CO lowers as the load and % of biodiesel grow. CP increases as the percentage of biodiesel increases [20]. Nanoparticles from titanium oxide of sizes 100 and 50 nm are blended into the Honge biodiesel to lower the emissions from the engine [21]. In ginger grass biodiesel, a nano additive such as cerium oxide at 30 ppm is mixed in to observe the engine characteristics. BTE improved and BSFC decreased for blends B10, B20 and B40. HC rises as the percentage of biodiesel rises [22]. Coconut oil and Jatropha oil are utilized as alternative fuels for compression ignition (CI) engine. Experiments were carried out separately at B20 to B50 using diesel, Jatropha, and coconut biodiesel at various loads on a diesel engine with a CR of 18:1 and a constant speed of 1500 rpm. BTE is slightly lower at a B20 blend when compared with diesel oil. BSFC is close to diesel oil in a B20 blend of Jatropha and coconut biodiesel [23]. Ethanol, diesel and Niger biodiesel in different proportions were prepared as fuels and experiments were conducted on diesel engine at different pressures. BTE improved, BSFC and emissions decreased for blend proportions of 15% biodiesel, 70% diesel and 15% ethanol at higher injection pressures [24]. The palm oil is used in a two-cylinder hydraulic dynamometer diesel engine to observe the performance of a blend B10. The engine was operated at various loads and at 1800 rpm. Torque, fuel consumption, engine speed, air consumption, motor oil temperature, exhaust gas temperature, HC, CO, carbon dioxide (CO_2), NO_x, and oxygen are the working variables. An ANOVA analysis and a regression model were used to recognize the emission variables. At 50% load, air consumption is high compared to 80% load [25]. An open-source simulation tool has been developed to inspect the combustion, performance and emissions of different biodiesel. The software results are compared to the experimental results. The numerical research used engine specifications and operating conditions that were similar to the experimental work. Engine power, NOx and CO_2 emissions, CP, fuel consumption, and ignition delay were measured at 25, 50, 75, and 100% load. At 100% load, corn biodiesel had a maximum power output of 4.209 kW, while Jatropha biodiesel had lower fuel consumption. The maximum CP of transformer oil biodiesel was higher compared with diesel. Almost every biodiesel had a shorter ignition time. Biodiesel had higher NOx levels compared with diesel, but lower CO_2 emissions [26]. Hibiscus cocos nucifera oil is used in a VCR engine to observe the performance of the engine. The Taguchi technique was applied to optimize the performance parameters. BTE was improved by 4.07% for the B20 blend at an 18:1 CR [27]. Biodiesel made from cottonseed oil and rice bran oil is used in different proportions in the VCR engine at various loads from zero to maximum load and a CR of 15, 16, 17 and 18. BP was reduced and BSFC increased for blend B20 of both the biodiesel. The emissions of B20 are lower for both the test fuels compared to diesel [28]. Jojoba biodiesel blends B05, B10, B15 and B20 are tested on diesel engines. CO, HC and smoke emissions are reduced, NOx increases and BTE is improved for the B20 blend [29]. Co-pyrolysis oil was made from polystyrene and neem de oiled cake in a 2:1 ratio and blended with diesel at 5%, 10%, 15% and 20%. Blends B05 and B10 gave good results. BTE was decreased for all blends at full load. When the load rises, BSFC falls and when the blend percentage increases, BSFC increases. BP increases as the load increases and BP decreases as the composition of pyrolysis oil is increased. The missions are increasing as the composition of pyrolysis oil increases [30]. Castor biodiesel was made from castor oil in an ultrasonicator. B30 blend obtained as a good BTE result, B20 blend obtained a good BSFC value, and B10 blend obtained less emission [31]. Rubber seed biodiesel and linseed biodiesel blend into diesel and tested on diesel engines. Blend 1 is prepared with rubber seed biodiesel (5%) and linseed biodiesel (5%), including (90%) diesel. Blend 2 is prepared with rubber seed biodiesel (10%), linseed biodiesel (10%), along with (80%) diesel. CO and NOx emissions are less than diesel for both blends. BTE rises with load, BSFC lowered with a rise load [32]. The properties of diesel and different biodiesel fuels developed by different authors are given in *Table 1*.

Table 1 Major Biodiesel and diesel fuel properties

Property	**Palm oil**	**Pongamia**	**Recycled waste engine oil**	**Tamarind**	**Waste cooking oil**	**Sunflower**	**Neem**	**Diesel**
Density (kg/m^3)	870	881	940	884	816.6	880	860	832
Calorific value (MJ/kg)	38.3	38.5	49.9	38.7	46.62	37.5	41	44.3
Kinematic viscosity at 40^{0}C(cSt)	5.3	5.4	7.8	7.2	2.288	4.7	4.5	1.6:7
Flash point(^{0}C)	178	180	210	159	28	160	152	55
Pour point(^{0}C)	6	5	-	-	-27	-9	-	3:15
Cetane number	54	55	64	52	54.6	-	51	46
References	[33]	[34]	[35]	[36]	[37]	[38]	[39]	[40]

According to the literature review, numerous researchers have attempted to identify a suitable replacement to diesel fuel without modifying the engine. Experiments were carried out on diesel engines to examine the performance, emission, and combustion parameters at varied loads, speeds, blends, and pressures. Transesterification is one of the procedures used to manufacture biodiesel from oil seeds. There has been no investigation into the use of hibiscus coconut biodiesel in a VCR engine operating at CR 17.5. Therefore, the present research concentrates on the performance, emission, and combustion parameters of a VCR engine powered by hibiscus coconut biodiesel.

3.Materials and methods

3.1Materials

The Hibiscus is a Malvaceae family plant. Hibiscus is a genus with roughly 300 different species. Because most species produce stunning flowers, the plants are frequently used in scenery as small trees. The ingredients used to make Hibiscus coconut oil are hibiscus flowers & leaves, coconut oil, and Murraya koenigii leaves, obtainable worldwide. They are growing greatly on any kind of land. All chemicals, including methanol and potassium hydroxide (KOH) in pellet form, were used as a catalyst for the transesterification process.

3.2Production of biodiesel

The hibiscus flowers and leaves are taken from the hibiscus plant and washed to remove the dust and foreign particles. Curry leaves are also taken from their plants and washed. Coconut oil is easily available in local areas. *Figure 1* represents the manufacturing process of hibiscus coconut biodiesel. Murraya koenigii leaves, hibiscus flowers, and leaves should all be cut into little pieces. Combine all of the ingredients in a food processor and process until smooth. Combine the ingredients in a bowl with pure coconut oil and heat for 45 minutes on a low flame, or until the oil becomes a different colour. Turn off the heat in the pan and let the mixture cool. Transfer the oil to an appropriate container after filtering. Hibiscus coconut oil is now available. Transesterification is used to transform raw hibiscus coconut oil into hibiscus coconut biodiesel.

3.2.1Apparatus

Experiments were conducted in a laboratory using a reaction glass flask with an airtight stopcock to keep any vaporised methanol from entering the reaction liquid, a magnetic stirrer, a beaker and a thermometer. One reaction glass flask has three necks: one for the stirrer, one for the condenser, and one for the thermometer to monitor the reaction temperature. A bomb calorimeter is used for calorific value, and Pensky-Martins apparatus was used to find out the flash point and fire point of the test fuel. The viscosity of fuel is measured by a redwood viscometer. A hydrometer is used to measure the density of a fuel.

3.2.2Transesterification process

Transesterification is used to decrease the viscosity of vegetable oil. The transesterification is defined as the turning of a triglyceride into a fatty acid ester in the presence of a catalyst [41].The transesterification was carried out using monohydric alcohol and an alkali catalyst. Methanol or ethanol is used to make biodiesel. The transesterification process chemistry for methanolysis is the same as that of ethanolysis. The transesterification reaction was carried out with Hibiscus coconut raw oil, methanol and KOH as a catalyst. Take one litre of hibiscus coconut oil in a three-necked glass flask and heat the oil up to a temperature that reaches 60^0C. Prepare the catalyst with a 10% methanol solution and 2 mg of KOH. This mixture is stirred until all the pellets are well mixed in the methanol solution. Now add this catalyst to the hibiscus coconut oil contained in a three-necked glass flask. Continue the heating process at 60^0C for up to two hours with continued stirring at 1100 rpm. When the reaction had ended, the liquid is transferred into a separate flask to settle about 12 hours. Due to the dense nature of the glycerol layer, it settled and was removed from the mixture. Glycerin and contaminants are separated from methyl ester by washing with distilled water at 60^0C. Water, being denser, settles down in the flask for up to one hour; after that, separate the water and biodiesel. After washing, the biodiesel was heated to around 110°C to eliminate the moisture. Biodiesel was finally ready for use in diesel engines. The properties of diesel and hibiscus coconut biodiesel are given in *Table 2.*

Table 2 Diesel and biodiesel characteristics

Fuel	Specific gravity	Density	Calorific value	Flash point	Fire point	Kinematic viscosity
Unit	**---**	**gm/cm^3**	**Cal/gm^{0}C**	**^{0}C**	**^{0}C**	**cst**
Diesel	0.830	830	10,236	53	56	2.09
Biodiesel	0.863	863	9578	96	105	2.96

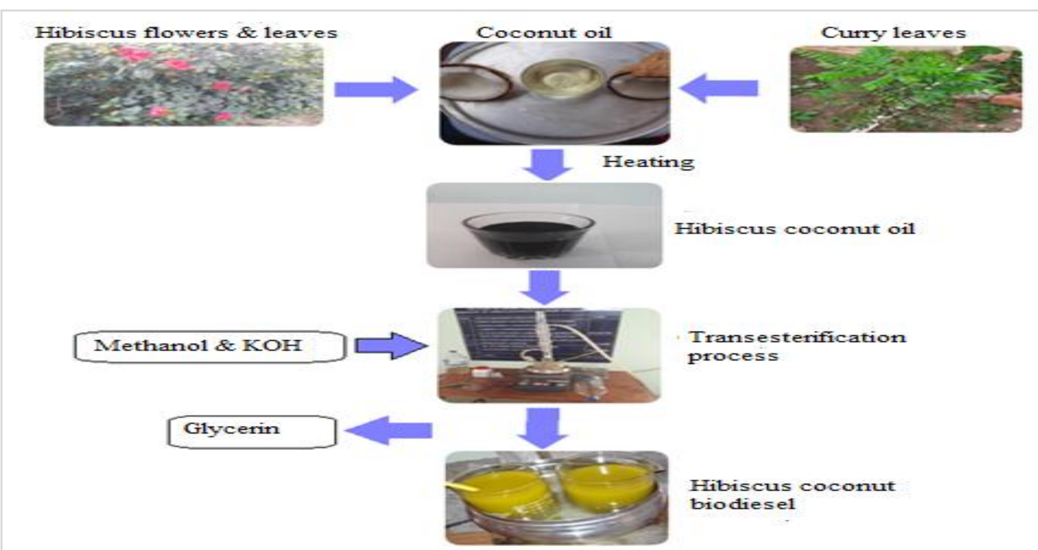

Figure 1 Block diagram of the production process of hibiscus coconut biodiesel

3.3Experimental procedure

Biodiesel and pure diesel are mixed in separate flasks as per our blend proportions: BO5, B10, and B15, and 100% diesel. Now tests were carried out on the engine with the above blends. The engine was equipped with a computer, a gas analyzer for emissions measurement, and a smoke metre is utilized to measure the level of smoke. The engine runs at a constant speed at various loads of 25%, 50%, 75%, and full load, with a CR of 17.5:1. Before starting each analysis, the engine ran for 15 minutes until the test motor reached steady state conditions. The engine is reverting to diesel when the testing is completed, and it continues to run until the blends are sweep out from the fuel line, injector, and injection pump. Measure the fuel consumption, engine emissions, and smoke level for each test. A computerized single-cylinder, Kirloskar made, VCR diesel engine with a maximum rated output of 3.5 kW is used in this work. The schematic diagram of the experimental setup is shown in *Figure 2*. *Table 3* shows the specifications of the engine. The load is changed using an eddy current dynamometer.

Table 3 Engine details

Parameter	Specifications
Power	3.5 kW
Speed	1500 rpm
Number of cylinders	Single
Number of strokes	Four
Eddy current Dynamometer	Water cooled, with loading unit
Bore	87.5 mm
Stroke	110 mm
CR	17.5:1
Capacity	661 cc
Injection	0-25 deg bTDC

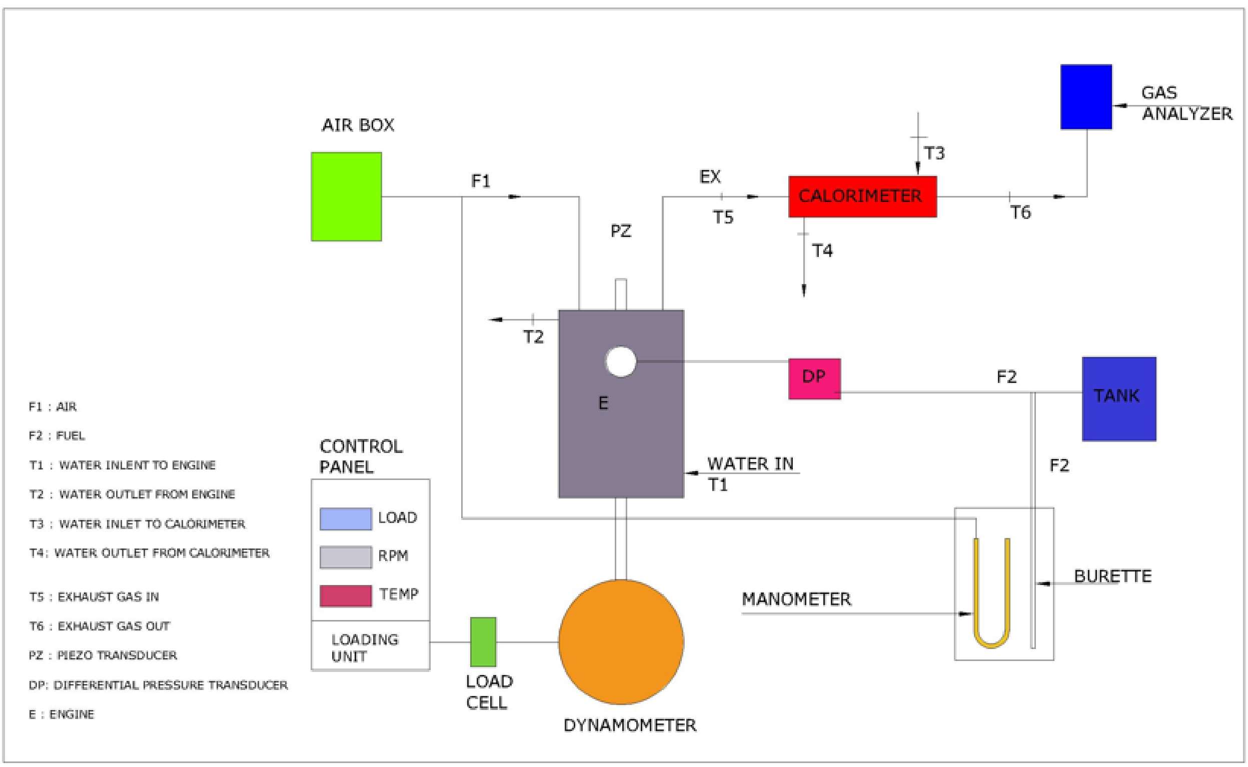

Figure 2 Schematic diagram of experimental setup

3.4Uncertainty analysis

There is an uncertainty in every task. Calibration, observations, test processes, sensors, and environmental conditions all contribute to these uncertainties. The test results of any work can be considered in light of uncertainty [42]. In every experiment, there is a definite angle of uncertainty while operating with an instrument due to certain numerical, physical and operational parameters. As a result, uncertainty analysis is required in relation to the number of experiments performed again and again in order to ensure the correctness of the results acquired [43]. Hence, uncertainty analysis is important to provide precise experimental results. *Table 4* shows the parameters along with the uncertainty percentages, and *Table 5* shows the accuracy of various measuring devices. Uncertainties for different parameters like BP, BTE, and BSFC are calculated based on measured values and net possible errors in measuring parameters. *Table 5* shows the emission measurement device resolution and accuracy.

$$\%\ \text{Error in measured value} = \frac{\text{Net possible error}}{\text{Measured value}} \times 100 \quad (1)$$

Table 4 Measured parameter uncertainty

S. No.	Parameter	Uncertainty	Unit
1	BP	±0.052	kW
2	BTE	±0.73% = 0.0073 value	BTHE (%)
3	Mass of fuel flow (kg/hr)	± 0.0012	kg/h
4	BSFC	±0.0231	kg/kWhr
5	CP Maximum	±1.21	bar
6	HC emissions	±1.25	ppm
7	CO	±0.002	% Vol
8	Nitric Oxide	±8.75	ppm
9	Carbon dioxide	0.23	%Volume
10	Smoke opacity	±2.44	% Volume

Table 5 Emissions measurement device details

AVL444NFiveGasAnalyzer				
Parameter	**Unit**	**Measurement**	**Resolution**	**Accuracy**
CO	%Vol	0 to 15	0.01% Vol	<0.6%:±0.03 ≥0.6%:±5%ind. Val
HC	ppm Vol	0 to 20,000	1/10 <2000rpm/>2000rpm	<200: ±10 ≥200: ±5% ind.Val
CO_2	%Vol	0 to 20	0.1	<10%:±0.05 ≥10%:±5%ind. Vol
O_2	%Vol	0 to 25	0.01	<2%: ±0.1 ≥2%:±5%ind. Vol
NO	ppm Vol	0 to 5000	1	<500: ±50 ≥500: ±10%ofind.Val

4.Results

4.1Engine performance characteristics

BP, BTE and BSFC were studied at various loads with diesel, B05, B10, and B15 blends.

4.1.1 Brake power (BP)

The engine is operated at 25%, 50%, 75% and 100% of load for different blends. *Figure 3* represents the BP variation with load. From the *Figure 3* it is noticed that BP rises with rises in load for the blends B05, B10, B15 and diesel fuel. Further, with an increase in biodiesel composition, BP increased. The peak value of BP obtained for the blend B15 as 3.43 kW which is 1.78% higher than diesel due to the higher oxygen percentage of biodiesel. When biodiesel is added to diesel, the oxygen level increases dramatically, resulting in greater heat energy being produced [44].

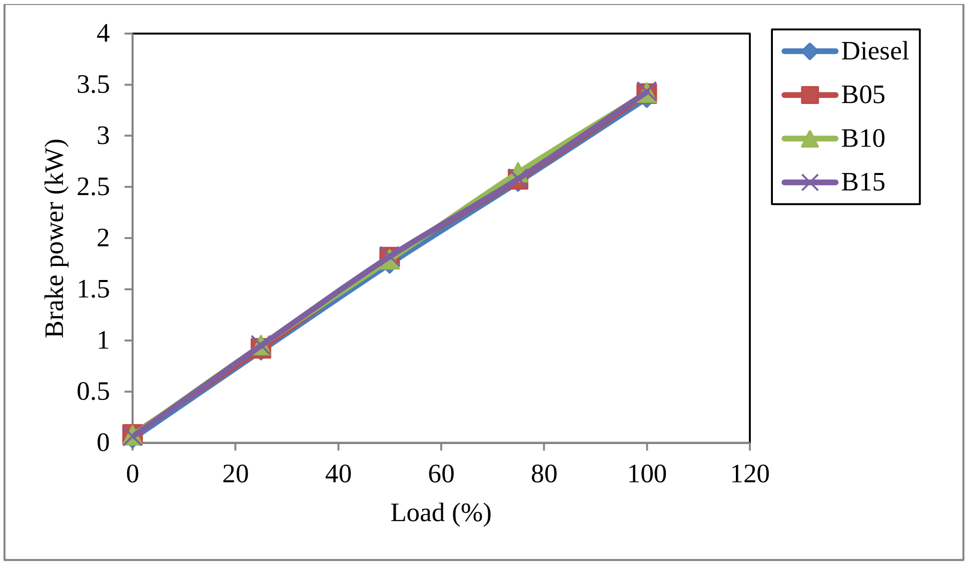

Figure 3 Brake power variation with load

4.1.2 Brake thermal efficiency (BTE)

Figure 4 represents how BTE varies with load. According to the graph, for diesel, blends B05, B10, B15, BTE increases as the load rises. Furthermore, it was discovered that when the biodiesel concentration increased, so did the BTE. The highest value of BTE obtained for the blend B15 was 24.36%, which is 2.48% higher than diesel at peak load and with a CR of 17.5:1 due to complete combustion. With increasing load, the BTE of diesel and blend B10 increased [45].

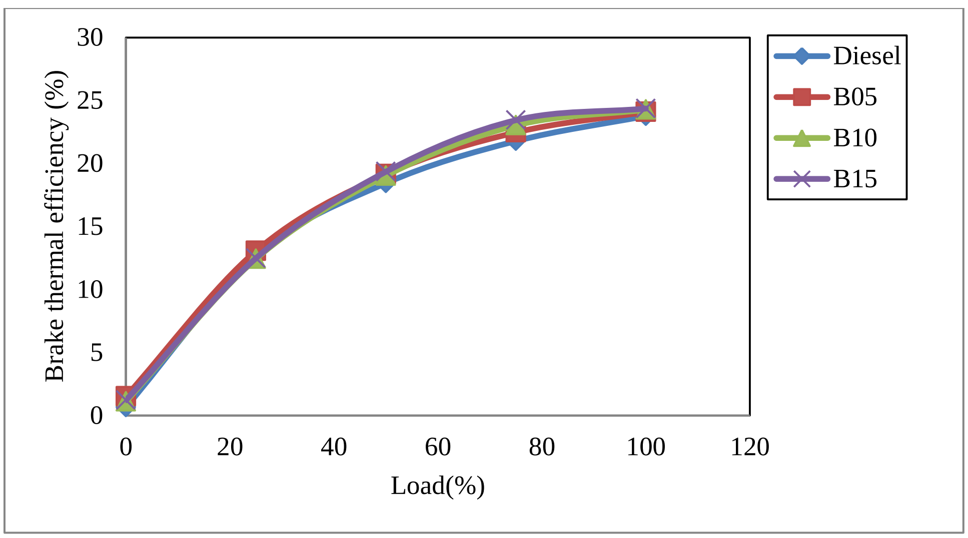

Figure 4 Graph between load and BTE

4.1.3 Brake specific fuel consumption (BSFC)

It is the measurement of the engine efficiency in producing work with a given fuel. *Figure 5* depicts the change of BSFC with various loads for B05, B10, B15, and diesel fuel. The BSFC of diesel, B05, B10 and B15 drops with the increase in load. Additionally, BSFC has decreased as the percentage of biodiesel has increased. At 100% load conditions, the BSFC of all blends and diesel is found to be a constant value of 0.35 kg/kW-hr. Because of the reduced rate of fuel flow, BSFC falls as load increases. BSFC of blends falls as load increases because of improved combustion, and loss of heat is less at maximum load [46].

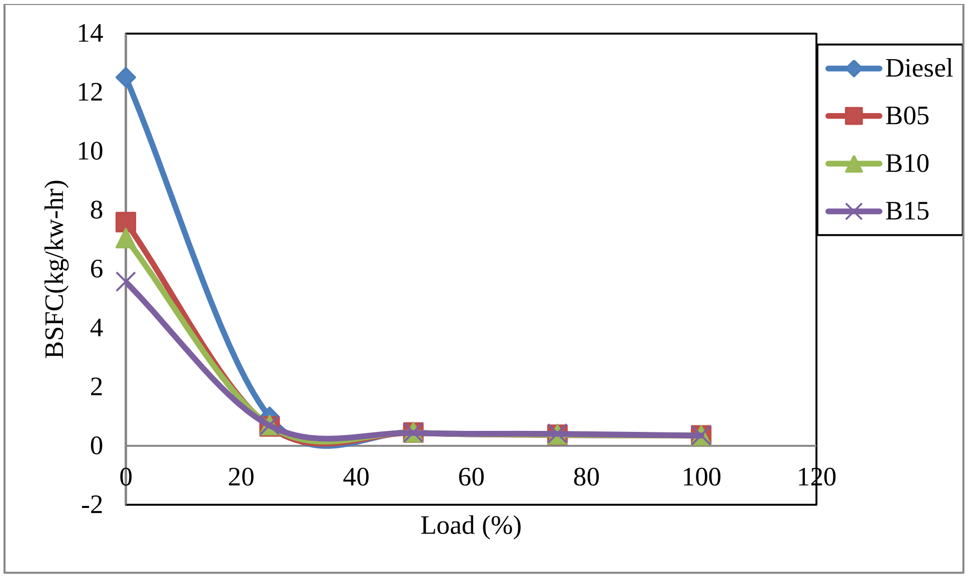

Figure 5 Brake specific fuel variation consumption with load

4.2 Combustion characteristics

4.2.1 Cylinder pressure (CP)

Figure 6 depicts the CP with crank angle of the blends B05, B10, B15 and diesel at a compression of 17.5:1. The *Figure 6* shows that the CP rises with increasing biodiesel concentration at 100% load. The maximum CP for B15 occurs at 63.82 bars at 372^0 crank angles with a CR of 17.5:1. The maximum CP rises with the rise in load because the pressure and temperature are higher in the combustion process. The maximum CP rises as the concentration of biodiesel rises because of the greater cetane number of biodiesel [47].

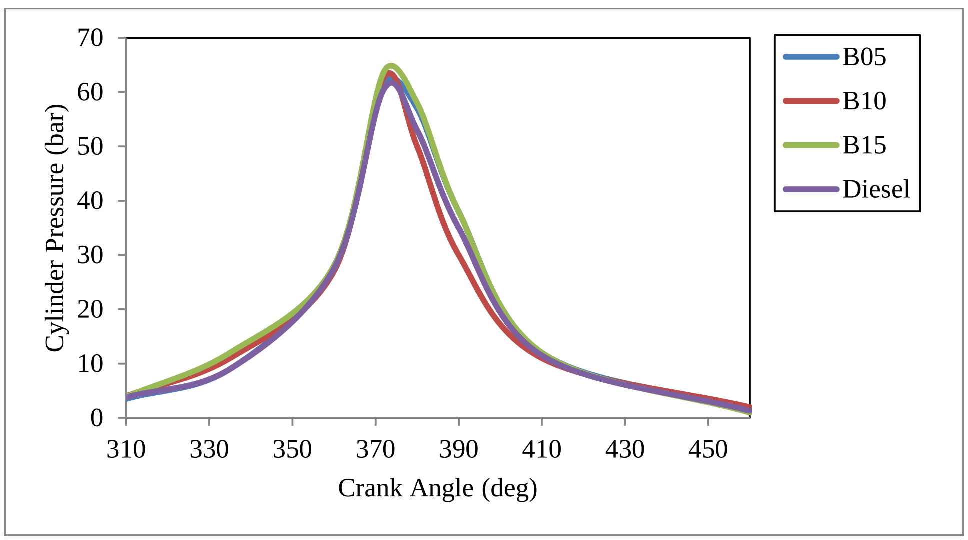

Figure 6 Variation of cylinder pressure at different crank angles at full load

4.3 Exhaust emission analysis

4.3.1Carbon monoxide (CO)

Figure 7 shows the effect of load on CO emissions of the diesel, B05, B10, and B15 at CR of 17.5:1. For the blend B15, CO emissions decreased by 18.03% when compared with diesel fuel. CO emissions are decreased at low loads and higher at large loads. At 100% load, diesel emits more CO than biodiesel fuels. Because biodiesel contains more oxygen, CO emissions are reduced as the percentage of biodiesel rises [48].

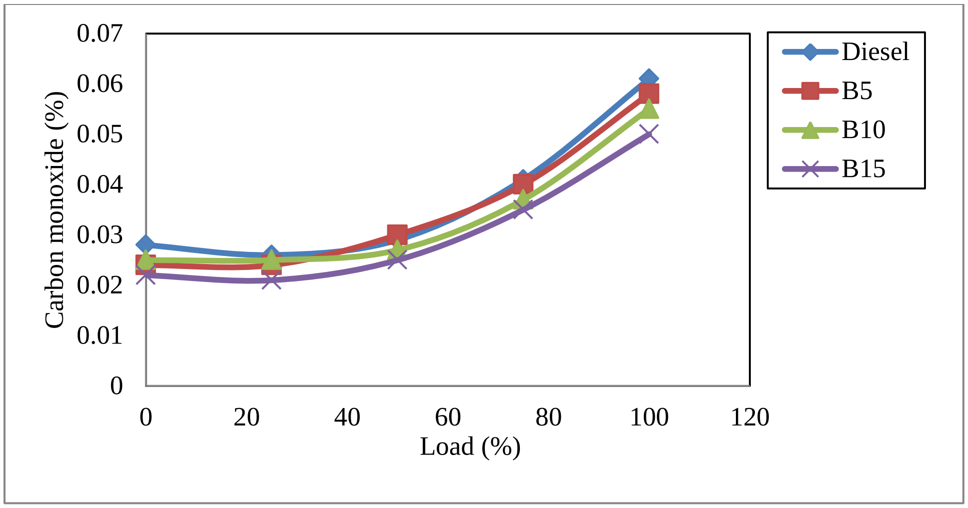

Figure 7 Variation of load on CO emission

4.3.2 Hydrocarbon (HC)

Figure 8 shows the relationship between HC and load for the various fuels examined. The amount of HC emitted rises as the load rises. HC emissions decrease as the percentage of biodiesel increases. HC emissions for B15 are reduced by 13.79% when compared with that of diesel. The oxygen content in biodiesel creates favourable conditions to accelerate the oxidation of HC during the mixing of air-fuel. Because of the higher cylinder temperature and clean combustion, HC for biodiesel blend are less than for diesel [49].

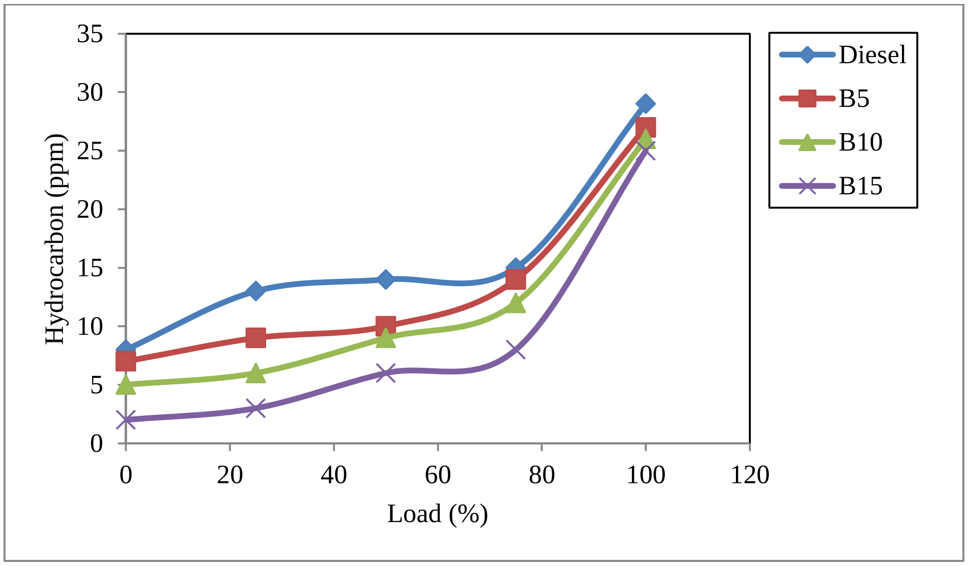

Figure 8 Hydrocarbon graph with load

4.3.3 Nitrogen oxide (NOx) emission

Figure 9 depicts the effect of load on nitrogen oxide emissions at constant speed for the CR of 17.5:1. Load increases NOx emissions increase for diesel and biodiesel blends. Nitrogen oxide emissions increased for B15 by 14.37% when compared with diesel. As the composition of biodiesel increases, NOx emissions rise at all loading percentages except at zero load due to the greater burnt fuel and higher cylinder temperature. With a high oxygen concentration in the biodiesel, increased flame and cylinder temperatures resulted in higher NOx emissions [50].

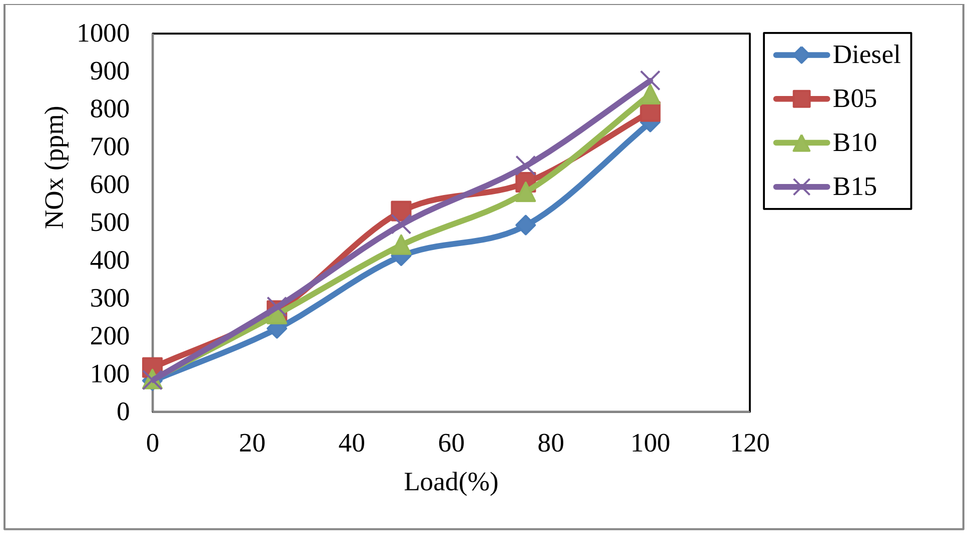

Figure 9 Effect of load on NOx emission

4.3.4 Smoke level

The smoke occurs in the rich fuel region during combustion. *Figure 10* depicts the variation of engine load on smoke level at constant speed and a CR of 17.5:1. The maximum and minimum smoke emission levels are between 51.6 and 24.4 for diesel and B15 respectively, at peak load. Blend B15 gives the lowest smoke emissions of the studied fuels. Smoke emission for B15 is decreased by 52.71% when compared with diesel. The smoke level increases for diesel, B05, B10, and B15 as the load rises. Smoke emissions decrease as the percentage of biodiesel rises. Burning does not take place at an acceptable rate due to improper fuel air mixing, resulting in the emission of smoke or soot [51].

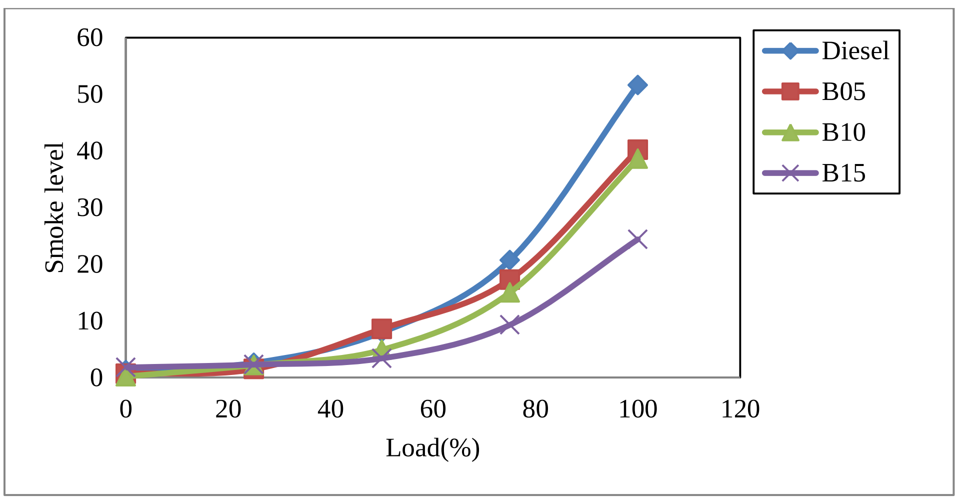

Figure 10 Effect of load on smoke level

5. Discussion

5.1 Comparative analysis

BP

BP is the amount of power obtainable at the crankshaft. The BP changes depending on the load. At peak load and a CR of 17.5:1, the BP of B05, B10 and diesel is 3.41 kW, 3.42 kW and 3.37kW, increased power due to complete combustion. In view of the fact that the density of the biodiesel blend is greater than that of diesel fuel, it is poured volumetrically into the diesel engine cylinder. If the engine obtains more mass flow at the same volume, power will increase.

BTE

The relationship between output power and input energy as fuel is given by BTE. The B15 blend had a greater BTE than diesel at 100% load because of better atomization and vaporization. The improved BTE could be attributed to more complete combustion. For test fuels, BTE improved as the load rises. The BTE of B05, B10 and diesel is 24.09%, 24.27%, and 23.77%.

BSFC

An engine generates power during the combustion of fuel. The ratio between the rate of fuel flow and power generated is known as BSFC. The BSFC of blends falls as load increases because of enhanced combustion owing to biodiesel has higher oxygen content.

Maximum CP

The maximum CP for diesel, B05, B10, and B15, occurs at 60.5 bar, 61.5 bar, 62.7 bar, and 63.82 bar at 372^0 crank angle with a CR of 17.5:1. The maximum cylinder pressure occurs at 372^0 crank angle for blend B15 as 63.82 bars which is 5.48 % higher than diesel because of better mixing of air fuel ratio and smooth vaporization.

Carbon monoxide (CO)

CO emissions for blends B05, B10, B15 and diesel at maximum load are 0.058, 0.055, 0.05, and 0.061%, respectively. CO falls as the percentage of biodiesel rises on account of elevated temperature of combustion chamber results in complete combustion of fuel.

Hydrocarbon (HC)

HC emissions from diesel engine cause lean mixture combustion. The maximum HC emission levels are 29 ppm for diesel, 27 ppm for B05, 26 ppm for B10 and 25 ppm for B15, respectively, at full load. Blend B15 gives the lowest HC value of the studied fuels. HC emissions for B05, B10, and B15 were reduced by 6.89%, 10.34%, and 13.79%, respectively, when compared to diesel. The biodiesel engine emits fewer HC emissions because of higher cetane number of biodiesel.

Nitrogen oxide (NOx) emission

When the load on the engine grows, the engine speed lowers, resulting in more NOx emissions. When the load increases, nitrogen oxide emissions increase for diesel and biodiesel blends. Nitrogen oxide emissions increase for B05, B10 and B15 by 3.66%, 9.67% and 14.37%, respectively, when compared with diesel due to peak combustion temperatures.

Smoke level

The maximum smoke emission levels are 51.6, 40.2, 38.6 and 24.4 for diesel, B05, B10, and B15, respectively, at full load. Blend B15 gives the lowest smoke emissions of the studied fuels. Smoke emissions for B05, B10, and B15 were reduced by 22.09%, 25.19%, and 52.71%, respectively, when compared to diesel. It was discovered that as the blend concentration increases, the amount of smoke produced decreases.

5.2 Limitations

The direct use of vegetable oils is limited due to some undesirable qualities. Straight vegetable oil produces fuel atomization, inefficient combustion, and fouling due to its increased viscosity. The manufacturing cost of biofuels is twice that of fossil fuels. Biodiesel manufacturing requires more land, must be combined with fuel, and emits more nitrogen oxide. Cold start performance is poor. The higher the olefin percentage of biodiesel, the more deposits accumulate on the injectors in the combustion chamber.

A complete list of abbreviations is shown in *Appendix I.*

6. Conclusion and future scope

A diesel engine was tested using hibiscus coconut biodiesel blends. The engine characteristics of hibiscus coconut biodiesel are examined and compared with those of diesel fuel. The investigation yielded the following conclusions: The oil was esterified by KOH as a catalyst in transesterification. The engine BP has risen as the load and percentage of biodiesel have increased. The maximum value of BP obtained for the blend B15 was 3.43 kW, which is 1.78% more than diesel fuel at 100% load. The engine BTE improved as the percentage of biodiesel and load increased. The maximum value of BTE for the B15 blend was 24.36%, which is 2.48% more than diesel at maximum load. At lower loads, the BSFC is greater, but it decreases as load increases. The BSFC of diesel, B05, B10 and B15, is determined to be a constant value of 0.35 kg/kW-hr at full load. The peak CP of the engine for blend B15 at full load is 63.82 bars. CO emissions rise as the load rises, but as the composition of biodiesel grows, CO emissions fall, and for the B15 blend, CO emissions are reduced by 18.03%. The amount of HC emitted increases as the load grows, and as the percentage of biodiesel increases, HC emissions reduced by 13.7% for blend B15 compared to diesel at maximum load. Load increases Nitrogen oxide emissions increases for diesel and biodiesel blends. Nitrogen oxide emissions increased for B15 by 14.37% when compared with diesel. The smoke level rises as the load rises. As the quantity of biodiesel increases, the amount of smoke produced decreases by 52.71% for blend B15 compared with diesel. According to the results of the experiments, it is clear that hibiscus coconut methyl ester can be mixed with diesel up to 15% without requiring engine modifications and so could be considered as a good replacement fuel for diesel.

The findings indicate that the utilization of biodiesel has made an impact on the engine performance and emissions. However, more research into techniques to reduce NOx emissions when utilising biodiesel is needed. It can also be extended for different CR.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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.

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Appendix I

S. No.	Abbreviations	Description
1	B05	5% Biodiesel and 95% Diesel
2	B10	10% Biodiesel and 90% Diesel
3	B15	15% Biodiesel and 85% Diesel
4	BP	Brake Power
5	BTE	Brake Thermal Efficiency
6	BSFC	Brake Specific Fuel Consumption
7	CI	Compression Ignition
8	CO	Carbon Monoxide
9	CO_2	Carbon Dioxide
10	CP	Cylinder Pressure
11	CR	Compression Ratio
12	HC	Hydrocarbon
13	KOH	Potassium Hydroxide
14	NOx	Oxides of Nitrogen
15	NaOH	Sodium Hydroxide
16	VCR	Variable Compression Ratio