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Article

Impact of high blends of Madhuca Logifolia biodiesel on the performance, combustion and emission parameters in a CRDI diesel engine at variable compression ratio

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Abstract: The country today uses a variety of industrial and transportation facilities that are fueled by diesel fuel. However, because of its non-sustainable and polluting nature, there is an urgent need for a more environmentally acceptable substitute that can be utilized in existing engines with no or little modification. Madhucalongifolia (Mahua) was considered a main source for biodiesel production based on its availability and its nature to not impact the food chain. The raw oil was converted to biodiesel using the process of transesterification. The higher blends of B80 (80% mahua biodiesel, 20% diesel by vol.) and B90 (90% mahua biodiesel, 10% diesel by vol.) were prepared. The experiment was carried out using an eddy current dynamometer and involved a Kirloskar 4-stroke single-cylinder which was water-cooled, CRDI diesel engine. The base run was generated using 18:1 compression ratio diesel fuel. These outcomes were contrasted with identical engine conditions using blends of B80 and B90 biodiesel as fuel. The most favourable results in terms of the engine parameters ie. BTE, SFC, cylinder pressure, HC, NOx and CO were as stated here. There was an increase of 8.87% in BTE for the B90 blend. A minor increase of 2.77% in SFC was observed with the B90 blend. The cylinder pressure for B90 was decreased by 0.024%. The emissions for B80 and diesel were lesser in comparison to B90. Diesel showed the lowest CO (7.9%) emissions whereas HC and NOx for B80 decreased by 24.39% and 3.42% respectively. The engine was made to run at two lower compression ratios of 16 and 17. When using a fuel blend of B80 at a compression ratio of 16, the performance metrics were significantly better. It could be concluded that, the compatible results were found with B80 biodiesel blend with compression ratio of 16. The BTE, SFC, cylinder pressure, HC, NOx and CO were quantified as 25.61%, 0.34kg/kWh, 30.27 bar, 50ppm, 1204 ppm and 0.24% by volume respectively. In comparison to the base run (diesel fuel and compression ratio of 18), there was 15.98% increase in the BTE, 5.55% decrease in the SFC, 16.07% decrease in the cylinder pressure, 21.95% decrease in the emission of HC, 23.55% decrease in NOx and 9.09% increase in CO emissions.

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1. Introduction

After the US and China, India has one of the economies with the quickest rates of economic growth and is the third-largest end user of primary energy worldwide. 42% of the additional energy demand between 2017 and 2040 is met by coal, which means CO2 emissions will more than double by that year. Gas production is increasing but is not keeping up with demand, implying a significant increase in gas imports. The Indian government has placed a strong emphasis on enhancing its energy autonomy by, among other things, reducing import dependency. It has set a target of reducing the country's use of fossil fuels by 10% from present levels by the year 2024 and by 30–35% by the year 2030 [1]. The government's 2018 "National Policy on Biofuels" stated a benchmark target of 20% ethanol blend in gasoline by 2030. As a result of the government's numerous interventions since 2014, the goal of 20% ethanol blend was moved up to 2025–2026 in light of the encouraging performance [2].

Ensuring a steady and sustainable supply of feedstock for the manufacture of biofuels is one of the major issues. There is a need to create a balance between the demand for biofuels and other industries, such as food and agriculture, to prevent negative effects on food availability and deforestation. Proper technology and infrastructure are needed for the generation of biofuels. India must spend money on R&D to advance conversion technology and build effective processing facilities. It is crucial to building an exhaustive policy and legal structure that supports the production and use of biofuels [3]. India has advanced in this area by establishing goals and providing incentives, but more legislative changes are required to solve problems with pricing, taxation, blending requirements, and sustainability standards. When utilizing biodiesel in any certain engine, several fuel compatibility-related issues must be taken into account. It makes sense that the blend level utilized will have an impact on how biodiesel behaves in engines and after-treatment systems [4].

While high-level blends or straight B100 are frequently assumed to have the biggest impact, intermediate-level blends can sometimes be more prone to filter clogging and the precipitation of fuel insolubles. Prolonged use of low biodiesel mixes can potentially have some additive consequences. Castor seed oil [5] was utilized to create the biodiesel and after testing it in the diesel engine it's the outcomes were assessed, concluding B20 as the optimum fuel blend with 26.49 higher BTE. Use of Waste frying oil biodiesel-diesel blends [6] were experimentally and theoretically explored to find out the effects of employing 20% (B20), 50% (B50), and 100% (B100) on emission and performance parameters at full load of 1500–3000 rpm ranges in the diesel engine. The highest B20 reductions were 4.51% for CO2, 29.27% for CO, 39.06% for HC, 6.52% for NOx, and 25% for smoke opacity emissions.

Rapeseed oil biodiesel [7] and diesel-biodiesel blends were used in a four-stroke, single-cylinder, direct-injection diesel engine with a constant injection pressure to examine the performance, combustion, and emission characteristics. B25 was seen to obtain the best results. Using the commercial code AVL FIRE, numerical simulation is performed using a single-cylinder, naturally aspirated diesel engine [8]. It concluded that the change in the piston bowl geometry with a variation in the compression ratio can help to enhance the performance and emission parameters of the diesel engine. A three-dimensional computational fluid dynamics (3D-CFD) numerical simulation was conducted [9]. A lower blend of biodiesel was showing

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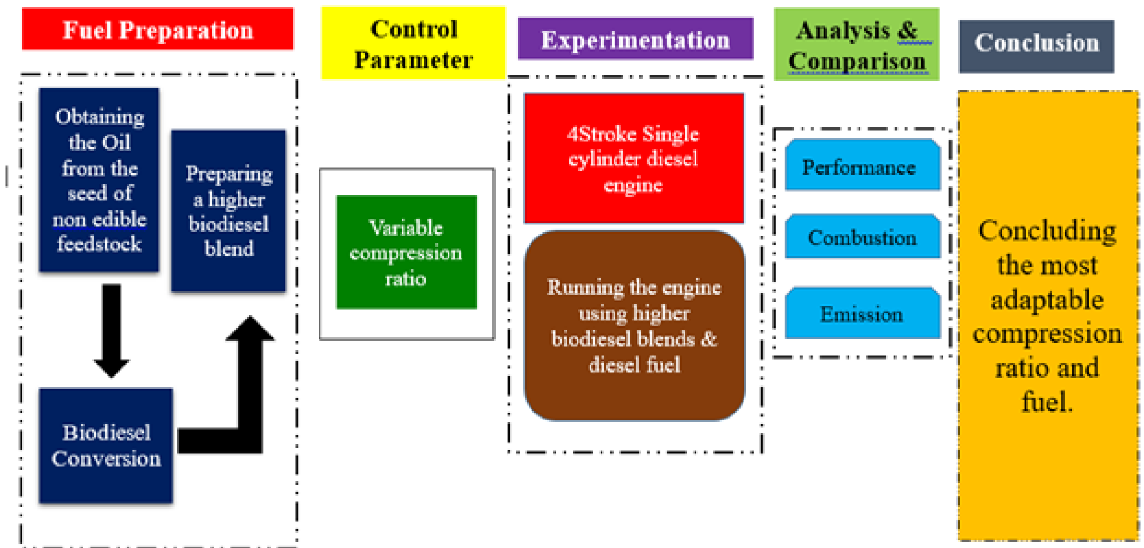

Figure 1. Methodology layout.

the most prominent results according to this research. The modification technique of different injection pressure and preheating of the fuel was incorporated in this research.

The literature shows a lot of work done on the biodiesel of the seeds procured from the edible sources creating food vs fuel debate. Also, the literature shows more of the analytical or numerical work done on the higher blend of biodiesel than the actual experimental work as it foresees deterioration of performance parameters of the engine. So carrying out an experimental work on a higher blend of a biodiesel obtained from a non-edible feedstock makes this a novel work. On the basis of the availability and research gap, change in the compression ratio severed best to acknowledge the use of biodiesel in the already built diesel engine.

2. Objective

The experimental work was divided into two parts one to identify the feedstock and to obtain the biodiesel out of it and second to conduct an experimental observation regarding the changes in the performance, combustion and emission parameters of the 4 stroke diesel engine.

The objectives of the work are listed below:

- To identify second generation feedstock (non-edible seed) that are acceptable for internal combustion engines and procure them locally.
- To obtain biodiesel from the chosen oils and assess its properties.
- To prepare a higher blend of biodiesel.
- To conduct an experimental test with standard piston geometry and compression ratio.
- To conduct the test with varied compression ratios.
- To examine the impact of a greater biodiesel blend by assessing the fuel's efficiency and emission properties.
- To obtain the most compatible biodiesel blend and compression ratio according to the performance analysis.

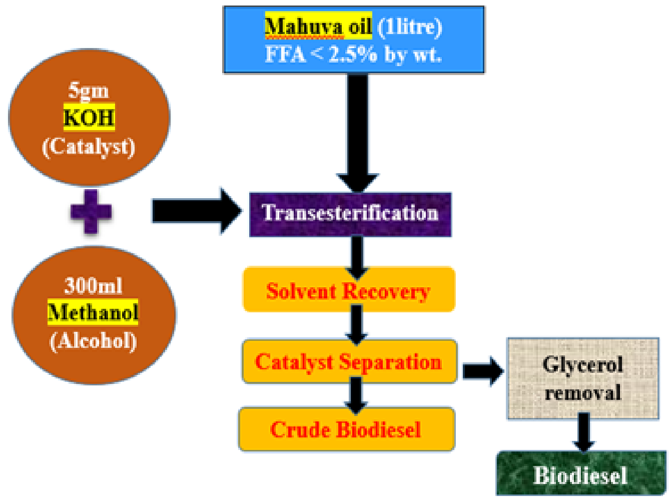

Figure 2. Schematic diagram of biodiesel production.

The methodology is described in the Figure 1. Working with different compression ratio on a CRDI diesel engine with a higher blend of biodiesel makes this experimental work a novel one. The primary goal of experimenting with multiple compression ratios was to improve operating characteristics from the setup because research indicates that using higher biodiesel mixes in diesel engines may have negative effects on emission and performance parameters. Also working with non-edible feedstock avoids the burning question of food vs fuel. These are the novel methodology of the experimental work.

3. Experimental work

The non-edible seed was procured from the tribal area of Chhota Udaipur district of Gujarat State. In the region where it was obtained, it is referred to as Dori/Doliya and is used for pharmacology purposes. As an alternative fuel, biodiesel produced from non-edible oils has a lot of potential. Transesterification was employed to turn the unprocessed seed oil into biodiesel. Figure 2 and Figure 3 explains the biodiesel production in the form of the flow chart. In the current research work to obtain the biodiesel, first, one litre of mahua seed oil is added to three necked glass flasks. This three-necked glass vessel has a magnetic starring facility and is heated. In order to measure temperature, a thermocouple is also inserted. Oil is heated to 1000°C for 10 min in order to dehydrate and filter out contaminants. It is also given time to cool to room temperature. Then for, 1 litre of raw mahua oil, 5gm catalyst is used along with 300ml of alcohol. The catalyst used in this work is potassium hydroxide (KOH) and the alcohol used is methanol. To make biodiesel, this solution of catalyst and alcohol is added to the oil and the complete solution container is heated on a mantle and constantly agitated with the help of the stirrer at 500 rpm for one hour at 60 °C. After the process the solution is transferred into the separating funnel from which the glycerol is removed and the biodiesel is separated.

The mahua biodiesel produced from raw mahua seed oil was mixed with diesel fuel in order to prepare two blends. The two blends used in the research were B80 and B90. They were prepared by adding 80% (by vol.) of biodiesel to 20% (by vol.) of diesel fuel for B80 and 90% (by vol.) of biodiesel to 10% (by vol.) of diesel fuel for B90. The mahua biodiesel produced from raw mahua seed oil was mixed with diesel fuel in order to prepare two blends. The two blends used in the research were B80 and B90. They were prepared by adding 80% (by vol.) of biodiesel to 20% (by vol.) of diesel fuel for B80 and 90% (by vol.) of biodiesel to 10% (by vol.) of diesel fuel for B90.

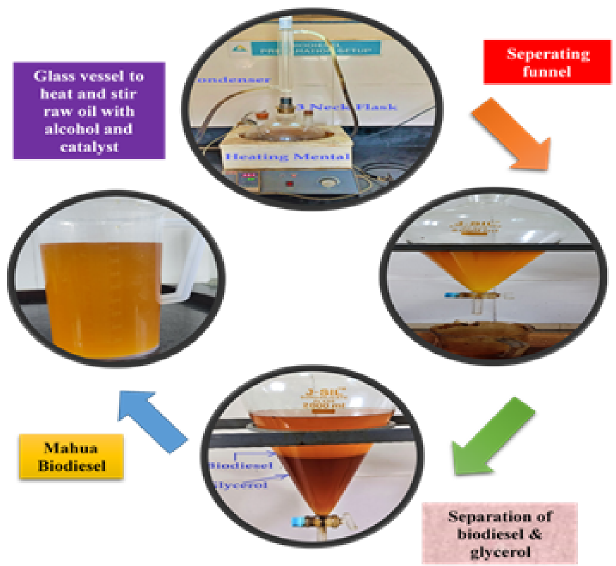

Figure 3. Preparation of biodiesel.

The following table lists the characteristics of the fuels utilized in the experiment. The different properties tested were flash point, density, fire point, calorific value, dynamic and kinematic viscosity. All the tests were based on the ASTM standards.

Table 1. Properties of the fuel.

Properties	Acid Value	Free Fatty Acid	Density At 250C	LCV Calorific Value	HCV Calorific Value	Flash Point	Fire Point	Kinematic Viscosity @400C	Dynamic Viscoisty @400C
Units	$\frac{\text{mg of KOH}}{\text{gm of oil}}$	%	$\frac{kg}{m^3}$	$\frac{\text{Calorie}}{gm-°C}$	$\frac{\text{Calorie}}{gm-°C}$	°C	°C	cSt	cP
ASTM Standard	D6751	–	D287	D4809	D4809	D9358T	D9358T	D445	D445
Sample					Properties				
StDI	0.6	0.3	816	10236	10822	53	56	2.09	1.73
Raw oil	2.20	1.10	910	8967	9553	256	270	39.6	36.0
B80	0.93	0.47	859	9399	9986	92	98	4.25	3.65
B90	1.10	0.55	861	9296	9882	96	99	4.54	3.91
B100	1.31	0.56	871	9470	10056	101	110	4.98	4.34

An eddy current dynamometer was linked to a single-cylinder, direct-injection diesel engine with a 3.5 kW rated output for the trials in the current experiment. There was a variable compression ratio system on the engine [10]. A crucial element determining a diesel engine's efficiency is the compression ratio. The engine can optimize the air-fuel mixture for combustion and increase thermal efficiency by modifying the compression ratio based on the operating conditions. Diesel was used as the base fuel with 18 compression ratios, and the initial testing was done at a constant speed of 1500 rpm with loads starting at zero load to a full load of 12 kg. Mahua biodiesel with greater blends of B80 and B90 was used in the experiments to investigate the direct injection diesel engine's performance, emission, and combustion characteristics based on baseline measurements [11]. The experimental setup's schematic diagram is displayed in Figure 4. The actual photographic view of the setup is as shown in Figure 5.

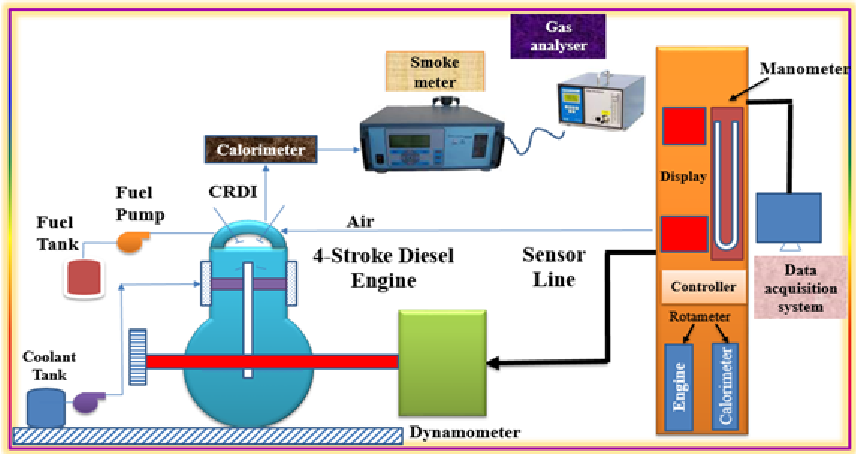

Figure 4. Schematic figure of the experimental set up of 4 stroke CRDI diesel engine with variable compression ratio.

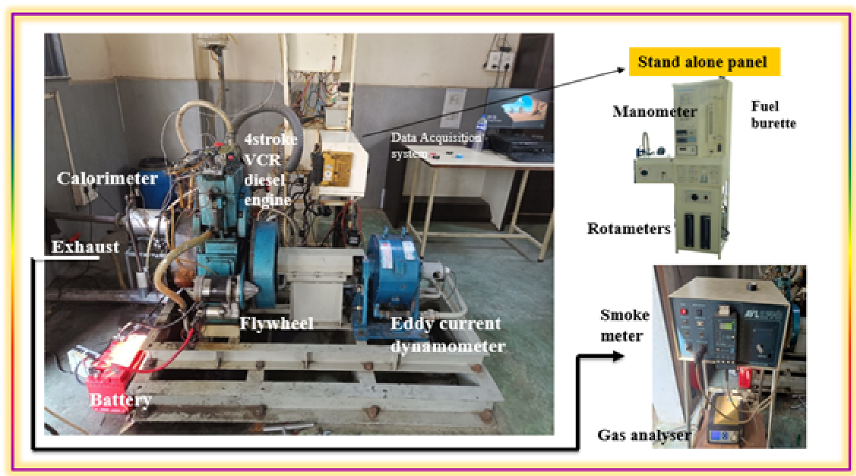

Figure 5. Photographic view of experimental set of 4 stroke CRDI diesel engine with variable compression ratio.

4. Results and discussion

The combination B80 and B90 having compression ratios of 16 and 17 are compared to that of the blend with compression ratio of 18, which is regarded as the baseline reading, in terms of performance, combustion, and emission parameters. The performance parameters measured are BTE and SFC. The combustion parameters compared is cylinder pressure. The emission parameters of HC, NOx and CO are compared. The emission characteristics were measured with accurately calibrated equipment. The calibration sheet containing the information about the equipment's and its precision level are tabulated below.

Figure 6 shows how the brake thermal efficiency varies in relation to braking power at three distinct compression ratios (16, 17, and 18), using diesel, B80, and B90 blends of mahua biodiesel as the fuels. The graphic shows that, under full load, the BTE drops as the compression ratio increases. The same trend was observed for all the three compression ratios under study. A greater compression ratio enables the engine to extract more usable work from each unit of fuel used, improving efficiency. As the compression ratio increases, so does the temperature of the pressurised fuel-air mixture inside the combustion chamber. This

Table 2. Calibration sheet.

Sr. No.	Name	Make/Model	Range	Calibration measurement capability
1.	Analog temperature transmitter	Type K, WIKA	0-1200 °C	±0.5%
2.	Load sensor	Sensotronics Sanmar Ltd., Model 60001	0-50 kg	±0.25%
3.	Pressure sensor	PCB Piezotronics	0-350 bar	±1%
4.	Gas analyser	AVL DIGAS 444N	CO - 0-10% CO_2 - 0-20% NO - 0-5000 ppm vol. HC - 0-20000 ppm vol.	±0.003% ±0.5% ±0.1 ±0.5%

increased temperature might induce pre-ignition, which can damage the engine and limit efficiency [12]. Furthermore, with an increase in the compression ratio, the engine may face increased heat losses to the combustion chamber walls, reducing the amount of heat available to accomplish productive work. As a result, the engine's thermal efficiency could be decreased [13]. At higher compression ratios, achieving an optimal air-fuel mixture becomes more challenging with biodiesel due to its higher viscosity and different spray characteristics. Poor mixing can lead to incomplete combustion and lower BTE. Also at high compression ratios, due to high cylinder pressure there could have been increase in the mechanical friction between the moving parts. This could affect the work output and reduce the BTE. At full load, B80 with compression ratio 16 shows the highest thermal efficiency which is 25.61%. It is almost 15.98% higher than the base fuel of diesel and condition of 18 compression ratio. Using a compression ratio of 18, B80 gasoline exhibits the lowest BTE. There is a 4.52% drop from the baseline state. Diesel fuel with an 18 compression ratio has a BTE of 22.08%. At full load, the BTE for diesel, B80, and B90 with compression ratios of 16, 17, and 18 were 25.09, 24.13, 22.08, 25.61, 23.61, 21.08, 24.19, 22.01, and 24.04 respectively.

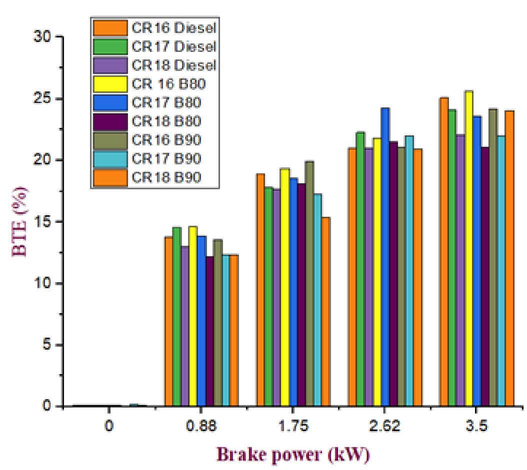

Figure 6. Variation of BTE with respect to brake power comparing the compression ratios (16,17,18) and fuels (diesel,B80,B90)

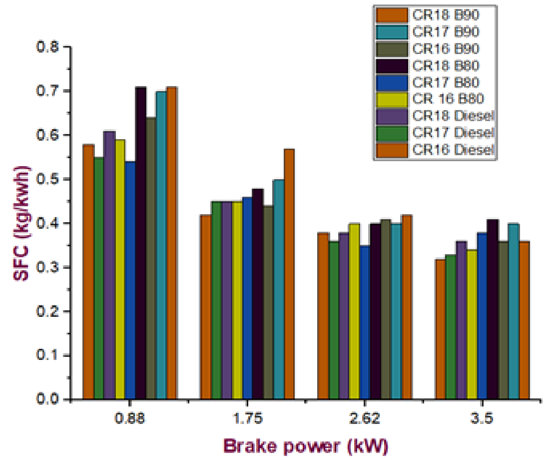

Figure 7. Variation of SFC with respect to brake power comparing the compression ratios (16,17,18) and fuels (diesel,B80,B90).

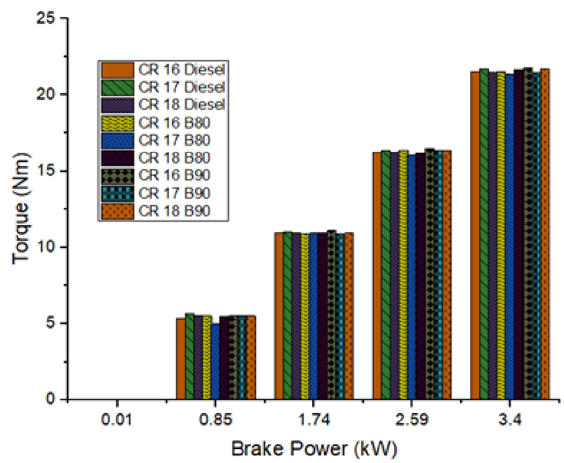

Figure 8. Variation of Torque with respect to brake power comparing the compression ratios (16,17,18) and fuels (diesel,B80,B90).

With diesel and biodiesel mixes, Figure 7 illustrates the fluctuation of specific fuel consumption relative to brake power for compression ratios of 16, 17, and 18. When operating at maximum capacity, B80, which has a compression ratio of 18, exhibits the greatest specific fuel consumption (SFC) of 0.41 kg/kWh, a 13.88% increase over base fuel and condition diesel, which has a ratio of 18. The lease SFC at full load was observed with diesel fuel and 16 compression ratio which was 0.32kg/kWh. It was 11.11% lower than the base fuel. Additionally, it was seen that the SFC was generally rising as the compression ratio increased under full load conditions. One reason that SFC increases with compression ratio is that higher compression ratios result in elevated combustion pressures and temperatures, which can cause the fuel to burn inefficiently [10]. This is because, at greater temperatures and pressures, the fuel is more inclined to interact with oxygen in the air before it gets a chance to properly mix with the air, resulting in incomplete combustion and increased fuel consumption [14]. The SFC at full load for diesel, B80, and B90 for the compression ratio of 16, 17, and 18 were found to be 0.32, 0.33, 0.36, 0.34, 0.38, 0.41, 0.36, 0.4, 0.36kg/kWh respectively.

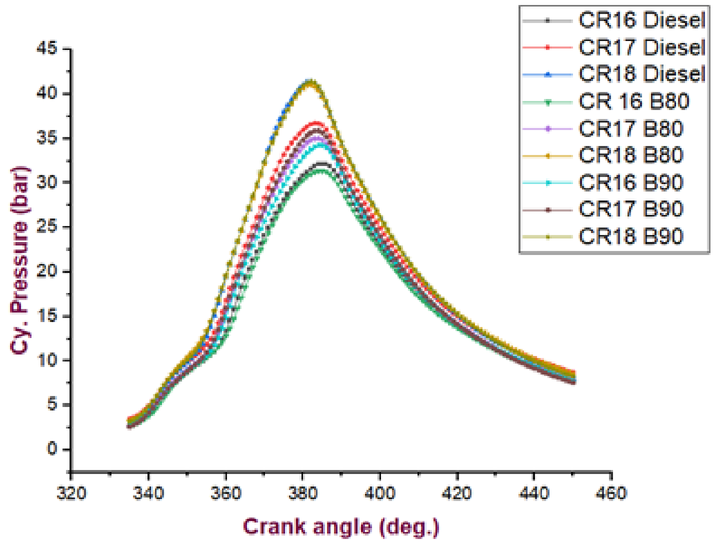

Figure 9. Variation of Cylinder pressure with respect to crank angle comparing the compression ratios (16,17,18) and fuels (diesel, B80,B90).

Figure 8 illustrates how torque varies in relation to braking power. It is evident that when brake power increases, torque also increases. The engine usually runs more efficiently at higher loads and speeds (which translate into more brake power), burning gasoline more thoroughly and exerting more force on the pistons. Increased torque is the immediate result of this increased force. Additionally, extra gasoline is pumped into the combustion chamber to increase brake power. Higher fuel leads to higher combustion energy, which raises cylinder pressure and exerts more force on the pistons. The engine produces more torque as a result of the increased force on the pistons. At the maximum brake power, the fuels essentially exhibit the same characteristics. The highest torque is displayed by the B90 with a compression ratio of 16, albeit slightly. This may be explained by biodiesel's advantageous combustion properties, which include its greater cetane number, oxygen concentration, and smoother burning. Lower compression ratios can also improve thermal efficiency and lessen the chance of knock, enabling more ideal combustion phasing and increased torque production while using biodiesel. The torque for the B90 fuel with compression ratio 16 is 21.82 Nm. For the highest brake power the torque so obtained for the fuels diesel B80 and B90 with compression ratio 16,17 and 18 are 21.56, 21.71, 21.55, 21.57, 21.42, 21.69, 21.82, 21.52 and 21.74 respectively.

Figure 9 illustrates how the cylinder pressure, or combustion parameter, varies in relation to crank angle. For diesel fuel, the base fuel and condition at compression ratio 18 yields the highest peak cylinder pressure. It was 41.44 bar at 3820 crank angle. For the B80 biodiesel blends, the final peak in-cylinder pressure was recorded at a compression ratio of 16. It was 24.25% lower than the base fuel and was operating at 31.39 bar. The figure shows that at a higher compression ratio, higher peak cylinder pressures were obtained. Prior to ignition, the temperature and pressure inside the cylinder rise when the air-fuel mixture is compressed to a smaller volume due to higher compression ratios. This is because whenever the volume of a gas reduces, its molecules have to settle into a smaller area, which raises the frequency and energy of their collisions, increasing both pressure and temperature [15]. The peak cylinder pressure for diesel, B80, and B90 with the compression ratio of 16,17 and 18 were 32.16, 36.75, 41.44, 31.39, 35.01, 40.84, 34.26, 35.9, 41.43 bar respectively.

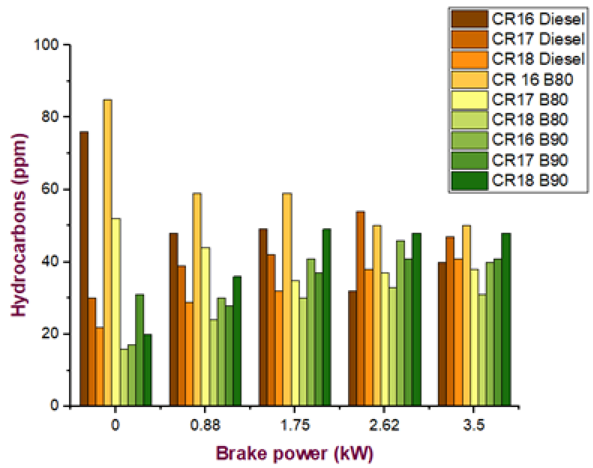

Figure 10. Variation of Hydrocarbon with respect to brake power comparing the compression ratios (16,17,18) and fuels (diesel, B80,B90).

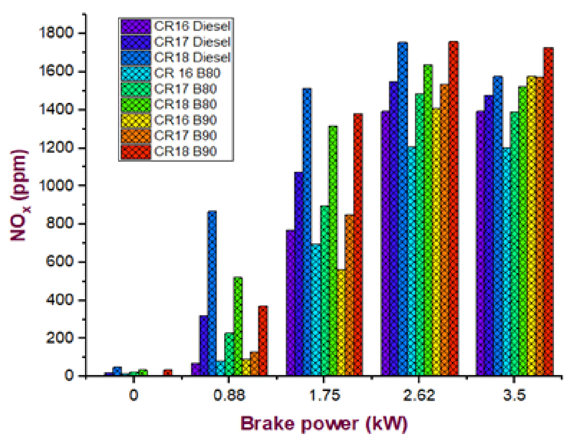

Figure 11. Variation of NOx with respect to brake power comparing the compression ratios (16,17,18) and fuels (diesel,B80,B90).

The emission parameter's change is depicted in Figure 10. Here, the figure shows how the amount of hydrocarbon in the exhaust varies with brake power for various fuels and compression ratios According to the data, the B80 biodiesel mix, which has a compression ratio of 16, has the highest HC emissions. At full load, it was discovered to be 50 ppm, or over 21.95% more than the base fuel. The B80 biodiesel mix, with a compression ratio of 18, has the lowest HC emissions. It was 31ppm which was 24.39% lower than the base fuel and the condition at full load. No substantial trend was observed but still for biodiesel, increasing the compression ratio was decreasing the HC. A higher compression ratio improves fuel atomization and air-fuel blending by compressing the air to greater pressure and temperature [16]. With compression ratios of 16, 17, and 18 at full load, the HC for diesel, B80, and B90 are 40, 47, 41, 50, 38, 31, 40, 41, and 48 ppm, respectively.

Figure 11 illustrates the variations in NOx levels in relation to brake power. The chart shows that with 2.62kW brake power and a compression ratio of 18, the B90 biodiesel blend yields the greatest NOx. The B80 biodiesel mixture has the lowest NOx at full load when the compression ratio is 16. It was 1204 ppm.

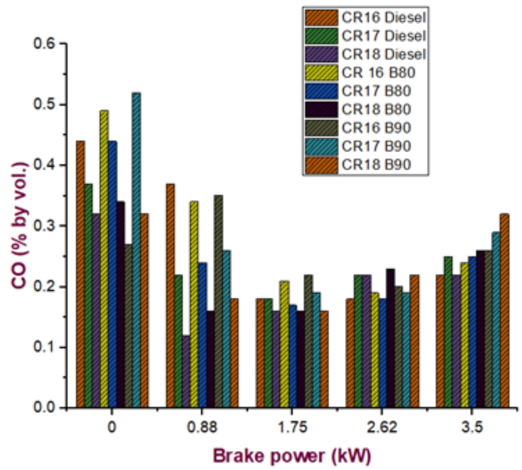

Figure 12. Variation of CO w.r.t. brake power comparing the compression ratios (16,17,18) and fuels (diesel, B80,B90).

It was 23.55% lower than the base fuel. The maximum NOx was noted for the B90 biodiesel blend with a compression ratio of 18. It was 1728 ppm which was 9.71% higher than the base fuel. It was noted that the NOx rose as the compression ratio increased. NOx is produced when oxygen and nitrogen in the air combine at high temperatures, like those seen in a diesel engine's combustion chamber [17]. The more thermal NOx produced the greater the combustion temperature. Prior to combustion, the mixture of air and fuel is tightly compressed, raising the mixture's temperature as a result of an increased compression ratio. As a result, this may increase the production of thermal NOx [18]. Higher compression ratios can also induce longer ignition delays, causing the fuel to partially burn before the piston hits the top of during its compression stroke.At full load, the NOx for diesel, B80, and B90 with compression ratios 16, 17, and 18 are 1392, 1477, 1575, 1204, 1390, 1521, 1575, 1571 and 1728 ppm respectively.

Figure 12 illustrates the fluctuation in CO emissions from the exhaust of an engine running on base diesel and higher ratios of B80 and B90 biodiesel with varying compression ratios. For the B90 fuel mix with an 18 compression ratio, the permissible amount of CO is specified. It was almost 45.45% higher than the base fuel at full load. Diesel fuel exhibits the lowest CO with a compression ratio of 16, while a comparable result is observed for the basic fuel of diesel at a ratio of 18. When the diesel engine is operating at maximum load, CO emissions are observed to rise as the compression ratio rises. Additionally, when braking power increases, CO emissions drop. As a diesel engine's compression ratio increases, the air-fuel mixture's increased compression causes the combustion chamber's inside temperature to rise [19]. This greater temperature improves combustion efficiency, which results in improved brake power output. However, with the higher the temperature and pressure CO is produced in the exhaust gases [20]. At higher braking power, the duration of the fuel injection is increased to deliver greater fuel to the engine. Because of the longer injection time, there is more fuel in the combustion chamber, which leads to incomplete combustion and higher CO concentrations in the exhaust gases. Also at a given compression ratio diesel shows lower CO emissions compared to biodiesel, especially at full loading conditions [15]. This can be due to the different atomization characteristics of the biodiesel resulting in poorer fuel-air mixing, leading to localized rich combustion zones where there is insufficient oxygen to fully oxidize carbon to carbon dioxide (CO2), resulting in higher CO emissions. Atfull load, the NOx for diesel, B80, and B90 with compression ratios 16, 17, and 18 in % by volume are 0.22, 0.25, 0.22, 0.24, 0.25, 0.26, 0.26, 0.29, and 0.32 respectively.

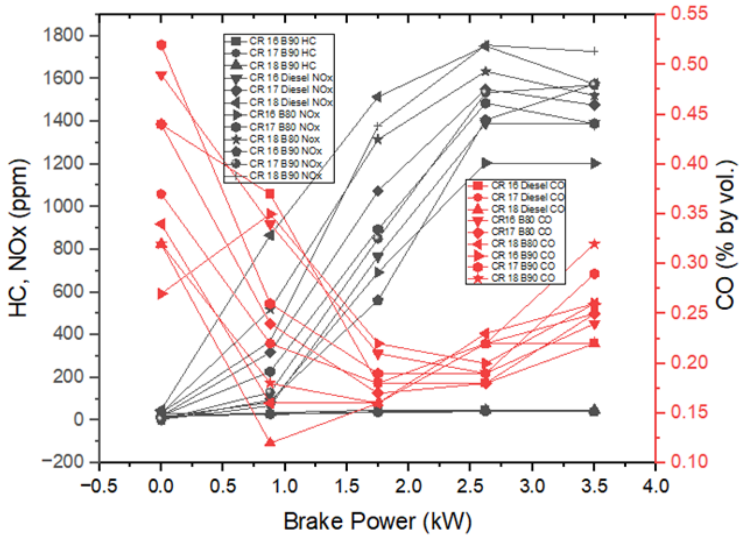

Figure 13. Variation of HC, NOx and CO w.r.t. brake power comparing the compression ratios (16,17,18) and fuels (diesel, B80,B90).

The fluctuation of all the emission parameters, such as CO, NOx, and HC, with respect to braking power is shown in Figure 13. It is evident that for the same brake power, the NOx is significantly larger than the HC. This might be the case because emissions are greatly influenced by the air-fuel ratio. Because lean mixtures (extra air) burn at a higher temperature, their NOx emissions are often higher. On the other hand, incomplete combustion in richer mixtures (more fuel) can result in increased HC emissions; however, modern engines are usually designed to operate leaner in order to enhance fuel efficiency and reduce CO2 emissions, which favors NOx generation over HC. Higher brake power causes CO2 to drop whereas HC and NOx were shown to increase. Higher combustion temperatures, leaner mixes at high braking power, incomplete combustion under high load and transient situations, and these factors all contribute to a rise in HC and NOx. Higher temperatures and improved air-fuel mixing typically result in more complete oxidation of carbon to CO2 rather than CO, which could explain why CO may be declining. CO emissions hence typically decline. This intricate interaction of variables under various operating circumstances emphasizes the difficulties in controlling emissions in internal combustion engines and the requirement for sophisticated control techniques to maximize efficiency and reduce negative environmental effects.

5. Conclusions

The BTE of B80 with compression ratio 16 was found to be the highest which was 15.98% higher than the base reading. The base reading taken here is that of compression ratio 18 (maximum offered by the experimental set up) and standard diesel fuel. Similarly the least BTE was observed for B80 with a higher compression ratio of 18 which was 4.52% lower than the base reading. With a compression ratio of 18 (13.88%) for B80 and 16 (11.11%) for diesel fuel, the SFC was higher for the former and lower for the latter. Therefore, it was determined that, in comparison to the base condition, the compression ratio of 16 displays a better performance parameter. B80 as well as diesel fuel provides better performance characteristics. The cylinder pressure for the base reading which was diesel as a fuel and compression ratio of 18 was found to be the highest. The least cylinder pressure was obtained for B80 with compression ratio of 16 which was 24.25% lower than the base reading. The compression ratio of 18 provides better combustion characteristics with diesel as a fuel.

Table 3. Conclusion table.

Parameters	CR 16, B80	CR 18, diesel (base reading)	Difference
BTE (%)	25.61	22.08	15.98% ↑
SFC (kg/kWh)	0.34	0.36	5.55% ↓
Cylinder Pressure (bar)	30.27	36.07	16.07% ↓
HC (ppm)	50	41	21.95% ↓
NOx (ppm)	1204	1575	23.55% ↓
CO (% by volume)	0.24	0.22	9.09% ↑

For emissions, HC was highest for B80 with the compression ratio of 16 which was 21.95% higher than the base reading. Least HC was for B80 with a higher compression ratio of 18 (24.39%). Least NOx was for compression ratio of 16 and B80 fuel. It was decreased by 23.55% from the base reading. Highest NOx was observed for B90 with compression ratio of 18 (9.71%). The B90 fuel and compression ratio of 18 (45.45%) showed the highest CO emission, while the base fuel of diesel and the lower compression ratio of 16 showed the lowest CO emission. Therefore, it can be said that the fuel type of B80 and compression ratio of 16 exhibit the lowest emissions. Experimental testing was done on the diesel engine's performance while it was operated on diesel and two higher blends of mahua biodiesel at the engine's maximum compression ratio. In comparison to regular diesel fuel, biodiesel has demonstrated significant environmental advantages. By lowering greenhouse gas emissions, it aids in the prevention of climate change. Also, biodiesel contains fewer pollutants such as sulphur, particulate matter, and hazardous compounds, resulting in better air quality and fewer health concerns [21]. The engine ran more efficiently and produced lower emissions when the compression ratio was lowered to 16. This was because the shorter combustion phase resulted in less heat loss and better air-fuel mixing. The reduction in NOx was also facilitated by the decreased peak temperature [22]. The BTE was increased by 15.98% when the engine was running at the compression ratio of 16 fuelled with B80 biodiesel. The SFC was decreased with diesel as a fuel and compression ratio of 16 by 11.11%. A greater compression ratio resulted in enhanced combustion characteristics. The best combustion parameters were obtained with cylinder pressure of 41.44 bar and a compression ratio of 18 when diesel fuel was used. The emissions were less for the compression ratio of 16. NOx (1204 ppm) was less for B80 with a compression ratio of 16.

The BTE of B80 with the compression ratio of 16 has found to be the highest. The SFC for the same rightly decreases as the engine converts more of the fuels energy into useful work because its BTE is higher and so the amount of fuel required to produce a specific amount of power eventually decreases. The higher oxygen content of the biodiesel blend B80 leads to better combustion efficiency, meaning, the energy extracted from the fuel is higher which should result in higher combustion pressure given that it has higher BTE, but the reduction in the compression ratio, reduced the cylinder pressure because the air-fuel mixture is not compressed as much which leads to lower pre-ignition pressures and temperatures. Due to more complete combustion facilitated by biodiesel's oxygen content and higher cetane number the emissions were mostly found to be lower [23].

Therefore, based on the results of the entire experiment, which took into account every parameter, it can be said that using B80 as fuel and a compression ratio of 16 will provide the best results in terms of performance, combustion, and emission parameters. The results show that by lowering the compression ratio and using a biodiesel blend, the engine characteristics improve. The compression ratio of 16 with B80 produced the best results. Reducing the compression ratio to 16, gave the fuel and air more time to blend fully before combustion. This enhanced mixing improved the air-fuel ratio, resulting in a more thorough and effective combustion process and lower emissions.

6. Practical implications of experimental work

The results of the experiments unequivocally demonstrate that using a B80 blend will assist reduce carbon footprint because it emits less NOx and HC. Maduca longiflia is a wonderful option if the final application is more likely to be used in agriculture because it degrades more quickly and lowers the possibility of spills causing long-term environmental harm. It will improve national energy security by lowering reliance on imported or soon-to-run-out fossil fuels. Its manufacturing boosts regional agriculture and generates employment in the farming, processing, and distribution industries. Because of its superior lubricating qualities, it can prolong engine life by lessening engine component wear and strain.

7. Future scope

Due to the inbuilt properties of the biodiesel, there are certain limitations for optimization of the results. But certainly even better performance and emission parameters can be obtained if any of the following is incorporated into the experimental work as per the literature survey.

- Exhaust gas recirculation (EGR) in which part of the exhaust gas is reintroduced in the intake manifold in order to lower down the emissions due to oxygen dilution can be performed.
- The engine's combustion characteristics can be improved even at lower compression ratios by preheating the air to achieve complete combustion through more profound mixing of the air and fuel.
- Preheating the biodiesel fuel in order to reduce its viscosity might allow better atomization when fed into the engine's combustion chamber. It results in greater fuel-air mixing, which promotes more thorough combustion and increases engine efficiency.
- Cetane improvers and nano additives can be used as these additives can improve fuel atomization, vaporization, and mixing with air, leading to higher combustion efficiency.
- Increasing the injection pressure of the biodiesel can lead to improved combustion characteristics as it results in finer atomization of the fuel giving rise to better air fuel mixing and complete combustion.
- Variable injection time can also lead to improved combustion efficiency because the engine's air-fuel mixture can be optimized. This also has the potential to reduce emissions.
- Modifying the piston bowl geometry from the conventional one, in order to increase the kinetic turbulent energy with a view to enhancing the combustion efficiency, increase the power output, reduce emissions and augment thermal management.

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