Original Research Article

ASSESSMENT OF CI ENGINE PERFORMANCE UTILIZING PALM OIL BIODIESEL BLEND

Abstract

~~This study~~ explores vegetable oils as potential future fuels for internal combustion engines, particularly compression ignition engines designed for diesel. However, these oils have distinct properties from diesel, requiring modifications for direct use. Integration approaches include adjusting oil properties or adapting engines. Commonly, transesterification aligns oil properties, but using biodiesel often affects engine performance. In this study palm oil biodiesel as a diesel substitute, evaluating engine performance and emissions. In a short-term test, engine performance and emission traits by employing biodiesel blends of 0, 20, and 50 % with diesel at full load. Findings indicated that B20 and B50 exhibited 2.40% and 3.88% lower brake power than pure diesel. Volumetric efficiency percentages were 82.44 for B20, 81.64 for B50, and 82.93 for diesel. Notably, B20 and B50 showed 9.35% and 10.70 % decreased brake thermal efficiency compared to diesel. Interestingly, B20 and B50 displayed 1.09 and 2.44 % higher mechanical efficiency than diesel. Exhaust gas temperature was notably elevated in B20 and B50 blends. Nitric oxide concentrations were 98.74 ppm for diesel, 105.48 ppm for B20, and 111.78 ppm for B50. Carbon dioxide levels decreased by 4.14% for B20 and 7.86% for B50 relative to diesel. Carbon monoxide concentrations were 0.082% for B20 and 0.080% for B50, in contrast to diesel's 0.10%.

Comment [m1]: Start with some introduction line

Keywords: *Palm Oil, Bio diesel, Performance, Emission, Transesterification, CI engine.*

Introduction

The increased industrialization and motorization of the world in recent years has resulted in great demand for petroleum products. Petroleum is the largest single source of energy, which has been consuming by the world's population, exceeding the other energy resources such as natural gas, coal, nuclear and renewable. About 90% of energy consumption of the world is from petroleum fuels. Petroleum based fuels are obtained from limited reserves and estimated to last only for new decades (Velmurugan and Gowthamn, 2012, Gojiya et al., 2022). However, because of their non-renewable nature, these fossil fuels are projected to be exhausted in the near future. The main consumers of energy are the electricity generation and transportation sectors. The diesel engine forms a vital part of both of these sectors throughout the world.

Increasing fossil oil prices, limited reserves of fossil fuels and environmental concerns have boosted the research on alternative fuel sources such as biodiesels. Moreover, the combustion of these fuels has polluted the environment. Because of increasingly reduction of fossil-based sources and their negative effects on the environment, the importance of alternative energy sources has become more apparent (Gojiya et al., 2023). Biodiesel was found as the best alternate fuel, technically and environmentally acceptable and easily available. Bio-diesel is methyl or ethyl ester of fatty acid from fresh or used vegetable oil and

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animal fats. For certain reasons, which include its properties, palm oil bio-diesel ester is often used, as a synonym for bio-diesel in India, as has been the case with rapeseed oil methyl ester (RME) in Europe (Pathak, 2004). The usage of straight vegetable oil as fuel causes the coking of injector nozzles, piston ring sticking, crankcase oil dilution, lubricating oil contamination, and other problems.

The use of clean and renewable fuels may be the key to overcome emission regulations without significant changes in engine efficiency and fuel economy. Pure biodiesel fuel (ester-based oxygenated fuel) and blends of biodiesel/diesel fuel have been used in compression ignition (CI) diesel engines without any engine modification. Biodiesel fuel is produced from renewable resources like vegetable oil or animal fat; it is biodegradable and has beneficial effects on engine exhaust emissions as compared to diesel fuel. It was also reported that besides being a renewable and domestic resource, biodiesel blends reduce most emissions while engine performance and fuel economy are nearly identical when compared to conventional fuels. Regarding exhaust emission, the use of biodiesel results in lower emissions of unburnt hydrocarbons; carbon monoxide, smoke and particulate matter with some increase in emissions of NOx (Gaadhe and Mehta, 2019).

Materials and methods

The performance of a compression ignition engine was studied using biodiesel blends. The experiment was conducted in the College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh.

Experimental Set Up and Performance Measurement

The set up would comprise of one engine testing rig with power measurement device, exhaust gas temperature sensors fitted at different places and one digital exhaust gas analyser. The engine was installed on the platform. In the foundation, holes were drilled with hand drill so that engine can be fixed with nails/studs. Initially wooden block is to be placed between engine and platform to absorb the socks and vibration. The proper alignment of the engine would be made and nails/studs are to be fixed properly around the engine to minimize vibration. The engine was connected to overhead water supply tank for cooling of the engine.

The setup consisted of single cylinder, four stroke engine connected to water-cooled eddy current type dynamometer for loading. It provided necessary instrument for combustion pressure, crank-angle, airflow, fuel flow, water flow, temperatures and load measurement. These signals are interfaced to computer through high-speed data acquisition device. Data acquisition can be described as the process of sampling signals that measure real world physical conditions, like data signals sent from the sensors of an experimental setup; and then converting the resulting samples into digital numeric values that can be manipulated by an attached computing source based on the relations fed into it or as pre-programmed by the manufacturer. Data acquisition systems (DAS) typically convert analogy waveforms into digital values for processing. DAS products centrally connect all the components together, such as sensors that indicate temperature, flow, performance, combustion parameters etc. The average data of the pressure and crank angle values, occurrence of the peak pressure, maximum rate of pressure rise and heat release rate were recorded by the DAS and stored in

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the computer as HTML files. This data acquisition software is developed by Technical Teaching (D) Equipment's Pvt. Ltd.

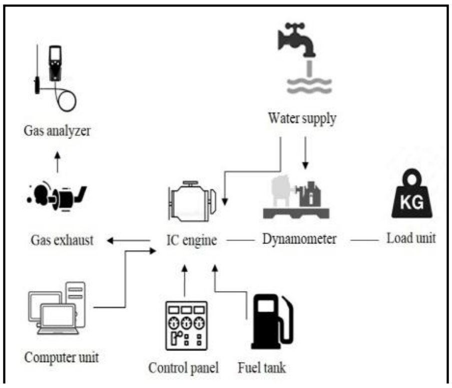

Fig 1: Experimental set up

Fig 2: Pure bio diesel and petroleum diesel fuel

The engine performance and emission test were conducted using diesel fuel for comparison with blends of methyl and ethyl esters of Jatropha oil. The diesel fuel was allowed to come down to the burette through a valve attached to the tank. The engine was hand cranked and started with a care having that a fixed amount of water was passing through the cooling system of the engine. The engine was allowed to warm up and achieve its operating temperature at no load. The operating temperature would be observed with the help of temperature sensors mounted at the water jacket out let. As the operating temperature is achieved, the engine was loaded with full load. Then again, the warm up time would be given to achieve operating temperature and by the time all the heaters specified for the load were at their full gleam. Thereafter the observations for the dependent parameters for performance and emissions were recorded by means of specified instruments i.e., performance measurement unit, exhaust gas analyzer. The increasing awareness of the depletion of fossil fuel resources and the environmental benefits of biodiesel fuel has made it more attractive in recent times (Dulawat et. al., 2020).

Engine Performance Parameters

Volumetric efficiency (%)

It is the ratio of actual weight of air introduced by the engine on the suction stroke to the theoretical weight of air that should have been introduced by filling the piston displacement volume with air at atmospheric pressure and temperature (Gojiya et al., 2023).

Specific fuel consumption (kg/kW-h)

Specific fuel consumption designated as SFC is the quantity of fuel consumed per kW h in an engine.

Specific fuel consumption = Total fuel consumption / Power output

$$SFC = \frac{TFC}{P}$$

Where,

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SFC = Specific fuel consumption (kg/kW-h)
TFC = Total fuel consumption (kg/h)
P = Power output (kW)

Brake power (kW)

Power developed by the engine using the diesel fuel and blend fuels under test was calculated from the observed values of current and voltage developed by the generator attached to the engine (Gojiya and Gohil, 2022).

$$Bp = \frac{V \times I}{1000}$$

Where,

V = Voltage (V) and
I = Current (A)

Brake thermal efficiency (%)

$$\text{Brake thermal efficiency (\%)} = \frac{Brake\ power\ (kW)}{Power\ value\ of\ fuel\ (kW)} \times 100$$

Indicated power (kW)

$$\text{Indicated power (ip)} = \frac{PLAn}{60 \times 10^{12}} \times \frac{x}{2}$$

Where,

P = Mean effective pressure (Pa)
L = Length of stroke (mm)
A = Cross sectional area of piston (mm2)
n = Engine speed (rev/min)
x = Number of cylinders

Mechanical efficiency (%)

$$\text{Mechanical efficiency } (\eta mech) = \frac{bp}{ip} \times 100$$

Where,

bp = Brake power (kW)
ip = Indicated power (kW)

Indicated mean effective pressure (IMEP)

$$\text{IMEP} = \begin{pmatrix} \text{Avg. pressure during} \\ \text{power stroke } (Pa) \end{pmatrix} - \begin{pmatrix} \text{Avg. pressure during} \\ \text{other stroke } (Pa) \end{pmatrix}$$

Brake mean effective pressure (BMEP)

$$BMEP\ (Pa) = \frac{bp \times 60 \times 10^{12}}{L \times A \times n \times \frac{x}{2}}$$

Where,

bp = Brake power (kW)
L = Length of stroke (mm)
A = Cross sectional area of piston (mm^2)
n = Engine speed (rev/min)
x = Number of cylinders

Exhaust Gas Analyser and Emission Measurement

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Exhaust gas analyser (PRIMA FEM-55), which measures the concentration of the exhaust gases in parts per million (ppm) or percentage and temperature in °C. They are microprocessor based, and can store real time data with which can later be either printed or copied to a computer disk for long time storage. The measurements were made under all the selected load conditions and different biodiesel blends. The heart of the instrument is an electrochemical sensor, which converts the concentration of gas encountered around it into an electrical signal, which was sensed by the instrument, amplified, compensated and displayed in terms of percentage on the LCD. Temperature of exhaust gas was measured by a thermocouple.

Engine emission parameters

The engine emission parameters Exhaust gas component and exhaust gas temperature were measured using exhaust gas analyzer. In which CO_2 and CO ware measured in percent. While NO and exhaust gas temperature was measured in ppm and °C respectively.

Comment [m2]: Rewrite the sentence in a correct form

Results and discussion

Effect of various blend on volumetric efficiency of CI engine

Fig.3 it is clear that as percentage of biodiesel is increased in blend, volumetric efficiency was found to be decreasing successively. These findings closely aligned with the results reported by (Gaadhe and Mehta, 2019). The average pod output capacity for groundnut varietyGG-22 was observed as 524.66 kg/h and it was varied from 518.63 kg/h to 531.97 kg/h (Amrutiya at. Al., 2020).

Comment [m3]: The paragraph should not start like this Fig.3

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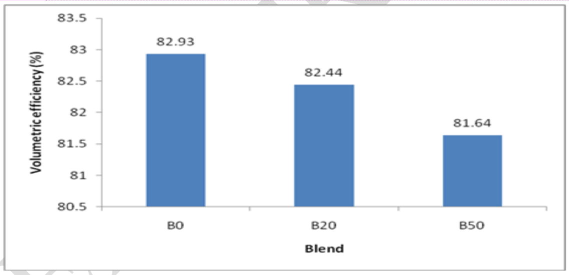

Fig 3: Effect of different blend on volumetric efficiency

Effect of various blends on specific fuel consumption of CI engine

Effects of different fuel blends on specific fuel consumption are shown in Fig. 4. As percentages of biodiesel were increased in blend, specific fuel consumption was found to be increasing as compared to diesel fuel.

Specific fuel consumptions for biodiesel are higher than diesel fuel due to the lower calorific values of Jatropha biodiesel as compared to diesel fuel. In case of biodiesel and its blends with diesel fuel, diesel engine consumes more fuel than diesel fuel to develop the same power (Agarwal and Agarwal, 2007).

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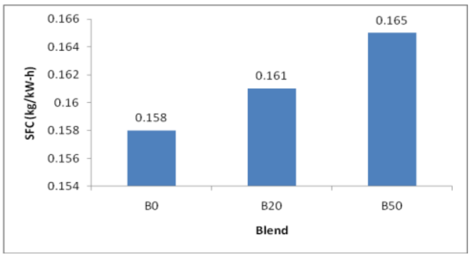


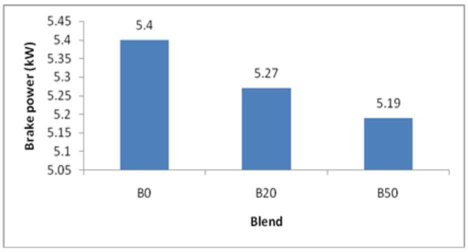


Fig 4: Effect of various blends on specific fuel consumption

Fig 5: Effect of various blends on brake power

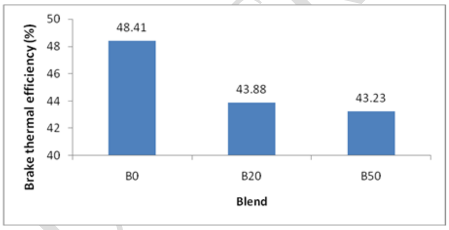
Effect of various blends on brake power of CI engine

Fig. 5 reveals effects of variation in biodiesel blends on brake power. As percentage of biodiesel is increased in blend, brake power was found to be lowering than that of pure diesel fuel. This may be due to lower spray characteristics of biodiesel blend, improper mixing of fuel–air and incomplete combustion occurred due to higher density of biodiesel blend as compare to pure diesel (B0) (Nagaraja *et al.*, 2015).

Comment [m5]: Rewrite the sentence

Effect of various blends on brake thermal efficiency of CI engine

Brake thermal efficiency is slightly lower for biodiesel blends B10 and B20 compared to blend B0 (Pure diesel) fuel at full load shown in Fig. 6. This drop in brake thermal efficiency for biodiesel blends was due to the poor combustion characteristics of biodiesel due to lower calorific value, higher density, higher viscosity and poor volatility of biodiesel blends as compared to diesel fuel (Patnaik *et al.,* 2015). Temperature increases, the bio-char yield decreases, this is due to the reason that as the pyrolysis temperature increases then the reaction of devolatilisation occurs, resulted is loss of volatile organic compounds (Makavana et. al., 2020).



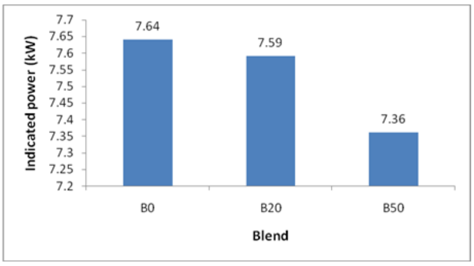


Fig 6: Effect of various blends on brake thermal efficiency

Fig 7: Effect of various blends on indicated power

Effect of various blends on indicated power of CI engine

Fig. 7 shows as percentage of biodiesel is increased in blend, indicated power was found to be lowering than that of pure diesel fuel. This may be due to lower spray characteristics of fuel, improper mixing of fuel–air and incomplete combustion occurred due to higher density of biodiesel blend as compare to pure diesel (Nagaraja *et al.,* 2015).

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Effect of various blends on mechanical efficiency of CI engine

As percentage of biodiesel is increased in blend, mechanical efficiency was found to be increasing successively which is represent in Fig. 8. Reason behind the increment of mechanical efficiency was lubrication effect due to higher glycerol content into biodiesel than that of diesel fuel. ~~Power weeders are most commonly used machines for removing weeds, to prevent them from competing with main crops.~~ However, these power weeders are power by either petrol or diesel engine. With the shortage of fossil fuel, its unavailability in rural areas and for reducing emission due to burning of fossil fuel (Kachhot et. al., 2020).

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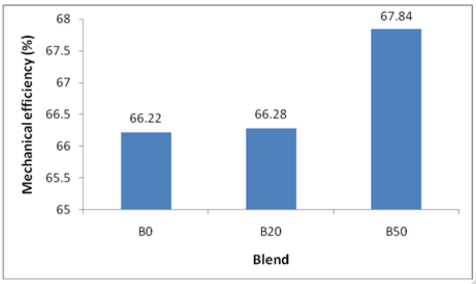
Effect of various blends on indicated mean effective pressure (IMEP) of CI engine

As a percentage of biodiesel is increased in blends, indicated mean effective pressure was decreased continuously due to lower volatility of biodiesel than that of pure diesel (Attard *et al.*, 2007).



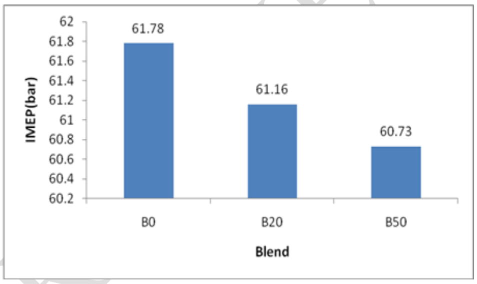
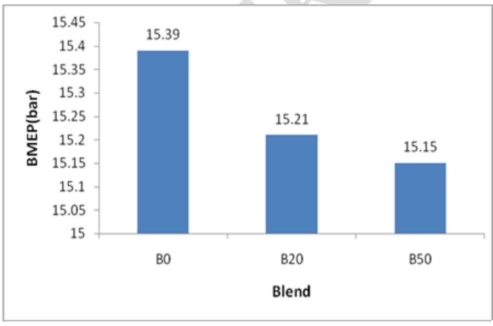


Fig 8: Effect of various blends on mechanical efficiency

Fig 9: Effect of various blends on IMEP

Effect of various blends on brake mean effective pressure (BMEP) of CI engine

Brake mean effective pressure (BMEP) of diesel fuel is higher than biodiesel blend (Fig. 10) due to higher combustion characteristics and higher volatility of diesel fuel (Attard *et al.*, 2007).



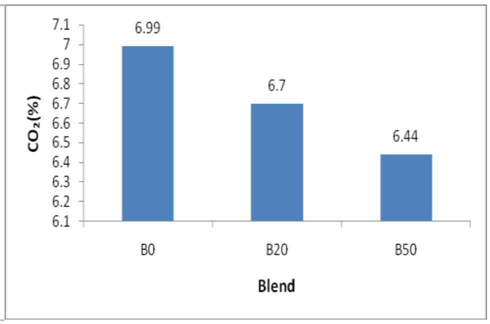


Fig 10: Effect of various blends on BMEP

Fig 11: Effect of various blends on CO_2 emission

Emission Characteristics of CI Engine Using Biodiesel Blends

Effect of various blends on carbon dioxide (CO_2) emission of CI engine

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Fig. 11, as percentage of biodiesel is increased in blend, carbon dioxide (CO_2) emission was found to be decreasing successively. CO_2 emission indicates that how efficiently fuel is burnt in the combustion chamber of a diesel engine. Since the biodiesel blend fuel burns more efficiently than diesel due to higher oxygen content in biodiesel (Hulwan and Joshi, 2011).

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Effect of different blend on carbon monoxide (CO) emission of CI engine

Lower carbon monoxide emissions of biodiesel blends may be due to more availability of oxygen leads to complete oxidation as compared to diesel. Carbon monoxide produced during combustion of biodiesel blends might have converted into CO_2 by taking up the extra oxygen molecule present, thus reduced carbon monoxide formation (Ganapathy *et al.*, 2011).

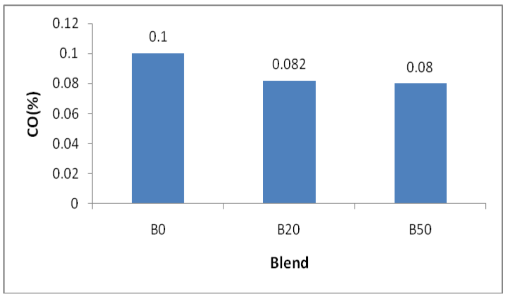

Fig 12: Effect of various blends on CO emission

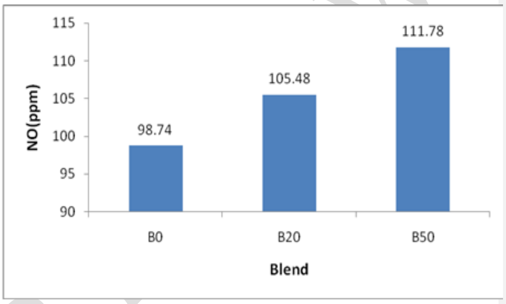

Fig 13: Effect of various blends on NO emission

Effect of various blends on nitric oxide (NO) emission of CI engine

Fig. 13 shows the effect of different fuel blends on nitric oxide (NO) emission. As percentage of biodiesel increased as fuel in blend, nitric oxide (NO) emission was found to be increasing as compare diesel fuel. The higher temperatures of combustion and the presence of fuel oxygen with the blend combustion caused higher NO emissions, especially at medium engine speed (around engine speed of 1500 rpm) (Ganapathy *et al.*, 2011).

Effect of various blends on exhaust gas temperature of CI engine

From Fig. 14 it is clear that, as percentage of biodiesel increased as fuel in blend, resultant exhaust gas temperature was found to be increasing as compare diesel fuel. Because of the poor combustion characteristics, a higher exhaust gas temperature was recorded for biodiesel blends compared to fossil diesel for the entire engine load. This may be due to higher temperature inside the engine cylinder as more fuel is burnt to meet the higher load demand (Buyukkaya, 2010). Thermal properties become useful for each and every step for determining fuel potential from agricultural residues (Makavana et. al., 2018).

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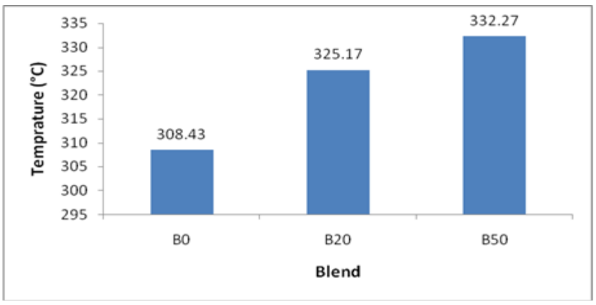

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Fig 14: Effect of various blends on exhaust gas temperature

Conclusions

The Experiment yielded significant conclusions regarding various aspects. The properties of blends, including density, viscosity, and flash point, were found to be higher, with a calorific value ranging from 0.85 to 0.9 times that of diesel. Notably, the lowest emissions of carbon dioxide (CO_2) and nitric oxide (NO) were achieved without blending, under a 14:1 compression ratio and full load conditions, registering values of 3.40% and 48.66 ppm, respectively. On the other hand, the maximum brake mean effective pressure of 26.80 bar was observed with a 20% blend, utilizing a 14:1 compression ratio at full load. When there was no blending, a 14:1 compression ratio, and full load operation, the experiment recorded impressive metrics: a maximum brake power of 9.00 kW, a peak brake thermal efficiency of 63.52%, a maximum indicated power of 11.50 kW, a top indicated mean effective pressure of 79.66 bar, and a minimum specific fuel consumption of 0.123 kg/kW-h. In terms of mechanical efficiency and energy consumption, the highest figures of 78.37% and 80.52 MJ/h, respectively, were achieved under no blending, employing an 18:1 compression ratio, and operating at full load. Moreover, the experiment established that employing a 50% blend, a 12:1 compression ratio, and operating under a no-load condition resulted in the lowest fuel cost, amounting to ₹ 71.34 per hour. This study revealed that the brake thermal efficiency and brake specific fuel consumption of blends were lower and higher, respectively, in comparison to diesel. This can be attributed to the blends' higher viscosity and lower calorific value. Additionally, the blends demonstrated a lower presence of CO_2 and CO emissions than diesel due to more efficient fuel combustion within the cylinder. As a conclusion, the findings highlight that a blending ratio of 20% provides optimal values for both performance and emission characteristics.

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UNDER PEER REVIEW

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