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Performance Evaluation and Emission Characteristics of a 3.74 kW Commercial Diesel Engine Using Stable Blended Fuels

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ABSTRACT

This study evaluates the performance and emission characteristics of a compression ignition (CI) engine fueled with diesel and ethanol-based substitute fuels formulated with varying proportions of ethanol, ethyl acetate, and biodiesel. The experimental setup involved testing at five brake load levels (no load to 100%) and measuring key parameters such as brake power, fuel consumption, brake-specific fuel consumption (BSFC), and exhaust emissions (O_2, CO_2, NO_2, and NO). Results revealed that the engine delivered comparable brake power across all fuels, with substitute fuels exhibiting slightly higher values at full load due to increased engine speed. Fuel consumption was higher for substitute fuels, reflecting their lower calorific value, with 2000-20/10/70 showing the highest consumption. BSFC decreased with increasing brake load, indicating improved combustion efficiency, though substitute fuels recorded marginally higher BSFC compared to diesel.Emission analysis showed that substitute fuels reduced NO and NO_2 emissions significantly due to the ethyl acetate content, which influenced combustion dynamics. CO_2 emissions were slightly higher for substitute fuels, while O_2 emissions were lower at full load, suggesting efficient fuel-air mixing and combustion. The 2000-10/0/90 and 2000-15/5/80 blends demonstrated the most balanced performance and emission profiles. These results indicate that ethanol-based substitute fuels, particularly those containing ethyl acetate, are promising alternatives to diesel, providing environmental benefits with only minor compromises in fuel efficiency.This study concludes that ethanol and biodiesel blends can offer a sustainable solution for reducing emissions in CI engines while maintaining performance. Further research should focus on long-term engine impacts, durability testing, and optimizing fuel formulations to maximize environmental and operational benefits.

Keywords: Ethanol-based fuels, Biodiesel blends, Compression ignition engine, Emission reduction and Brake-specific fuel consumption (BSFC)

1.0 INTRODUCTION

Energy is essential for improving quality of life, economic growth and social development of people. Fossil fuels have been an important conventional energy source for years since their exploration. Energy demand around the world is increasing at a faster rate as a result of ongoing trends in industrialization and modernization. Most of the developing countries import fossil fuels for satisfying their energy demand. Consequently, these countries have to spend their export income to buy petroleum products. At the same time, diesel engines are major contributors of various types of air pollutant emissions such as carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM), and other harmful compounds. With the increasing concern of environmental protection and more stringent government regulation on exhaust emissions, reduction in engine emissions becomes a major research task in engine development. It is difficult to reduce PM and NOx simultaneously owing to the trade-off relationship between NOx and PM. There are many researchers dedicated to developing a new technology to reduce PM and NOx simultaneously. A potential biodiesel substitutes oil, consisting of the ethyl ester of fatty acids produced by the transesterification reaction of triglycerides of Karanja oils, and ethanol with the help of a catalyst. In addition, biodiesel is better than diesel fuel in terms of very low sulfur content and it is also having higher flash and fire point temperatures that of diesel fuel.AndritsakisEC *et al* (2007) conducted tests using each of the above fuel blends or neat diesel fuel. Volumetric fuel consumption, exhaust gas temperature, exhaust smokiness and exhaust regulated gas emissions such as nitrogen oxides, carbon monoxide,and total unburned hydrocarbons were measured. The differences in the performance and exhaust emission parameters from the baseline operation of the engine, that is, when working with neat diesel fuel, are determined and compared. Shaik et al. (2007) demonstrated thatVCR engine has great

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potential for improving part-load thermal efficiency and reducing greenhouse gas emissions. There were many attempts made to use ethanol in compression ignition (CI) engine. Huang *et al.* (2008)carried out tests to study the performance and emissions of the engine fueled with the ethanol-diesel blends. They found it feasible and applicable for the blends with n-butanol to replace pure diesel as the fuel for diesel engine. Li *et al* (2005)studied ethanol/diesel fuel blends, from5% to 20% of ethanol and found that brake-specific fuel consumption increased using all tested blends. Gautam *et al* (2000) studied the effects of 10% of different alcohols blended with petrol on spark ignition engines. The maximum amount of pentanol used was less than 3% however power, torque, and specific fuel consumption were not evaluated. Balakrishnan (2015) studied the effects of waste—used vegetable oil biodiesel as an injected fuel in a four-stroke naturally aspirated variable compression ratio engine and the results showthat smoke opacity has been reduced up to 16% than the fossil fuel without any modifications diesel engine. The objective of the present study is to investigate performance evaluation; exhaust emission of the engine is required for biodiesel obtained from such mixture of ethanol and surfactant.

2.0 METHODOLOGY

2.1 Selection of biodiesel fuels

The table outlines the composition of test fuels used in the study to evaluate the performance of ethanol-based substitute fuels compared to diesel. Diesel is used as the control fuel, containing no ethanol, ethyl acetate, or biodiesel. Three substitute fuel blends were tested, each with varying proportions of ethanol, ethyl acetate, and biodiesel, progressively replacing diesel by 10%, 20%, and 30%. The first blend, 2000-10/0/90, contains 10% ethanol and 90% biodiesel, with no ethyl acetate, representing a 10% biodiesel replacement. The second blend, 2000-15/5/80, consists of 15% ethanol, 5% ethyl acetate, and 80% biodiesel, corresponding to a 20% biodiesel replacement. The third blend, 2000-20/10/70, has the highest ethanol (20%) and ethyl acetate (10%) content, with 70% biodiesel, replacing 30% of diesel. This progression in blend composition was designed to assess the impact of increasing ethanol and ethyl acetate on engine performance, fuel consumption, and emissions, highlighting their potential as sustainable diesel alternatives.The constituents of selected test fuels are given in Table 2.1.

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Table 2.1 Fuel selected for engine test

Sl.	Fuel Types	Fuel Constituents (%)			Biodiesel Replacement (%)
		Ethanol	Ethyl Acetate	Biodiesel	
1	Diesel	-	-	-	-
2.	200^0-10/0/90	10	0	90	10
3.	200^0-15/5/80	15	5	80	20
4.	200^0-20/10/70	20	10	70	30

2.2 Design of the experimental layout

The factorial randomized design is used to analyze the data with the help of design expert software. The selected independent parameters with the experimental plan are given in Table2.2. The CI engine is used with four types of fuel and five levels of engine torque. The effect of this treatment is determined by assessing the brakehorse power (BHP), fuel consumption (FC), brake specific fuel consumption (bsfc) and exhaust emissions.

2.3 Brake horsepower

The brake horsepower developed by the engine is calculated using the following equation.

$$\mathrm{BHP} = \frac{\mathrm{NT}}{\mathrm{C}} \qquad 01$$

where, BHP = Brakehorse power, kW, T =Engine torque N-m, N = Engine speedrpm, C=Dynamometer constant, 9549.305

2.4 Measurement of fuel consumption

The fuel consumption is measured with the help of a SAJ-Froude make, SFV-75 model electronic volumetric fuel consumption measuring unit (Fig.2.1&2.2). It consists of a fuel tank, graduated glass pipette of 25, 50 and 75 ml, a solenoid valve, photosensor assembly and a timer. The consumed fuelis allowed to pass through the 25 ml pipette. The time taken for the

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consumption of 25 ml fuel is noted by means of a timer provided with the unit. The brake specific fuel consumption is calculated by using the relationship as given below

$$bsfc = \frac{Vcc \times \rho \times 3600}{BP \times t} \qquad 02$$

where, bsfc = brake specific fuel consumption, g /kWh;V_{cc}=Volume of fuel consumed, 25cc, ρ = density of fuel, g /cc; BP = Brake Power, kW; T = Time taken to consume 25 ccfuel, s.

Fig.2.1 Eddy Current Dynamometer Control Panel

Fig.2.2 Electronic Fuel Consumption Measuring Unit

Fig 2.3 Gas Analyzer

2.5 Measurement of exhaust emission

Exhaust emission is drawn with the help of a steel tube and a PVC gas selection pipe using an air pump. The discharge of air pump is taken to a gas analyzer and thus O_2, CO2, NOx, and NO are analyzed. The exhaust gas analyzer used is given in Fig. 2.3

2.6 Experimental process

The engine is run with the selected fuels ondifferentoperating condition and its speed is adjusted to 1500±10 rpm by adjusting the screw provided with the fuel injector pump rack. The engine is run to gain uniform speed after which it is gradually loadedas shown in Fig. 2.4. The experiments are conducted at five load levels viz., 20, 40, 60, 80 and 100%. For each load condition, the engine is run for at least three minutes after which data is collected. The parameters are measured and calculations are made.

Fig 2.4 Engine test setup

3.0 RESULTS AND DISCUSSIONS

3.1 Performance Evaluation of a Compression Ignition Engine Using Diesel and Ethanol-Based Substitute Fuels

The engine's performance was analyzed using diesel and ethanol–ethyl acetate–biodiesel blends (2000-10/0/90, 2000-15/5/80, and 2000-20/10/70) under varying brake loads shown in fig.3.1 (a-d). Parameters such as brake power, fuel consumption, and brake-specific fuel consumption (BSFC) were measured across no load, 20%, 40%, 60%, 80%, and 100% brake load conditions. The results indicated that the engine developed 3.74 kW brake power at 1500 rpm on diesel, aligning closely with the rated power of 3.669 kW. On substitute fuels, slightly higher brake powers of 3.674, 3.684, and 3.676 kW were recorded at 1502, 1506, and 1503 rpm, respectively, at full load. These findings suggest that substitute fuels perform comparably, with marginal variations due to higher engine speeds and biodiesel content, corroborating earlier studies by Meiring et al. (1983) on microemulsions affecting combustion characteristics. Fuel consumption increased with brake load, peaking at 100% load for all fuels. At full load, the engine's fuel consumption was 1.837 l/h on diesel and 2.037, 2.002, and 2.071 l/h on the substitute fuels.

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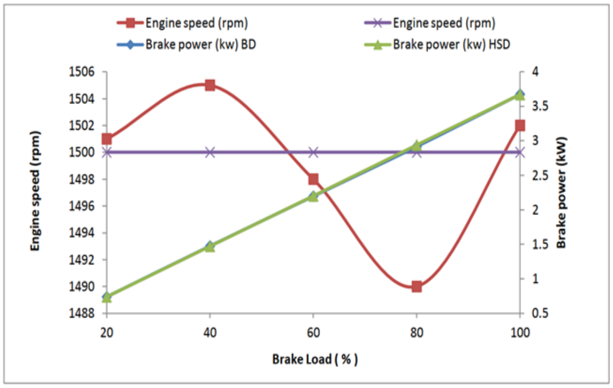
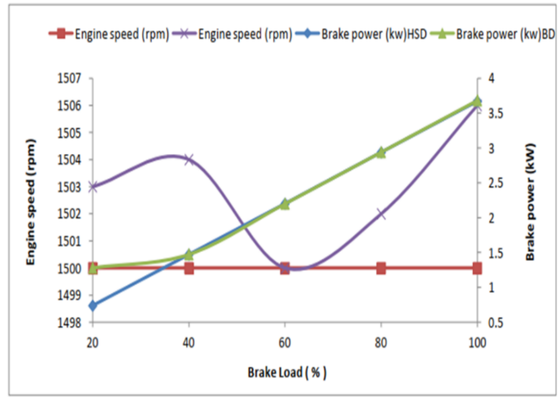
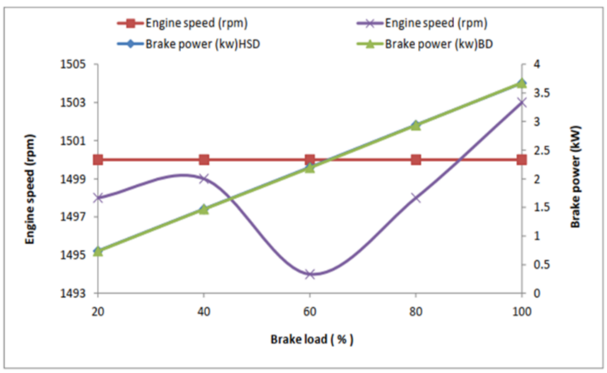


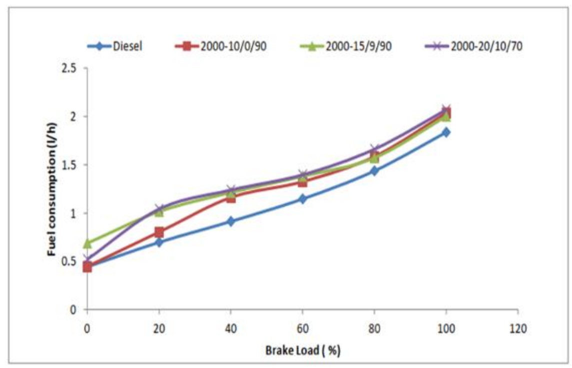
(a) Effect of brake load on developed by the engine on high-speed diesel and 200^0-10/0/90 substitute fuel



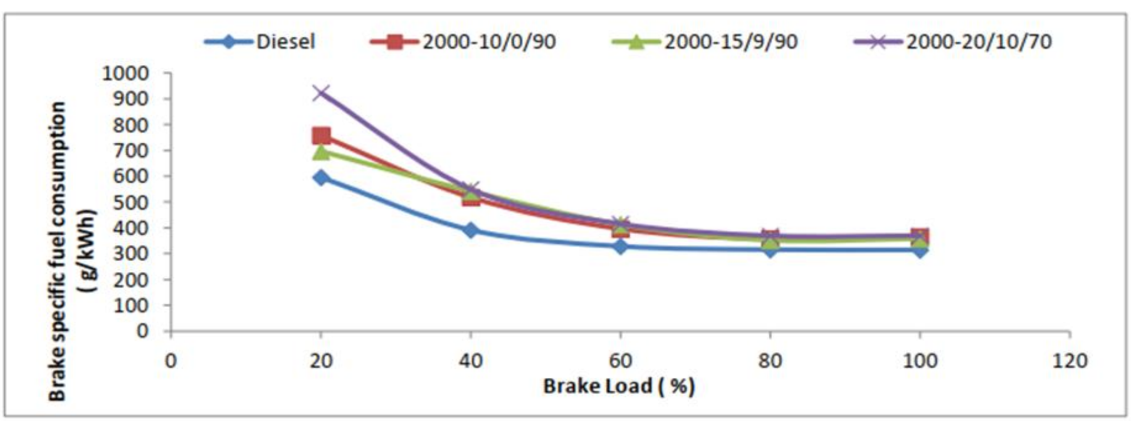
(b) effect of brake load on brake power developed by the engine on high-speed diesel and 200^0-15/5/80 substitute fuel



(c) Effect of brake load on brake power developed by the engine on high-speed diesel and 200^0-20/10/70 substitute fuel.



(d) Fuel consumption of the engine at different load on high-speed diesel and substitute fuel



(e) Brake specific fuel consumption of the engine at different load on high-speed diesel and substitute fuel

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Fig. 3.1 (a-e) Effect of Brake Load on Engine Performance and Fuel Consumption Using Diesel and Ethanol-Based Substitute Fuels

Higher fuel consumption on substitute fuels can be attributed to their lower calorific values. Among them, 2000-20/10/70 exhibited the highest fuel consumption across all load conditions. The BSFC showed a decreasing trend with increasing brake load, reflecting improved combustion efficiency at higher loads. At 100% load, BSFC was 314 g/kWh for diesel and 365, 357, and 369 g/kWh for the substitute fuels. The highest BSFC of 922 g/kWh was recorded for 2000-20/10/70 at 20% load, possibly due to incomplete combustion at lower loads. A rapid decline in BSFC was observed up to 60% brake load, after which the rate of decrease diminished, consistent with the relationship between brake power and fuel utilization efficiency. These findings indicate that ethanol-based substitute fuels can serve as viable alternatives to diesel with slightly higher fuel consumption but comparable brake power, aligning with the studies by Qi et al. (2010) and Huang et al. (2013), which emphasized ethanol blends' potential to maintain engine performance while offering environmental benefits.

3.2 Emission Analysis of CI Engine Fueled with Diesel and Ethanol-Based Substitute Fuels at Varying Brake Loads

This study evaluates the emission characteristics of a CI engine operating on diesel and ethanol-based substitute fuels under varying brake load conditions shown in fig. 3.2 (a-d). The oxygen (O_2) emissions from diesel ranged from 16.7% at no load to 5.6% at full load, with the substitute fuels (2000-10/0/90, 2000-15/5/80, and 2000-20/10/70) showing ranges of 17.2–3.1%, 16.4–4.0%, and 17.2–4.0%, respectively. The lowest O_2 emission of 3.1% at full load was observed for 2000-10/0/90, attributed to the higher fuel-to-air ratio. These findings align with Ecklund (1984), who noted reduced O_2 emissions when alcohol-based fuels are utilized. Carbon dioxide (CO_2) emissions from diesel were found to vary between 0–2% across brake loads, with substitute fuels exhibiting a broader range of 1–5.5%, with the highest CO_2 emission of 5.5% recorded for 2000-15/5/80. Nitrogen dioxide (NO_2) emissions for diesel ranged from 158 to 618 ppm, while substitute fuels exhibited reduced NO_2 emissions, varying from 72–613 ppm for 2000-10/0/90, 136–625 ppm for 2000-15/5/80, and 153–607 ppm for 2000-20/10/70. This reduction is attributed to the presence of ethyl acetate, which may mitigate NO_2 formation by influencing combustion dynamics (Ecklund, 1984). Nitric oxide (NO) emissions followed a similar trend, with diesel emissions ranging from 158 to 989 ppm. Substitute fuels showed lower

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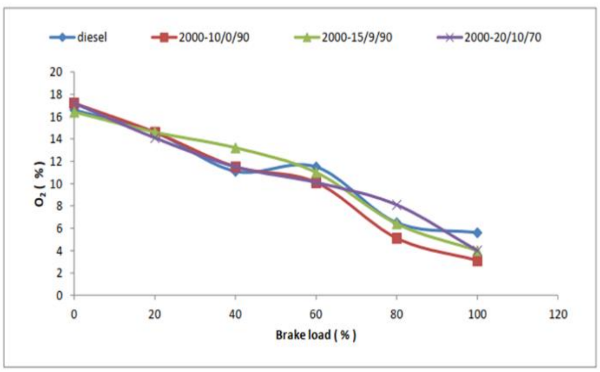
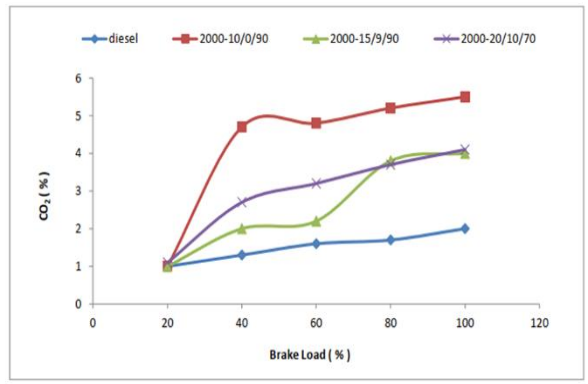
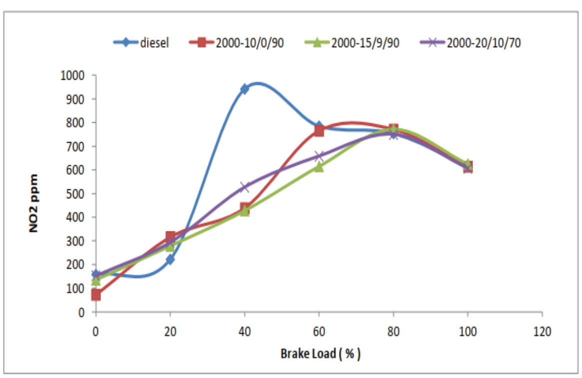
NO emissions, ranging from 63–681 ppm for 2000-10/0/90, 115–625 ppm for 2000-15/5/80, and 133–607 ppm for 2000-20/10/70, with the lowest emissions observed for 2000-20/10/70 at full load. The results highlight that increasing the proportion of ethanol and ethyl acetate in the substitute fuels effectively reduces NO emissions, a trend consistent with observations in alternative fuel studies (Ecklund, 1984). Overall, the findings suggest that ethanol-based substitute fuels, especially formulations with higher ethyl acetate content, demonstrate improved emission profiles compared to diesel, making them promising alternatives for reducing environmental pollutants in CI engines (Ecklund, 1984).



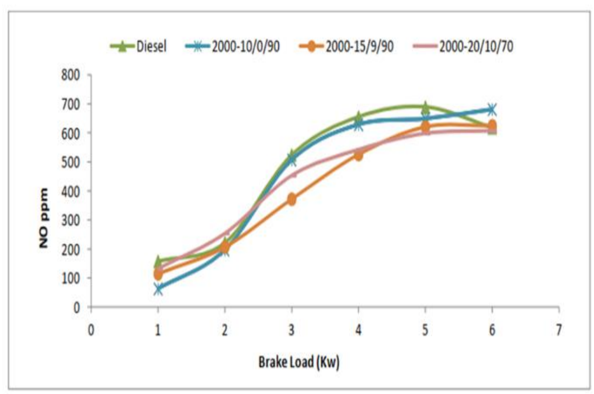
(a) Oxygen



(b) CarbonDioxide



(c) Nitrogen Dioxide



(d) Nitric oxide

Fig. 4.7 (a-b) Emissions from the engine at different brake load on high-speed diesel and substitute fuel

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4.0 CONCLUSIONS

The study demonstrates that ethanol-based substitute fuels can serve as viable alternatives to diesel in CI engines, offering comparable brake power with slightly higher fuel consumption due to lower calorific values. The brake-specific fuel consumption decreased with increasing loads, indicating improved combustion efficiency, while substitute fuels exhibited marginally higher BSFC than diesel. Emission analysis revealed that substitute fuels reduced NO and NO_2 emissions significantly, attributed to the presence of ethyl acetate, while CO_2 emissions were slightly higher. Among the tested blends, 2000-10/0/90 and 2000-15/5/80 showed the most balanced performance and emission characteristics. These findings suggest that ethanol and biodiesel blends, particularly those containing ethyl acetate, can provide an environmentally friendly alternative to diesel, with minimal trade-offs in engine performance. Further optimization and long-term testing are recommended to enhance the feasibility of these substitutes.

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