

Assessing the Effects of Ternary Oxygenated Fuel Blends on CI Engine Performance and Emissions

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Abstract- Growing environmental concerns and the depletion of fossil fuels have intensified the search for cleaner and more sustainable energy alternatives. Diesel engines, which are widely used in industrial and transportation sectors, are major contributors to air pollution, prompting stricter emission standards.

This study investigates the impact of ternary fuel blends—diesel, diethyl ether (DEE), and ethanol—on the performance and emissions of a compression ignition (CI) engine. Three blends were tested: D-DEE5-E5, D-DEE5-E10, and D-DEE5-E15. Among these, D-DEE5-E10 exhibited the most favorable results, achieving a brake thermal efficiency of 39.83% and the lowest brake-specific fuel consumption of 0.245 kg/kWh. These improvements are attributed to the high cetane rating of DEE and the oxygen-enriched nature of ethanol, which together enhance combustion. Emissions of carbon monoxide, hydrocarbons, and smoke were significantly reduced. However, a slight rise in nitrogen oxides was observed due to increased combustion temperature. Overall, D-DEE5-E10 emerges as a viable cleaner fuel alternative.

Keywords: Ethanol, DEE, Diesel Engine, Performance, Emissions

1. INTRODUCTION

The global energy landscape is increasingly challenged by the environmental consequences of heavy reliance on fossil fuels such as oil, coal, and natural gas [1,2]. These conventional energy sources are not only depleting but also contribute significantly to greenhouse gas emissions, leading to global warming and air quality deterioration [3-5]. In response, the search for clean and renewable alternatives has gained urgency.

Compression ignition (CI) engines are extensively used in industrial and transport sectors due to their high thermal efficiency and durability [6]. However, their widespread use has raised concerns, as they emit substantial amounts of nitrogen oxides (NO_x) and particulate matter (PM), which are harmful to both the environment and human health [7]. To mitigate these emissions without major engine modifications, the use of fuel additives especially oxygenated compounds offers a promising approach [8,9].

Oxygenated additives help improve combustion by promoting more complete fuel oxidation, thereby reducing the formation of pollutants. Among them, ethanol and diethyl ether (DEE) have shown considerable potential [9]. Ethanol, derived from biomass, is a renewable fuel with high oxygen content that reduces CO, HC, and PM emissions when blended with diesel [10]. However, its lower energy density and poor miscibility with diesel require careful blend preparation to maintain fuel stability and engine performance [10,11].

DEE, on the other hand, is known for its high cetane number and excellent volatility, which enhance ignition quality and flame propagation in diesel engines. Its inclusion as an additive supports improved thermal efficiency and lower emissions of unburned hydrocarbons and soot [12–16].

Blending ethanol and DEE with diesel in a ternary mixture offers synergistic benefits. While DEE offsets ethanol's lower cetane number, ethanol increases oxygen availability, promoting cleaner combustion [18,19]. This study aims to evaluate the performance and emission behavior of a CI engine using ternary fuel blends of diesel, ethanol, and DEE in different ratios. The goal is to identify an optimal blend that enhances engine efficiency while reducing harmful emissions, thereby contributing to the development of cleaner and more sustainable diesel alternatives.

2. COMPARISON OF VARIOUS PROPERTIES OF DIESEL, ETHANOL, AND DEE ADDITIVES

This is a comparison of the various properties of diesel, ethanol and DEE as fuel additives for CI engines [6,20-23].

Blending of diesel with ethanol and diethyl ether (DEE) improves engine performance and reduces emissions. Diesel provides higher energy efficiency, ethanol promotes cleaner combustion, and DEE improves ignition quality. Researchers have concluded that mixture such as 5% DEE with diesel improve thermal efficiency and reduce emissions of smoke, carbon monoxide and

hydrocarbons. The extra advantage of adding ethanol to the diesel-DEE mixture further reduces particulate matter and nitrogen oxides. Hence these triple mixtures provide a promising approach for achieving efficient and environmentally friendly diesel engine operation.

Table 1: Different properties of diesel, ethanol and DEE as fuel additives for diesel engines

Property	Diesel	Ethanol (C ₂ H ₅ OH)	Diethyl Ether (C ₄ H ₁₀ O)
Chemical Formula	C ₁₀ H ₂₂	C ₂ H ₅ OH	C ₄ H ₁₀ O
Density (g/cm ³ at 15°C)	0.83–0.85	0.789	0.713
Boiling Point (°C)	180–360	78	35.1
Auto-ignition Temperature (°C)	209–260	365	160
Cetane Number	41–55	9	125–133
Lower Heating Value (MJ/kg)	43–45	25.9	28
Oxygen Content (%)	0	34.7	21.6
Viscosity (cSt at 38°C)	2.5–4.5	1.2	0.23
Latent Heat of Vaporization (kJ/kg)	250	841	376
Flash Point (°C)	52–96	13	–45
Energy Density (MJ/L)	35.8	21.1	23.6

3. EXPERIMENTAL SETUP AND METHODOLOGY

Mixture Preparation:

Three ternary fuel blends—D-DEE5-E5, D-DEE5-E10, and D-DEE5-E15—were prepared by combining diesel with 5% diethyl ether (DEE) and ethanol in varying proportions of 5%, 10%, and 15% by volume, respectively. Diesel was measured initially, followed by the gradual addition of DEE under continuous stirring to ensure proper mixing by vol. /vol. Ethanol was then incorporated to complete the formulation and achieve a homogeneous blend. The stability of each blend was monitored over a 96-hour period to ensure uniformity and suitability for engine experimentation.

Engine Setup and Testing:

To comprehensively evaluate the impact of alternative fuel blends on engine performance and emissions, a single-cylinder, four-stroke, water-cooled compression ignition engine was selected as the experimental platform. The engine maintained a fixed operating speed of 1450 rpm, while systematic testing was carried out across five incremental load conditions (ranging from no load to full load) facilitated by an eddy current dynamometer to

ensure precise load control. Fuel delivery was regulated through a gravity-fed system equipped with a filtration unit to maintain fuel purity and consistency.

The study incorporated both baseline diesel and various prepared ternary blends to facilitate a comparative analysis. This configuration enabled a granular investigation into how differences in fuel composition particularly the inclusion of additives influence combustion dynamics, energy conversion efficiency, and exhaust gas behavior under variable operational stresses. Performance metrics such as brake-specific fuel consumption (BSFC) and thermal efficiency, along with emission parameters including NO_x, CO, HC, and smoke, were critically examined. This approach provided a robust framework for understanding the nuanced interactions between engine load, combustion characteristics, and environmental impact, thereby offering valuable insights into the suitability of additives-based fuel blends in conventional diesel engine applications. The experimental setup is illustrated in Figure 1, providing a visual representation of the test arrangement.



Figure 1: Pictographic view of experimental setup

4. RESULTS AND DISCUSSION

This study examined the performance and emission behavior of a compression ignition engine fueled with pure diesel and ternary blends of diesel, diethyl ether (DEE), and ethanol. Among the tested blends, the D-DEE5-E10 composition—comprising 5% DEE and 10% ethanol—exhibited the most favorable combination of thermal efficiency and emission reduction. Compared to conventional diesel, this blend significantly enhanced brake thermal efficiency (BTE) and lowered emissions of nitrogen oxides (NO_x), carbon monoxide (CO), hydrocarbons (HC), and particulate matter (PM).

As illustrated in Figure 2, D-DEE5-E10 recorded a peak BTE of 40.20% at full engine load, reflecting a 4.145% improvement over standard diesel. This enhancement is attributed to ethanol's oxygen-enriched structure, which facilitates more complete combustion, and DEE's high cetane number, which promotes quicker ignition. While D-DEE5-E5 offered modest improvements, the D-DEE5-E15 blend showed a slight decline in BTE, likely due to

ignition delays from excessive ethanol content. Overall, D-DEE5-E10 appears to be a promising clean alternative for diesel engines, offering both performance gains and environmental benefits.

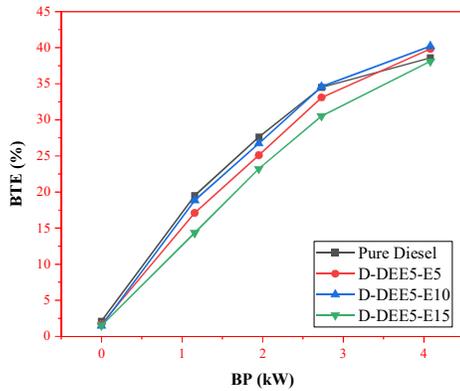


Figure 2: BTE v/s BP curve for diesel and different fuel mixture

The D-DEE5-E10 blend demonstrated a notable improvement in fuel efficiency by achieving approximately 5% lower brake specific fuel consumption (BSFC) compared to standard diesel. This reduction is primarily attributed to the synergistic effects of ethanol and diethyl ether (DEE) present in the blend. Ethanol, with its high oxygen content, promotes more complete combustion of the air-fuel mixture, thereby reducing unburnt fuel losses. Meanwhile, DEE's high cetane number and excellent volatility improve ignition characteristics, leading to quicker and more efficient combustion cycles. Together, these properties enhance the overall thermal efficiency of the engine and reduce the amount of fuel required to produce the same power output.

In comparison, the D-DEE5-E5 blend exhibited BSFC values similar to those of pure diesel, indicating that the lower ethanol concentration was not sufficient to yield substantial combustion improvements. On the other hand, the D-DEE5-E15 blend showed an increase in BSFC. This is likely due to excessive ethanol content, which can lower the overall cetane number of the fuel mixture, leading to delayed ignition and incomplete combustion. As a result, more fuel was consumed to maintain engine performance. These findings suggest that D-DEE5-E10 offers the most balanced composition for improving fuel economy without compromising combustion efficiency.

The D-DEE5-E10 ternary fuel blend comprising 5% diethyl ether (DEE), 10% ethanol, and 85% diesel demonstrated a substantial reduction in smoke emissions in compression ignition engines. This improvement is primarily attributed to the enhanced oxygen availability from ethanol and the superior ignition quality of DEE, which together promote more complete combustion and better atomization of the fuel-air mixture. As depicted in Figure 4, the D-DEE5-E10 blend significantly lowers smoke opacity compared to conventional diesel. Previous studies support this observation, indicating that the

inclusion of DEE in biodiesel-based fuels improves combustion efficiency and reduces smoke due to improved volatility and spray characteristics. Similarly, blends combining DEE with biodiesel and eucalyptus oil have shown marked reductions in particulate emissions.

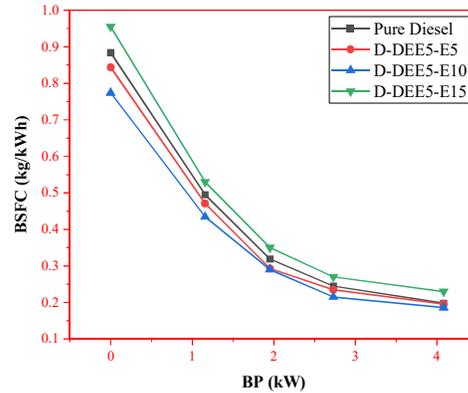


Figure 3: BSFC v/s BP curve for diesel and different fuel mixture

In addition to smoke reduction, Figure 5 illustrates that the D-DEE5-E10 mixture achieves a 60% decrease in carbon monoxide (CO) emissions relative to pure diesel. This substantial reduction stems from the oxygen-enriched fuel composition and improved ignition behavior, which collectively enhance the combustion process. D-DEE5-E5 exhibited moderate CO reductions, while D-DEE5-E15 recorded slightly higher CO levels than D-DEE5-E10, likely due to ignition delays caused by excessive ethanol content.

Hydrocarbon (HC) emissions also declined significantly for all ternary blends. As shown in Figure 6, the D-DEE5-E10 blend yielded the lowest HC emission level at 8 ppm a 61.9% reduction compared to diesel. Though D-DEE5-E5 and D-DEE5-E15 also demonstrated HC emission reductions, their effects were less pronounced than those observed with D-DEE5-E10. These findings confirm that the D-DEE5-E10 mixture offers the most effective combination for lowering particulate and gaseous emissions while ensuring efficient combustion in diesel engines.

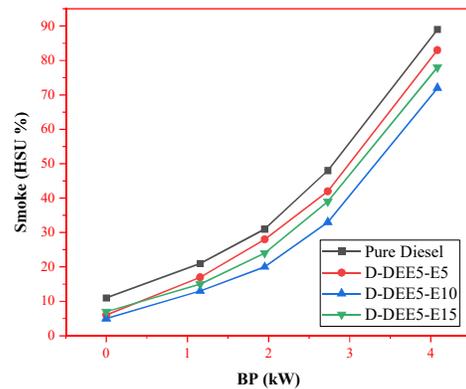


Figure 4: Smoke v/s BP curve for diesel and different fuel mixture

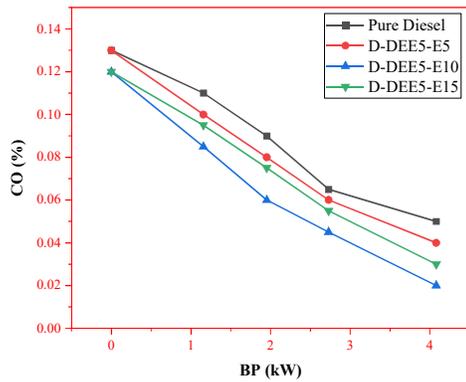


Figure 5: CO v/s BP curve for diesel and different fuel mixture

This suggests that the specific balance of ethanol and DEE in D-DEE5-E10 improves the combustion efficiency, leading to greater reduction in HC emissions.

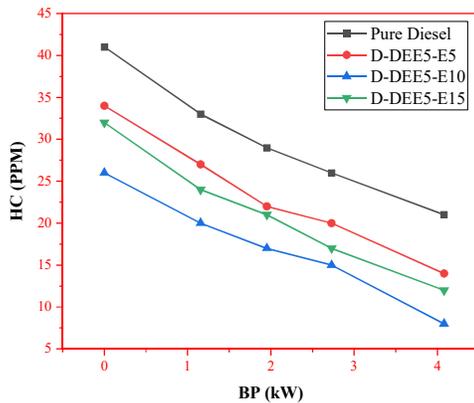


Figure 6: HC v/s BP curve for diesel and different fuel mixture

As illustrated in Figure 7, the D-DEE5-E5 fuel blend recorded the lowest nitrogen oxide (NO_x) emissions, showing a 6.8% reduction compared to pure diesel. This decline can be attributed to the moderate ethanol content in the blend, which introduces a latent heat of vaporization effect, thereby reducing the peak combustion temperature and limiting NO_x formation. However, as the ethanol concentration increased in the D-DEE5-E10 and D-DEE5-E15 mixtures, NO_x emissions rose correspondingly. This increase is likely due to the higher oxygen availability and enhanced combustion intensity at elevated ethanol levels, which raise in-cylinder temperatures and promote thermal NO_x formation [24,25]. These results indicate that while ethanol improves overall combustion efficiency, its proportion must be carefully optimized to minimize NO_x emissions. The D-DEE5-E10 blend, consisting of 85% diesel, 5% diethyl ether (DEE), and 10% ethanol, exhibited notable improvements in both engine performance and emission reduction compared to conventional diesel. This optimized mixture enhances combustion efficiency due to the synergistic effects of DEE's high cetane number and ethanol's oxygen content, contributing to cleaner and

more efficient fuel burning. As a result, it emerges as a promising alternative fuel for compression ignition engines. However, to fully evaluate its practical applicability and performance under varying operating conditions, further investigations are recommended, particularly with respect to its behavior at different compression ratios.

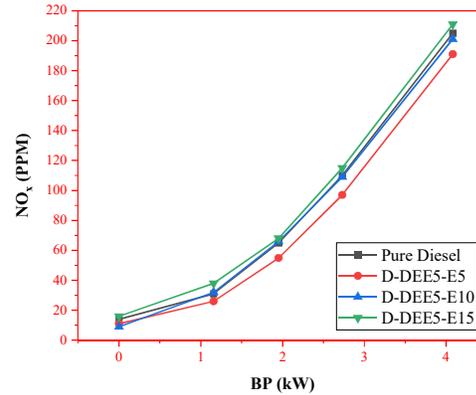


Figure 7: NO_x v/s BP curve for diesel and different fuel mixture

5. CONCLUSION

This study evaluated the performance and exhaust emission characteristics of a variable compression ratio (VCR) direct-injection compression ignition (CI) engine fueled with diesel blends containing ethanol and diethyl ether (DEE). The results demonstrate that incorporating these oxygenated additives significantly improves engine performance while reducing harmful emissions. Among the tested blends, the D-DEE5-E10 mixture (5% DEE and 10% ethanol) proved to be the most effective, achieving the highest brake thermal efficiency (BTE) of 39.83% at full load, compared to 36.21% for pure diesel. This enhancement is attributed to DEE's high cetane number, which promotes quicker ignition, and ethanol's oxygen content, which facilitates more complete combustion. Additionally, this blend recorded a lower brake-specific fuel consumption (BSFC) of 0.245 kg/kWh, indicating improved fuel economy.

In terms of emissions, D-DEE5-E10 significantly reduced carbon monoxide (CO) emissions to 0.12% by volume, smoke opacity to 6.8%, and hydrocarbon (HC) levels to 18 ppm. These reductions are mainly due to enhanced combustion supported by the oxygenated nature of ethanol and the ignition-promoting characteristics of DEE. However, an increase in nitrogen oxide (NO_x) emissions was observed, reaching 612 ppm, likely due to elevated combustion temperatures. Despite this, the notable reductions in CO, HC, and smoke emissions affirm the potential of D-DEE5-E10 as a cleaner alternative to diesel. Further studies are recommended to mitigate NO_x emissions and evaluate the blend's

performance across various engine types and operating conditions.

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