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Emission Control and Aldehyde Reduction Using Fish Oil Methyl Ester, Diethyl Ether, and Butanol Blends in CI Engines

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Abstract:- This study explores the analysis and mitigation of emission pollutants and aldehyde potential through the use of blends comprising Fish Oil Methyl Ester, Diethyl Ether, and Butanol in both conventional and Low Heat Rejection (LHR) Compression Ignition (CI) engines. The primary goal is to evaluate the effectiveness of these biofuel blends in reducing harmful emissions while maintaining engine performance. The experiments were conducted on a single-cylinder, four-stroke LHR diesel engine modified to operate with various fuel blends. Emission characteristics, including carbon monoxide (CO), Oxides of Nitrogen (NO_X), Smoke opacity and hydro carbon (HC) includes aldehydes were measured and compared to those of pure form of FOME and DEE and butanol blend fuel. Special emphasis was given to the examination and measurement of aldehyde emissions, given their substantial implications for human health and environmental quality. The results demonstrate that the use of FOME, DEE, and butanol blends significantly reduces CO, HC, and Smoke emissions. NO_X emissions showed variable trends depending on the blend composition. Aldehyde emissions were notably lower in blends with higher concentrations Iso butanol and play a crucial role in controlling aldehyde formation. The study concludes that 50%FOME, 15%DEE, and 35% butanol blends are promising alternatives to conventional fuel with the percentage 52.4%, 8%, 14.11%, 11.8% reduction of CO, NO_X, and HC along with aldehydes offering substantial reductions in harmful emissions. It was also noticed that from the results of emissions such as CO, smoke opacity and Hydrocarbon with aldehydes for LHR Engine were reduced by 17.2%, 28.8%, 2.4% with mixture of DEE and butanol additives and FOME blend, but the NO_X has increased with addition of DEE additive by 4.7%. According to the results, it is suggested to use FOME50DEE15BTN35 mixed fuel in CI engines reduce emissions.

Key words: FOME, DEE, Iso Butanol, hydro carbon, nitrogen oxides, Smoke opacity and aldehydes

1. Over view

In recent years, the quest for alternative fuel sources has gained significant importance due to the dwindling supplies of fossil-based energy resources. The limited reserves of petroleum-based fuels cannot keep pace with the rising demand for energy [1]. The search for alternative fuels seeks not only to mitigate the scarcity of fossil fuels but also to lower greenhouse gas emissions from combustion processes.

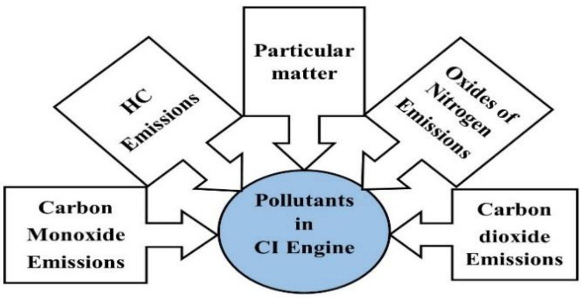


Fig.1 Pollutants in CI Engine

Emissions from compression ignition (CI) engines, commonly known as diesel engines, consist of several harmful pollutants, each with specific impacts on the environment and human health. These emissions include nitrogen oxides (NO_X), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), and sulfur dioxide (SO_2) are shown in figure 1. Un combusted exhaust, such as aldehydes, organic acids, and other oxygenated compounds, are primary contributors to exhaust odor. Among these, aldehydes significantly impact the smell of exhaust fumes. Additionally, automobile exhaust can irritate the nose, eyes, and throat. Certain aldehydes, including formaldehyde (HCHO), acetaldehyde (CH_3CHO), and acrolein (H_2C=CHCHO. Reducing aldehyde levels in automobile exhaust is crucial and identifying, quantifying these in exhausts is a necessary first step before implementing reduction measures.

Controlling emissions from compression ignition (CI) engines, or diesel engines, is critical to mitigating their environmental and health impacts. Several strategies and technologies are employed to reduce the emission of harmful pollutants such as NO_X, PM, CO, HC, and SO_2. Controlling emissions from compression ignition (CI) engines, such as diesel engines, is crucial to meet environmental standards and reduce the impact on environments and living organisms. Several methods employed control and reduce harmful emissions shown in figure 2, including both engine modifications and after-treatment technologies.

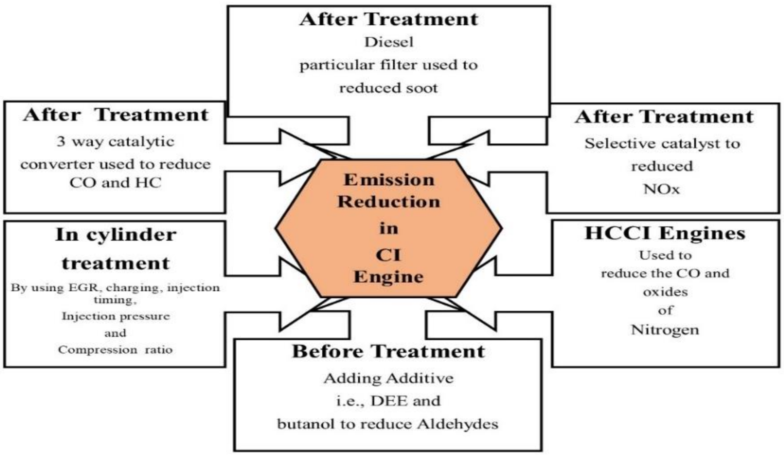


Fig. 2 Methods for Reduction of emissions in CI Engine

Among the various alternatives, biomass-based resources are abundant and cost-effective. Various types of biomass waste can be converted into valuable energy through different methods [2]. The thermochemical process, in particular, is highly efficient in producing high-quality fuel from both solid and liquid biomass wastes. Fish oil, obtained from the tissues of oily fish, has emerged as a promising alternative fuel source. While it is traditionally valued for its high omega-3 fatty acid content and nutritional benefits, fish oil can also be converted into biofuel. This transformation can be accomplished through processes such as transesterification, which creates biodiesel, and hydro processing, which generates renewable diesel [3].

Fish oil presents several benefits as a biofuel feedstock. It is abundantly available as a byproduct of the fish processing industry, making it both a cost-effective and sustainable option. Moreover, using fish oil for fuel helps reduce waste and encourages resource recycling [4]. The process of converting fish oil into biodiesel involves a reaction between the oil and an alcohol (typically methanol) in the presence of a catalyst, resulting in the production of FAME and glycerin. This biodiesel can be utilized in standard diesel engines with minimal or no modifications [5]. Producing renewable diesel from fish oil involves hydro processing, a technique that removes oxygen from the oil through hydrogenation. This method yields a high-quality hydrocarbon fuel that is similar to conventional diesel but with a reduced environmental impact [6]. Transesterification is a chemical process that converts the large triglyceride molecules into smaller and this transformation occurs by reacting the large triglyceride molecules with catalyst i.e., alcohol [7-8].

LFWCO is suitable for use in CI engines due to its favorable physical, cetane index, and thermal properties compared to WCO, making it efficient in diesel engines. The addition of high-cetane fuels like diethyl ether (DEE), which boasts a cetane index of approximately 125, can significantly reduce ignition delay [9] and different types of additives are shown in figure 3.

In experiments, a CI engine operated with blends of LFWCO and DEE ranging from 5% to 20% in 5% increments. The optimal blend identified was LFWCO with 15% DEE, demonstrating enhanced performance and reduced emissions. Under full load conditions, the LFWCO+15% DEE blend showed a 28.9% increase in BSFC and an 11.9% lower exhaust gas temperature (EGT) compared to diesel. Furthermore, emissions of CO, NO, and smoke opacity were reduced by 32.9%, 25%, and 29.4%, respectively, though NO_X emissions increased by 36% compared to diesel [10].

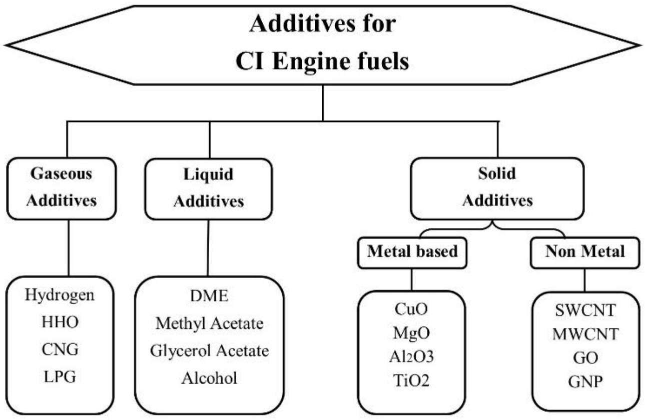


Fig. 3 Additives for CI Engines

In the realm of green technology, numerous processes aimed at environmental sustainability are swiftly emerging. A prominent strategy involves the production and adoption of biofuels, particularly within the automotive industry. Extensive research into renewable energy has underscored their potential to supplant fossil fuels, owing to their renewable nature and environmental advantages. Ongoing studies are continuously advancing proactive solutions, furthering the global transition towards renewable energy sources and biofuels [11]. For example, biodiesel derived from inexpensive feedstocks exhibits clean combustion traits and reduces global dependence on diesel when utilized in unmodified vehicles. Numerous studies have indicated that biodiesel blends can improve both the efficiency and emission profiles of diesel engines [12].

Parinari polyandra biodiesel blends in a six-cylinder diesel engine, noting enhanced performance and reductions in CO_2, HC, and CO emissions by approximately 65.7%, 53.8%, and 81.7%, respectively, with a 35.1% increase in NO_X emissions [13]. biodiesel blends of sunflower and soybean oil to neat diesel, finding significant improvements in BSFC and BTE, and reductions in UHC and CO emissions by 41.18% and 33.8%, respectively, although NO_X emissions were higher [14]. Biodiesel produced from parsley seed oil via alkali-induced transesterification was tested in an engine using different blends and it was found that a blend containing 20% biodiesel performed optimally without requiring any engine modifications., emitting fewer hydrocarbons and carbon monoxide than diesel, but more NO_X and CO_2. Compared to B5 and B10 blends, B20 showed greater reductions in CO (33.9%), CO_2 (29.73%), and HC (11.38%) [15].

Additives are frequently employed in biodiesel-diesel blends to replace traditional diesel fuel. Nanoparticles, renowned for their elevated thermal conductivity and favorable surface-to-volume ratio, function as catalysts to enhance physiochemical properties, engine performance, and emission reduction. Iso-butanol represents a promising alcohol additive with superior properties and greater energy content compared to ethanol, methanol, and n-butanol [16-19]. Iso-butanol and n-butanol, both isomers of butanol, share the same molecular weight but differ in chemical structure. Iso-butanol, a long-chain additive, blends easily with biodiesel-diesel mixtures and has high energy content [20-23]. Incorporating iso-butanol into diesel enhances performance and combustion characteristics while significantly reducing emissions. Similarly, n-butanol reduced in emissions due to its weaker carbon and hydrogen bond bond energy compared to iso-butanol. Higher alcohol concentrations also led to reduced NO_X emissions, with both alcohols enhancing performance and combustion characteristics [24-25].

Diesel engines running on WCO biodiesel with diesel and additives, showing improved performance and reduced CO and HC emissions and found WCO to be a viable diesel alternative, offering similar performance with lower in emissions but slightly increased in NO_X. WCO biodiesel effectively lowers emissions in CO and HC, though NO_X requires further mitigation. Adding diethyl ether (DEE) to diesel improves combustion efficiency and reduces CO, HC, and PM emissions due to DEE's high oxygen content similarly Jatropha biodiesel reduces CO and HC emissions but increases NO_X, suggesting it as a sustainable fuel with proper NO_X control found Jatropha biodiesel enhances combustion efficiency, reduces emissions, and exhibits a longer ignition delay. [26-32]

Nano additives in CI engines enhance fuel properties, improve combustion, and reduce NO_X, CO, and PM emissions and highlighted that nanoparticle improve fuel stability, enhance combustion, and reduce emissions in diesel engines. SiO_2 nanoparticles in a ternary fuel blend enhance combustion efficiency and reduce NO_X, CO, and HC emissions and found various nano additives significantly reduce emissions and improve engine performance when using WCOBD [33-35]. Turbocharged CRDI diesel engine using Tung oil-diesel-ethanol microemulsion improves performance and reduces CO and HC emissions, with optimization needed for NO_X and blends of n-butanol and iso-butanol with diesel fuel improve combustion efficiency, enhance engine performance, and reduce emissions. Iso-butanol demonstrates superior performance attributed to its higher volatility and oxygen content. [36-37]

The current experimental study focused on analyzing emission characteristics using fish oil methyl ester (FOME) blended with diethyl ether (DEE) and butanol at different composition percentages in a CI-DI engine. In the current study, fish oil methyl ester (FOME) derived from fish waste was distilled using a borosilicate round bottom flask to obtain purified FOME from raw fish oil. Subsequently, FOME was blended with 15%, 35%, and 60% of diethyl ether (DEE) and butanol (BTN) [35,36]. These FOME-DEE-BTN blends were tested in both a conventional single-cylinder engine and a low heat rejection (LHR) engine to analyze emission characteristics, which were then compared to the emissions from pure FOME.

2. Experimental Configuration and procedure

The experimental setup utilized for investigating both Conventional and LHR diesel engines with various fuel blends is depicted in Figure 4a, while the configurations of the engines are detailed in Table 1.

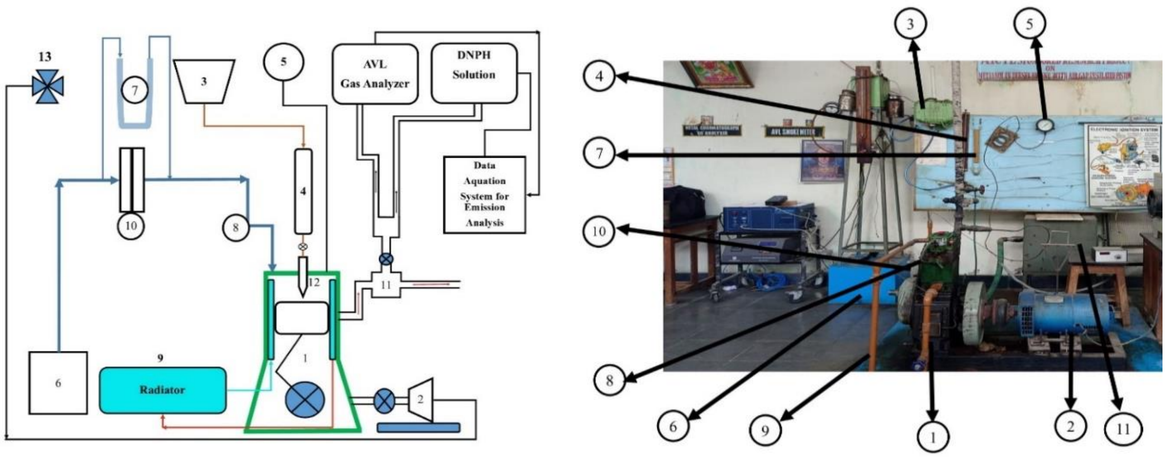
Table 1 Testing Engine Technical details

Engine parameters		Specifications
Engine Type		4 stroke single cylinder, constant speed, direct injection CI Engine
Manufacturer		Kirloskar
Rated power		3.68 kW at 1500RPM
Bore		80mm
Stroke		110mm
Specific volume		0.552 liter
Compression ratio		16.5:1
Cooling type		Water cooling
Insulated insert	Material	Ni90
	Thickness	5mm

The experimental setup utilized a compression-ignition engine featuring an aluminum alloy piston, with cylinder dimensions of 80 mm diameter and 110 mm stroke length. It operated at a rated output of 3.68 kW and a rotational speed of 1500 rpm. Fuel consumption was measured via the burette method, while air consumption was monitored using an AVL 5-Gas analyzer setup. Figure 4a illustrates both the schematic diagram and a photograph of the experimental configuration.

The naturally aspirated engine included a water-cooling system, maintaining an inlet water temperature of 30°C through regulated flow rates. Experiments were conducted at 1500 RPM, with fuel injection pressure of 190 bar, a 27° cranking angle, and a compression ratio of 16.5:1. Engine startup was manual, initially fueled with diesel until achieving steady-state operation. Water flow to the cooling jacket was maintained around 9 LPM. Once stability was achieved, various test fuels were introduced from a separate tank.

Load conditions were regulated using an eddy current dynamometer, incrementally increasing from 0 to 100% in 20% increments for each experimental cycle. Different fuel blends, including FOME, FOME85+DEE15, FOME50DEE15+BTN35, and FOME25+DEE15+BTN60, were evaluated. Key parameters such as manometer readings, engine load, and fuel consumption were systematically recorded throughout the experimental procedures.



a. Schematic layout **b. Photo graphic view**

1. Engine, 2. Electrical Dynamo meter, 3. Fuel tank, 4. Burette, 5. Piezo-electric pressure transducer6. Air box, 7. U-tube water manometer, 8. Air inlet, 9. Outlet-jacket water flow, 10. Orifice meter11. Exhaust gas sampling collection,12. Fuel Injector, 13. Dynamometer control

Fig. 4a Experimental setup

2D View of Ni90 fastened LHR Engine **Ni90 Insert** **Ni90 fastened LHR Engine**

Fig. 4b LHR Engine Piston

The LHR CI Engine featured a piston composed of two parts: an aluminum piston body and a top crown constructed from a low thermal conductivity material, specifically Ni90, with a thickness of 5mm. When the Ni90 insert was affixed to the engine crown, it featured a 3-mm air gap [23&24], a configuration identified as optimal for enhancing engine performance. This air gap, as determined from the study, was found to be the most effective thickness for improved engine performance. At a temperature of 500°C, the thermal conductivities of air and Ni90 are recorded as 0.057 W/mk and 20.92 W/mk, respectively. A depiction of the Ni90 insert with the air-gap piston can be observed in Figure 4b.

During the operation with FOME, DEE and butanol mixture, the primary pollutant emitted from the engine is aldehydes, which are known to be carcinogenic and harmful to human health. However, literature often lacks sufficient reporting on the measurement of these aldehydes. To address this, aldehydes were quantified using the wet method, chosen for its simplicity and efficiency. This method allows for the specific determination of individual aldehydes such as acetaldehyde and formaldehyde.

In the experimentation, the DNPH (2,4-dinitrophenyl hydrazine) method was employed to measure aldehydes in the exhaust. Here, the engine exhaust was passed through a solution of DNPH, forming hydrazones that were subsequently extracted into chloroform. The concentrations of formaldehyde and acetaldehyde in the exhaust were then analyzed using high-performance liquid chromatography (HPLC) to determine their percentage concentrations accurately.

3. Analysis of Experimental data

This section provides a comprehensive comparison of emission data between conventional and LHR engines using various blends of FOME, DEE, and butanol. The analysis includes a detailed evaluation of emissions such as carbon monoxide (CO), nitrogen oxides (NO_X), smoke opacity, and hydrocarbons (HC), which encompass measurements of aldehydes as well.

The outcomes of these tests offer valuable insights into how these biofuel blends contribute to emission reduction and enhance engine performance. By comparing the conventional and LHR engine results, we aim to identify the advantages and potential challenges associated with each engine type when utilizing these alternative fuels. The following discussion will delve into the specific impacts of FOME, DEE, and butanol blends on emissions and performance metrics, offering a nuanced understanding of their viability as cleaner fuel alternatives.

BTE serves as an indicator of how effectively fuel is converted into useful work through combustion within the engine. It's well-established that a significant portion of the energy released during combustion is diverted from the engine through processes such as lubrication, cooling, and exhaust gases. Consequently, the remaining energy can be harnessed to produce power within engines. Figure 5 depicts the changes BTE with varying engine load across different blends.

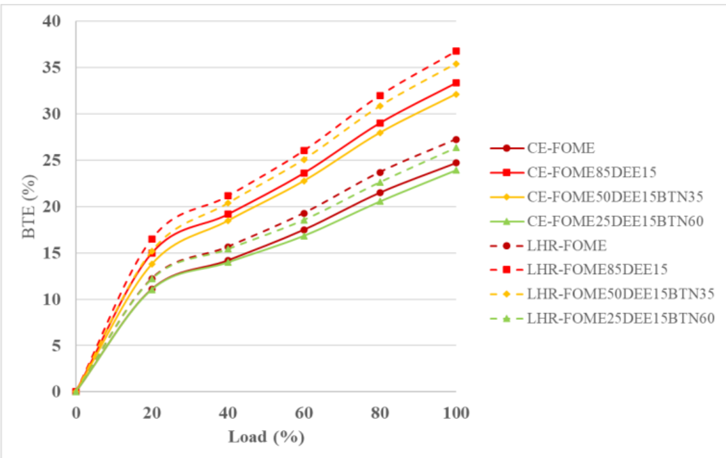


Fig. 5 Variation of brake thermal efficiency with respect to load

As shown in Figure 5, the addition of DEE to FOME increases BTE by 35% compared to pure FOME. This significant improvement in BTE is due to DEE's enriching effect and higher oxygen content, which enhances the uniformity of the fuel-air mixture in the combustion chamber. Consequently, this results in improved combustion efficiency and higher overall engine efficiency. However, it's observed that the addition of DEE to FOME can introduce irregularities in engine operation. Similarly, when butanol is added to the aforementioned blend, BTE is reduced by 4-6% with the addition of 35% and 60% composition in the blend. This reduction occurs due to the introduction of butanol, which diminishes combustion characteristics. In the case of the LHR engine, BTE experiences a notable increase of 10.2% compared to the CE. This enhancement is attributed to the surfaces coated with a thermal insulating material, which effectively minimizes heat loss through radiation from surfaces of engine.

Figure 6 illustrates the variation in CO emissions across different blends of FOME, DEE, and Butanol. CO emission rates decrease with increasing engine load for all fuel blends, but there is a slight increase after reaching 80% load for both conventional and LHR engines. This increase can be attributed to improved combustion efficiency at higher operating loads. Among the blends, FOME50DEE15BTN35 shows lower CO emissions compared to plain FOME and other blends across the entire load range. This reduction is attributed to the presence of dissolved oxygen, which facilitates more complete combustion of the fuel. The CO emissions from FOME50DEE15BTN35 blends are notably lower than those from plain FOME and FOME+DEE blends. This improvement may be due to the higher ignition rate and additional oxygen from DEE and butanol, which contribute to smoother fuel combustion and lower CO emission rates. The emission of CO for FOME50DEE15BTN35 lower with percentage of 52.45% with FOME,47.27% with FOME85DEE15 and 9.3% with FOME25DEE15BTN60 with conventional engine similarly for LHR Engine 52% with FOME,42% with FOME85DEE15 and 7.6% with FOME25DEE15BTN60. From these we can say that the combination of 50% FOME, 15%DEE and 35% of butanol shows lower emission of CO and specially for LHR engine it shows some lower emission with average percentage of 2.3% which is the better than the waste cooking oil [26-29].

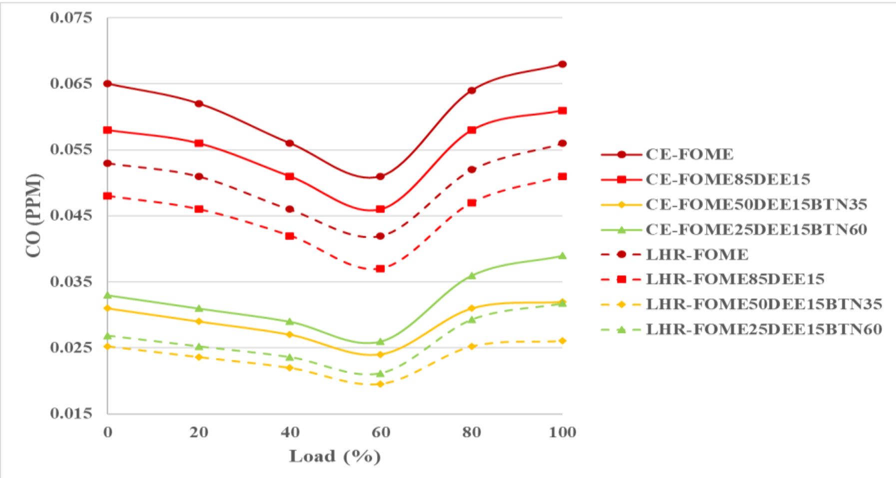


Fig. 6. Variation of CO emission versus load for FOME, DEE and Butanol blends

Figure 7 illustrates the NO_X emissions of FOME, DEE, and butanol blends tested across various load levels. Throughout all loads, NO_X emissions from these blends were higher than those from pure FOME. Specifically, NO_X emissions for FOME50DEE15BTN35 increased on average by 8.2%, 18%, and 2% compared to FOME, FOME85DEE15, and FOME25DEE15BTN60, respectively. This increase is influenced by fuel properties, engine load, and oxygen concentration in biodiesel blends [30].

The slight rise in NO_X emissions observed with FOME blended with DEE and butanol can be attributed to the higher oxygen content in biodiesel fuels. Moreover, biodiesel fuels containing more unsaturated fatty acids, as found in butanol, have higher adiabatic flame temperatures, leading to increase NO emissions [31]. These findings are consistent with previous research indicating that biodiesel blends generally emit higher levels of NOx compared to traditional diesel fuels [32]. Similar trends were observed in LHR engines using the same blend combinations, with NO_X emissions increasing by 3%, which is lower compared to waste cooking oil [33].

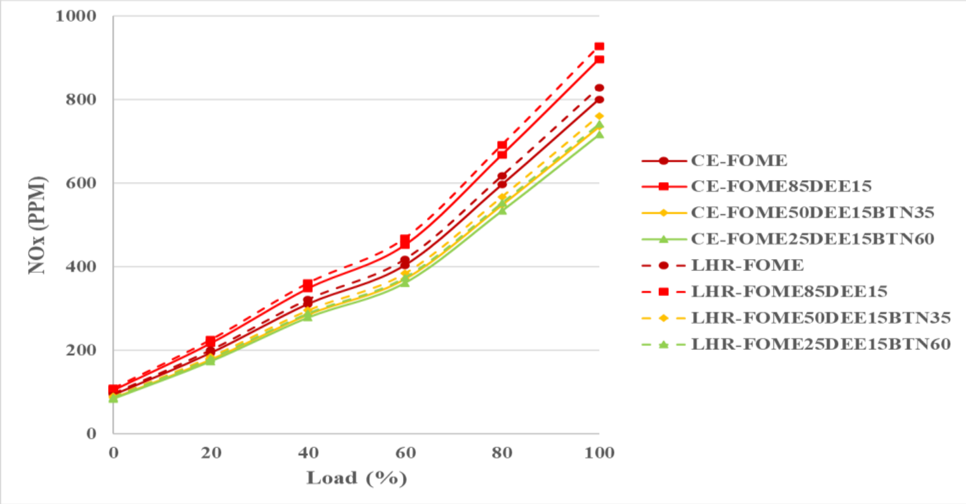


Fig. 7 Variation of NO_X emission with load for FOME, DEE and butanol blends

Figure 8 illustrates the impact of load on smoke opacity for different fuel blends. FOME fuel exhibits higher smoke emissions compared to blends of FOME with DEE and butanol. This is primarily due to greater fuel accumulation in the combustion chamber, lower oxygen content in rich fuel zones, and poor vaporization characteristics, resulting in smoke formation. Smoke emissions typically result from incomplete or partial combustion of fuel [34].

Blends like 85% FOME and 15% DEE show lower smoke emissions compared to pure FOME due to their higher oxygen content and faster oxidation processes in all rich fuel zones within the combustion chamber. Additionally, smoke emissions are reduced with the addition of butanol additives, attributed to their higher surface activity, greater surface area to volume ratio, improved ignition properties, shorter ignition delay, and better evaporation rates in the presence of oxygenated blends [35,36].

FOME25DEE15BTN60 exhibits lower smoke emissions due to its higher viscosity and fuel blend density. On average, smoke opacity for FOME25DEE15BTN60 is reduced by 15.3%, 4.6% for FOME85DEE15, and shows an increase for FOME50DEE15BTN35, which is within acceptable limits and lower [36].

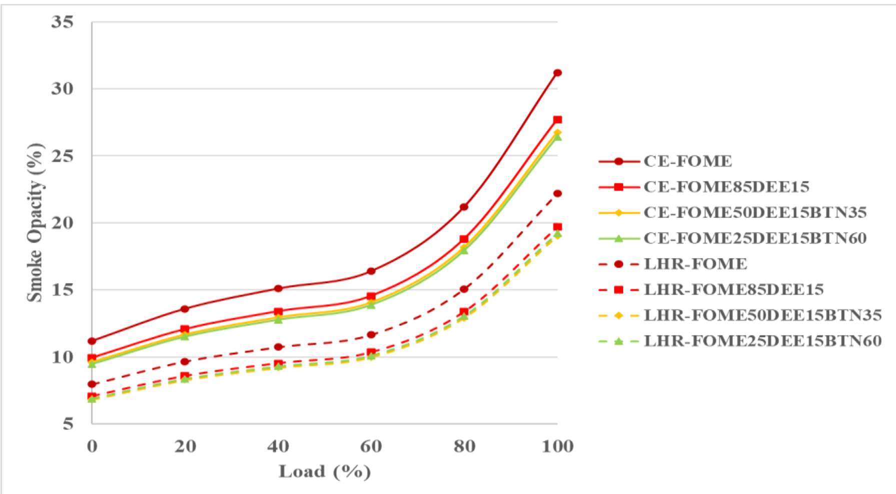


Fig. 8 Variation of Smoke opacity with load for FOME, DEE and butanol blends

The average highest reduction in smoke emissions was observed to be 14.12% for the FOME25DEE15BTN60 blend correlated to FOME fuel at average load condition similarly for LHR Engine it reduced by 28% compare to conventional engine at same combination.

Figure 9 illustrates the impact of load variation on hydrocarbon (HC) emissions for FOME, DEE, and butanol blends. HC emissions from the engine indicate lower performance, and it is observed that HC emissions are 19.2% higher for pure FOME85DEE15 compared to FOME, primarily due to the addition of alcohol additives to FOME. However, the addition of butanol reduces these hydrocarbon emissions by 26% and 28% with the inclusion of 35% and 60% butanol in FOME85DEE15, respectively.

The average HC emissions emitted for FOME, FOME85DEE15, FOME50DEE15BTN35 and FOME25DEE15BTN60 is 26.32, 31.37,2 3.21, 22.61 PPM respectively, at average loads. The higher HC emissions observed in the FOME85DEE15 blend are attributed to wall films forming in cold quench zones when a rich air-fuel mixture is supplied. Introducing iso-butanol into the FOME85DEE15 blend accelerates the evaporation rate of fuel droplets, owing to the low boiling point of iso-butanol. This action reduces the ignition delay period and promotes rapid combustion, thereby lowering HC emissions [37].

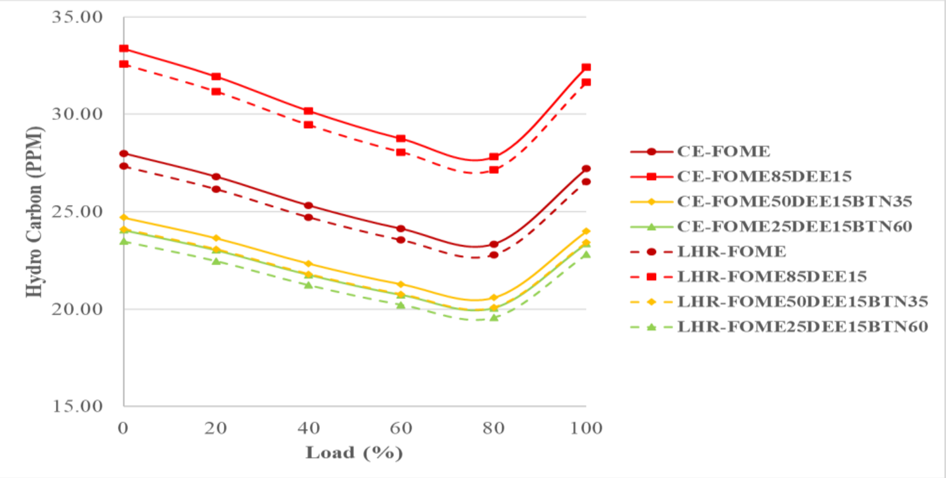


Fig. 9 Variation of Hydro carbon emission with load for FOME, DEE and butanol blends

Figure 10 illustrates the changes in formaldehyde levels at various loads for FOME, DEE, and butanol blends. One drawback of using ethanol is its tendency to increase formaldehyde levels. However, in LHR engines, formaldehyde levels are reduced compared to conventional engines due to enhanced combustion, improved heat release rates, and faster combustion rates.

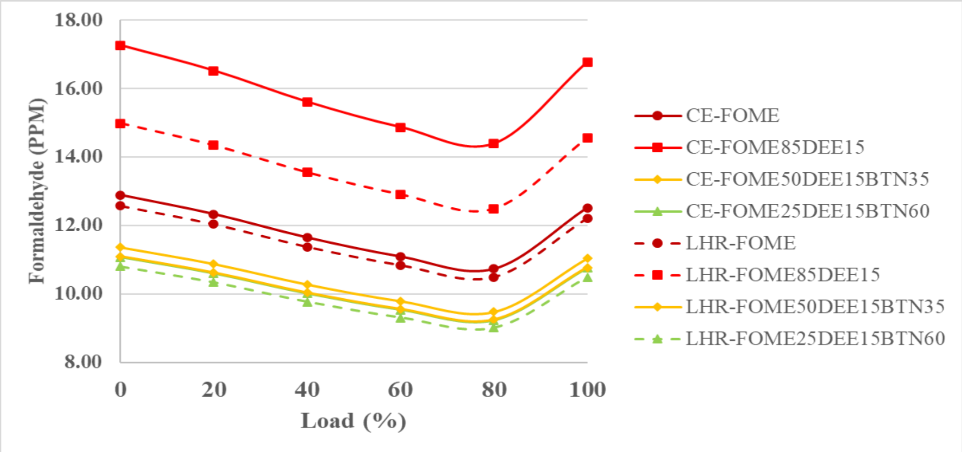


Fig. 10 Variation of Formaldehyde emission with load for FOME, DEE and butanol blends

With the addition of butanol to both engine configurations, formaldehyde levels decreased. Specifically, the inclusion of 15% DEE with FOME initially increased formaldehyde levels by 34%, attributed to its high oxygen content. However, when 35% butanol was added to the FOME+DEE blend, formaldehyde levels decreased by 34.12%. This reduction is due to improved atomization characteristics and faster combustion rates facilitated by the oxygenated fuel mixture.

The addition of butanol aimed to decrease aldehyde emissions in both engine types through enhanced fuel atomization and combustion with DEE and oxygen. In LHR engines, formaldehyde levels decreased by an average of 2.38% at 80% load compared to conventional engines.

Figure 11 shows how acetaldehyde levels vary at different loads for blends of FOME, DEE, and butanol. Using ethanol tends to increase acetaldehyde levels, but a Low Heat Rejection (LHR) engine demonstrated lower acetaldehyde levels compared to a conventional engine (CE) due to enhanced combustion, improved heat release rates, and faster combustion processes.

In both engine versions, acetaldehyde levels decreased with increasing amounts of butanol, with the greatest reduction observed when 15% DEE was added to FOME. This decrease is attributed to improved combustion characteristics and faster combustion rates facilitated by the presence of oxygen in the fuel mixture.

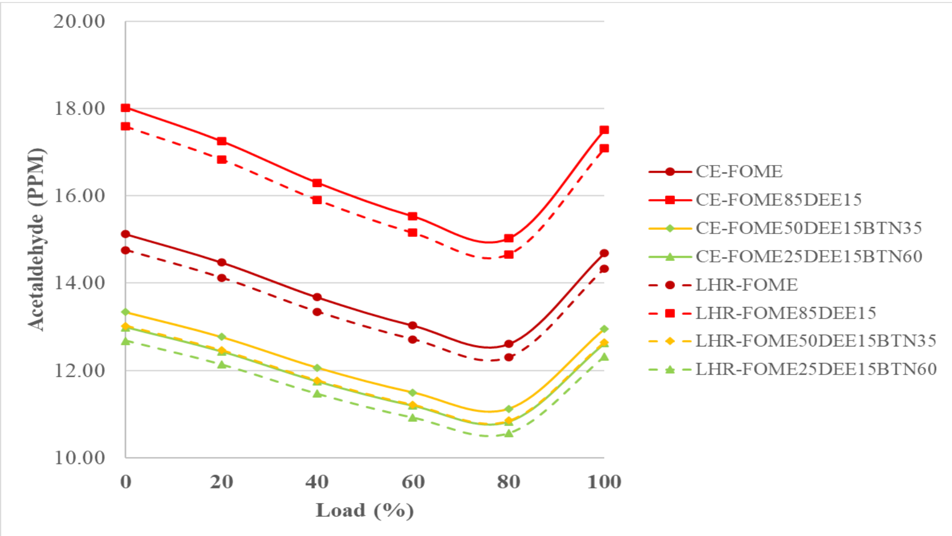


Fig. 11 Variation of Acetaldehyde emission with load for FOME, DEE and butanol blends

Adding DEE to FOME initially increased acetaldehyde levels by 19.16% due to the high oxygen content. However, when 35% butanol was added to the FOME+DEE blend, acetaldehyde levels were reduced by 22.22%. This reduction is attributed to better atomization characteristics and a faster combustion rate due to the oxygen-rich fuel. The primary purpose of incorporating butanol was to decrease aldehyde emissions in both engine versions by improving fuel atomization and combustion when combined with DEE. The LHR engine reduced acetaldehyde levels by an average of 2.44% at 80% load compared to the CE**.**

4. Conclusions

Emission control and aldehyde reduction using FOME, DEE, and butanol blends in CI engines can be drawn based on the analysis of experimental data and observations. Here are some potential conclusions that might be derived from such a study:

- BTE in the conventional engine is notably higher with FOME85+DEE15 fuels, showing a 34.3% increase compared to FOME and other blends. Moreover, for the LHR engine, BTE is increased by 10.2% compared to the CE.
- The integration of FOME, DEE, and butanol blends i.e., 50% FOME, 15% DEE and 35% of butanol significantly improved the combustion process in diesel engines similarly LHR engines demonstrated

superior combustion efficiency compared to conventional engines (CE), leading to lower emission levels overall.

- The combination of FOME, DEE, and butanol blends in CI engines led to a comprehensive reduction in harmful emissions, including CO, Smoke opacity and HC aside from aldehydes. FOME50DEE15BTN35 blends reduced by 52.45%, 17.3% and 10.73% present a promising alternative to pure FOME and conventional diesel fuel, contributing to cleaner engine operation and reduced environmental impact similarly for LHR engine shows a 17.2%, 28.8% and 2.3% at same blend but NO_X is increased by 3.1%.
- A notable drawback of using DEE as a fuel is the increase in acetaldehyde emissions. However, blending DEE with FOME increased acetaldehyde emissions by 19.16% due to its high oxygen content. The addition of 35% butanol to the 50FOME+15DEE blend effectively reduced acetaldehyde emissions by 22.22%, indicating that butanol helps counteract the increase in aldehyde emissions caused by DEE.
- Low Heat Rejection (LHR) engines consistently exhibited lower acetaldehyde levels than conventional engines (CE), especially at high load conditions. This reduction is attributed to the enhanced heat release rates and faster combustion facilitated by LHR engines. On average, LHR engines demonstrated a 2.44% decrease in acetaldehyde levels at 80% load compared to CE, underscoring their efficacy in controlling emissions.
- Incorporating butanol into the fuel blend not only decreased aldehyde emissions but also enhanced atomization properties and combustion rates. The oxygen content in butanol facilitates more thorough combustion, leading to further reductions in harmful emissions.

In conclusion, the use of FOME, DEE, and butanol blends in CI engines offers a viable solution for improving combustion efficiency and reducing harmful emissions including aldehydes. LHR engines further enhance these benefits, making them an attractive option for future diesel engine designs aimed at environmental sustainability from these we can say that 50FOME15DEE35BTN with LHR Engine is the best combination to achieve good performance and lower emissions.

Nomenclature

FOME	Fish oil methyl ester
DEE	Diethyl ether
BTN	butanol
CI	Compressed ignition
FOME85DEE15	85% fish oil methyl ester and 15% Diethyl ether
FOME50DEE15BTN35	50% fish oil methyl ester, 15% Diethyl ether and 35% butanol
FOME25DEE15BTN60	25% fish oil methyl ester, 15% Diethyl ether and 60% butanol
DI	Direct injection
CO	Carbon monoxide
HC	Hydro carbon
UHC	Un burnt hydro carbon
NO_X	Oxides of nitrogen
WCO	Waste cooking oil
WCOBD	Waste cooking oil bio diesel
LFWCO	Light fractured waste cooking oil bio diesel
CE	Conventional engine
EGT	Exhaust gas temperature
FAME	Fatty acid methyl esters

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