

# Consequence Reduction of Aldehydes Emissions from Heat Loss Diesel Engine with Butanol-Biodiesel Blend with Diethyl Ether

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## ABSTRACT

Diesel engine emission investigators are always interested in uncontrolled chemical species, such as particle emissions, olefins, alkanes, and carbonyl aldehydes. Describe the emissions of formaldehyde and acetaldehyde, two chemicals that are bad for human health but are not yet regulated for diesel engines. They cause health hazards, to reduction of aldehydes in exhaust emissions by modification of diesel engine at different operating parameters with alcohol fuel blends. When alcohol was added, more aldehydes were emitted. Experiments were conducted to reduce aldehydes emissions from heat loss diesel engine with different degree of insulation under standard temperature condition of Butanol and fish oil as biodiesel with 15% of Di-Ethyl Ether (DEE) blend operation with injection timing at 27°bTDC and varied injection pressures from 190 to 290 bar. The blends used in the experimental tests were BU30B55DEE15 (Butanol 35%-Biodiesel 50%- DEE 15%) and BU40B45DEE15 (Butanol 40%-Butanol 45%-DEE 15%), BU50B35DEE15 (Butanol 50%-Biodiesel35%-DEE15%) and BU60B25DEE15 (Butanol 60%-Biodiesel 25%-DEE 15%). Biodiesel with 15% DEE and diesel were evaluated as reference fuels. In order to increase the mass percentage of butanol fed into the engine at maximum load operation, a variable jet carburettor was installed at the engine's inlet manifold. Biodiesel was blended with 15% Di-Ethyl Ether (DEE) and injected through a standard injection system. Samples were extracted and analysed by dinitrophenyle (DNPH) method and to determine the emissions of aldehydes concentration. Comparative studies were made between heat loss (HL) diesel engine with conventional engine.

**Keyword:** Heat loss diesel Engine, Fish oil, Butanol, Biodiesel, DEE, Aldehydes

## 1. Introduction

Because alcohols are produced from renewable biomass, have a high oxygen content, and are liquid in nature, they are attractive fuel substitutes for diesel. There are numerous ways to introduce alcohols into CI engines, including surface ignition, dual injection, blending, and carburetion. Of these, it was discovered that the techniques of carburetion and blending were the most straight forward. Compared to ethanol and methanol, butanol has drawn more interest due to its properties that are comparable to those of fossil fuels. For internal combustion engines, butanol performs better than methanol or ethanol due to its higher heating value, higher cetane number, lower vapor pressure, and lower auto-ignition temperature. When diesel engine run with alcohol fuel then aldehyde emissions produced. Uncontrolled pollutants known as aldehydes are harmful to people. Complex atmospheric processes involving aldehydes can result in the production of extra gaseous oxidants like ozone, which can cause respiratory problems.

In an effort to boost the biodiesel economy, various researchers have searched for sustainable feed sources with significant lipid/oil content. Because of leftover cooking oil, fish oil, and microalgae oil, these natural resources, which do not compete with food supplies have drawn a lot of attention [1]. Fish oil has a wide range of applications, including medical ones. Around 90% of fish are consumed by humans, as well as for other purposes. The majority of fish waste is dumped. Discarded fish components include the dorsal fin, anal fin, caudal fin, operculum, pelvic fin, eye, and overlapping scales. As a result, the world's subcontinent offers enormous potential for producing value-added goods from fish waste, such as discarded fish oil. Yet, leftover fish parts are mostly thrown out and might only seem to be used in a few, really insignificant applications [2]. Fish oil biodiesel is made using fish waste or residue as a source material. According to the literature survey, research into the use of fish oil in diesel engines and leftover fish parts was quite

limited.. The goal of the investigation is to explore in a compression ignition engine with Fish Methyl Ester (FME-20) fuel and further enhance the Fish Methyl Ester (FME-20) fuel attributes with oxygenated Di-ethyl Ether (DEE) additive to increase engine performance and reduce hazardous emissions [3]. “The authors tested several blends of fish biodiesel on a common rail diesel engine by varying injection time from 12 degrees to 22 degrees bTDC and injection pressure from 12 to 15 psi. As the amount of biodiesel climbs, brake specific fuel consumption (BSFC) and NO<sub>x</sub> emissions increase, while soot, hydrocarbons (HC), and carbon monoxide (CO) emissions decrease”[4]. The literature review indicates that the usage of fish oil in diesel engines and abandoned fish pieces have not received much attention. The study aims to investigate the use of fish oil as biodiesel in diesel engines and the improvement of fish biodiesel properties with oxygenated Di-Ethyl Ether additive to boost engine performance and lower hazardous emissions. Diethyl ether or dimethyl ether should be blended at a ratio of 15% by volume, according to the literature review.

## 2. Literature Survey

Examined how injection time and pressure affected the operation and emission properties of diesel engines running on blended biodiesel [5]. The use of diesel-ethanol blends in diesel engines resulted in a 60% reduction in nitrogen oxide (NO<sub>x</sub>) emissions; nevertheless, total hydrocarbon (THC), carbon monoxide (CO), and aldehydes were found to have increased[6]. An experimental investigation was undertaken with blends of papaya methyl ester and eucalyptus oil to explore the impact of di-ethyl ether addition on the operation and emission characteristics of the LHR engine[7]. According to the research, the most common carbonyls are formaldehyde and acetaldehyde, followed by methanol-diesel fuel mixtures, acrolein, acetone, propionaldehyde, and crotonaldehyde. The combination of methanol with diesel fuel produces much larger levels of formaldehyde, acetaldehyde, and acrolein[8]. Examined were the emissions and performance of diesel engines running on mixes of Jatropha biodiesel, Jatropha-butanol mixed fuel, and Jatropha biodiesel [9]. Dinitrophenyl hydrazine (DNPH) solution was used to trap the carbonyl compound emissions from the exhaust gas of engines with spark ignition and homogenous charge compression ignition. These emissions were analyzed both qualitatively and quantitatively[10]. Diethyl ether addition might be a useful solution for biodiesel or alcohol-related issues. Diesel and biodiesel, diesel and butanol, or diesel and pentanol blends were studied for the impact of diethyl ether on engine performance and emissions[11]. The fuel blend decreased NO<sub>x</sub> and particle matter (PM) and marginally increased THC and CO as the water concentration increased. PM was lowered by 81% and 67%, respectively, with blended fuel[12]. An investigation was carried out on a partially adiabatic diesel engine that had supercharging to make up for the volumetric efficiency loss caused by changes in injector opening pressure and injection timing, as well as a partially stabilized zirconium coating on the cylinder head, inner side of the liner, and piston crown. Supercharging using partially adiabatic diesel engine controlled contaminants such as particle emissions, NO<sub>x</sub> levels, and aldehydes[13]. Engines using LHR combustion chambers and maximal alcohol induction, along with injected crude jatropha oil, performed better than CE at 270 and 310 bTDC. However, it caused levels of nitrogen oxide (NO<sub>x</sub>) to rise[14].

Diesel fuel's reactions to mixes of fish methyl ester and di-ethyl ether were studied to reduce pollutants while boosting engine performance[15]. Butanol-biodiesel blends were evaluated in an experimental single-cylinder, four-stroke direct injection LHR engine. The effect of fuel blends on brake specific fuel consumption, brake thermal efficiency, exhaust gas temperature, and NO<sub>x</sub>, smoke opacity emission was investigated[16]. “The effect of fuel injection timing and injection pressure on combustion and odorous emissions in a direct injection diesel engine”[17]. To learn more about the possibilities for reducing NO<sub>x</sub> in diesel-biodiesel blends, water emulsifications are investigated in a direct injection (DI) diesel engine. The emulsions' NO<sub>x</sub> levels decreased by about 15% when 10% water was introduced. When it came to aldehyde emissions, B100 showed a 35% reduction, and when combined with 10% water emulsion, it produced approximately 90% less aldehydes than diesel fuel—a notable decrease[18]. “The study examines the potential of the Fuzzy Inference System (FIS) to predict the performance, combustion, and exhaust emissions of the Compression Ignition (CI) engine when using fish oil biodiesel at different injection timings (210, 240, and 270bTDC)”[19]. Experimental research using fish oil as biodiesel mixed with DEE was conducted using a single-cylinder diesel engine. EGR and oxygenate are used in conjunction with technology to improve engine performance and reduce emissions[20]. examination of the combustion and emissions of blended fuels in a compression-ignition engine, including diesel, ethanol, and biodiesel[21]. Diesel engines running on mixtures of butanol fuel, microalgae biodiesel, and diesel were tested for performance and emissions[22]. The diesel engine was tested using a mixture of diesel and ethanol along with canola, soybean, and plasma oils. The study has reduced emissions of smoke, aldehydes, HC, CO<sub>2</sub>, CO, and NO<sub>x</sub>. Among the lower emissions are mixes of methanol and ethanol with vegetable oils[23]. A DI diesel engine's aldehyde emissions are analyzed using blends of diesel oil, biodiesel, and castor oil (B5, B10, B20, and B35). Gas chromatography along with a flame ionization detection analyzer were used to identify and quantify aldehydes. In every fuel combination that was tested, acetaldehyde showed a greater exhaust concentration than formaldehyde[24].

Determine the physical and chemical properties of blends consisting of fish oil methyl ester (FOME), diethyl ether (DEE), and butanol [25]. Analysis of emission pollutants and aldehyde potential through the use of blends comprising Fish Oil Methyl Ester, Diethyl Ether [26].

The purpose of this experimental work was to investigate the emission of aldehydes from a heat loss diesel engine with varying degrees of insulation, using carburated butanol-fish oil as biodiesel with 15% di-ethyl ether (DEE) injection timing at 27<sup>0</sup>bTDC and varying injection pressures.

### 3. Experimental Setup and Procedure

#### 3.1 Test fuels

a. **Fish Biodiesel:** Brown crude fish oil containing a variety of contaminants, including fish waste, saline compound, and water, was extracted from the soap supply of marine fish. As a result, it was polished through a series of pre-treatment techniques. Fish residue was absorbed using active clay, winterized for 120 minutes at 4 °C, solid impurities were removed by centrifuging at 3000 rpm for 10 minutes, the mixture was washed for 15 minutes with 5 vol.% distilled water, and it was heated for 30 minutes to 105 °C. Methyl alcohol was used to transesterify refined fish oil in order to produce biodiesel [25].

b. **Di-Ethyl Ether (DEE):** Additives It is the burning of several chemicals that improves engine performance. The limitations of biodiesel fuel, including its density, toxicity, viscosity, auto ignition, cetane number, and flash point, will be lessened with the aid of the additions. The additives protect the engine from corrosion. One of the most promising alternative fuels or oxygen additives for diesel engines is di-ethyl ether (DEE), due to its high cetane number and oxygen concentration [26].

c. **Butanol:** Renewable Butanol can be created by fermenting carbohydrates in a method known as ABE fermentation, which produces acetone, Butanol, and ethanol. In the first step of fermentation, acetic and butyric acids are produced, and in the second step, the acids are re-assimilated to generate acetone, butanol, and ethanol [27].

Five blends were prepared in order to assess fish oil as biodiesel with 15% Di-ethyl ether(DEE) , namely (BD15DEE) and BU30B55DEE15 (Butanol 35%-Biodiesel 50%- DEE 15%) and BU40B45DEE15 (Butanol 40%-Butanol 45%-DEE 15%) and BU50B35DEE15(Butanol 40%-Butanol 35%-DEE 15%) and BU60B25DEE15 (Butanol 60%-Biodiesel 25%-DEE 15%).

#### 3.2 Heat Loss Diesel Engine

The optimal blending ratio of additive diethyl ether (DEE) with fish oil as biodiesel was discovered to be 15% by volume, and this was implemented to optimize combustion and emission characteristics. The test fuels utilized in the experiment with Heat Loss (HL) Diesel engine and conventional engine were carburetted butanol and biodiesel as fish oil with diethyl ether blends. The considerable properties of the fuels were given in table 1.

**Table I. Properties of fuels**

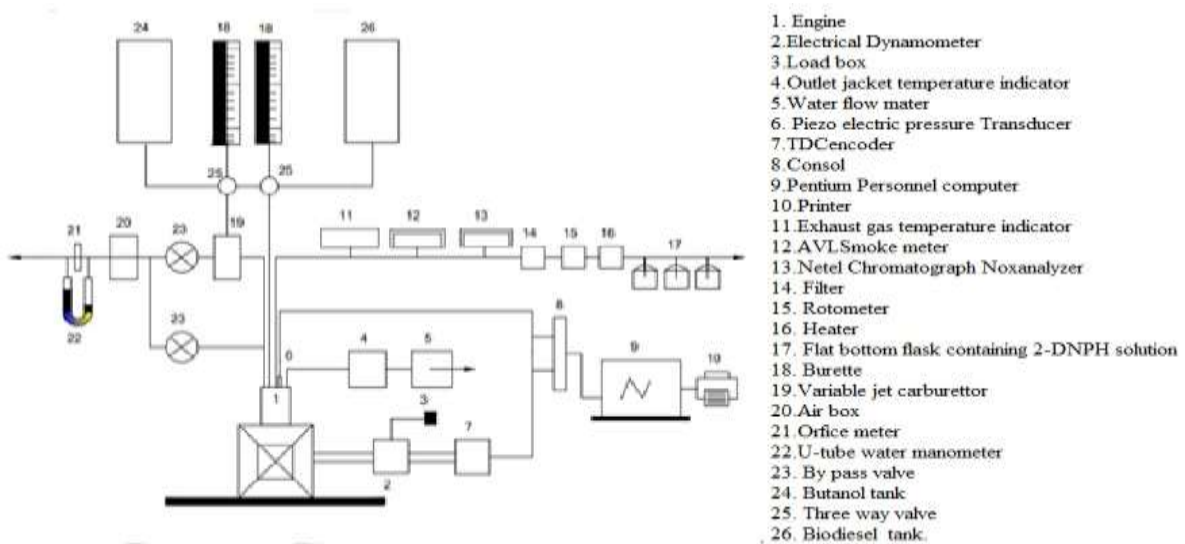
Fuel type	Viscosity at 40 <sup>0</sup> C (Centi-poise)	Density at 25 <sup>0</sup> C kg/m <sup>3</sup>	Cetane number	Calorific value (kJ/kg)
Diesel	3.06	840	55	42000
Biodiesel (Fish oil)	4.96	880	51	37800
Diethyl ether (DEE)	0.22	710	125	33980
Biodiesel with 15% DEE	3.23	850	61	39000
Butanol	3.64	810	25	37400

The Heat Loss diesel engine had a two-part piston, with the aluminum piston body and top crown made of superni-90, a low thermal conductivity material, screwed together with a 3 mm air gap between them. With a superni insert and diesel fuel, it was found that a 3-mm air gap in the air gap piston was the optimum thickness for improved engine performance. A 3-mm air gap separated the superni-90 insert from the liner body when It was fastened to the liner's top. The thermal conductivities of air and superni-90 are 0.057 W/m-K and 20.92 W/m-K, respectively, at 500 °C. The ceramic coated cylinder head , the superni-90 insulated air-gap piston , the insulated liner with superni insert are

depicted in Fig. 1. Using a plasma coating process, 500 microns of partially stabilized zirconium were applied to the cylinder head.



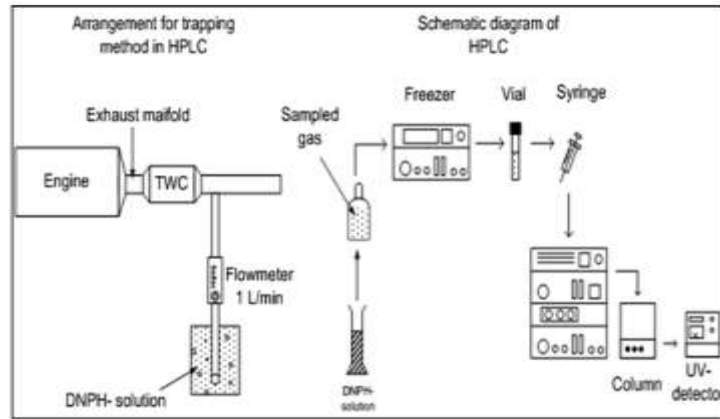
**Fig.1 Photographic views of Heat Loss diesel engine with different degree of insulation**



**Fig.2 An Experimental Setup Schematic Diagram**

The experimental setup for studies of the Heat Loss Diesel Engine using butanol and fish oil as biodiesel with 15% of Diethyl ether is shown by the image in Figure 2. An aluminum alloy piston with 80 mm bore and 110 mm stroke was used in conventional diesel engines. The engine's rated power was 3.68 kW @ 1500 rpm. The manufacturer's instructions stipulated that the injection pressure should be adjusted between 190 and 270 bars, the injection timing should be set at 27°bTDC, and the compression ratio should be 16:1.

Aldehydes are chemical molecules with a carbonyl group that are partly oxygenated. An aldehyde functional group is formed when a carbon atom forms a double bond with a hydrogen atom and an oxygen atom ( $O=CH-$ ). When butanol-biodiesel blends are used in the engine, aldehydes are the main pollution released. These aldehydes have a carcinogenic quality, making them extremely harmful to people. Aldehydes are measured using the DNPH technique. The DNPH method's process is depicted schematically in Fig. 3. The exhaust from the engine was passed through a 2, 4-dinitrophenyl hydrazine (2, 4 DNPH) solution. Using high-performance liquid chromatography (HPLC) to separate the produced hydrozones into chloroform, the percentages of formaldehyde and acetaldehyde in the engine exhaust were calculated.



**Fig.3 Measurement of aldehydes by DNPH method**

Observations were made on heat loss (HL) diesel engine with different butanol blend with percentage of 35%, 40%, 60% and biodiesel with 15% percent of Diethyl ether with injection timing at 27<sup>0</sup>bTDC and varied injection pressures. Experimental investigated the emissions of aldehydes from heat loss (HL) diesel engine and compared with conventional engine (CE).

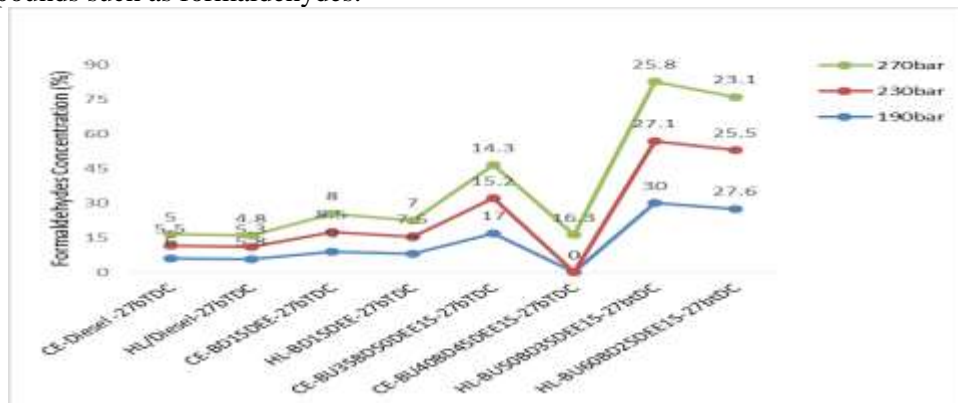
#### 4. RESULTS AND DISCUSSION

The fuel is injected into the diesel engine at the end of the compression stroke in the form of fine droplets, which are disintegrated and dispersed into the clearance space of the engine. The fuel-air ratios vary in the combustion space and in some regions; the mixture becomes leaner while in some regions it is richer, giving rise to the pockets of fuel-air mixtures lying between the lean limit and rich limit of combustion. Hence, in some regions fuel droplets find inadequate oxygen for the combustion to be completed. In such cases, only partial oxidation takes place, giving rise to unburnt hydro carbons which are emitted out through the exhaust. Such intermediate unburnt hydro carbon formed are the aldehydes. The problem would more pronounce in the case diesel engine employing oxygenated fuels, viz, alcohols. In the usage of butanol is used, aldehydes emitted in the exhaust of the engine. Therefore, a major contributor to aldehyde emissions during the ignition delay period is the over-leaning of gasoline injected, particularly in situations where the ignition delay is prolonged. Aldehydes can also form locally from an overly rich mixture that prevents flame propagation or ignition.

**4.1** The experimental analysis results are presented individually in the subsections on aldehyde emissions on Heat Loss Diesel Engines with varying degrees of insulation under maximum load conditions, injection pressure variations between 190 and 270 bar, and injection timing at 27<sup>0</sup>bTDC.

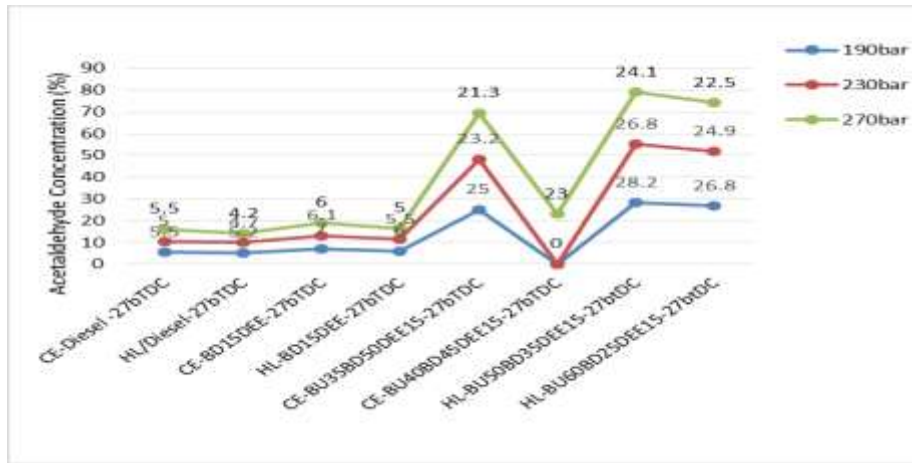
##### i. Ceramic Coated Cylinder Head (CC)

The experimental results displayed in Fig. 4 indicate varying levels of formaldehyde emissions from a heat-loss diesel engine with a ceramic-coated cylinder head (CC) operating on butanol-biodiesel with 15% diethyl ether. The increased end heat of butanol evaporation and lower cetane value may have contributed to reduced gas temperatures, which led to the creation of incomplete compounds such formaldehydes. Extremely significant formaldehyde emissions were seen in the exhaust of the heat loss engine when the butanol input was increased to 50% with low injection pressure. An increase in injector opening pressure also improved the combustion performance of the heat loss diesel engine by reducing intermediate compounds such as formaldehydes.



**Fig.4 Variation of formaldehydes emissions in CC**

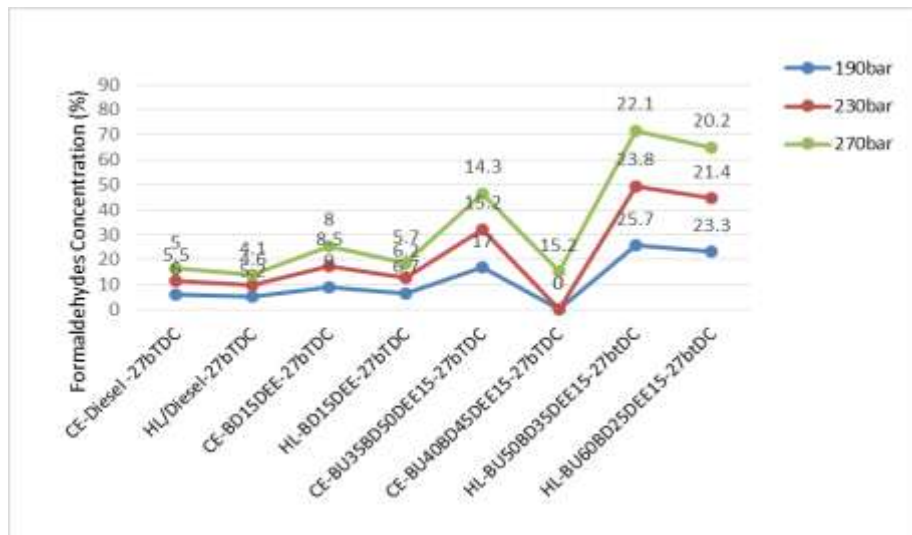
In a heat-loss diesel engine with a ceramic-coated cylinder head, Figure 5 illustrates the fluctuation in acetaldehyde emissions using butanol-biodiesel and 15% diethyl ether. With butanol induction, the patterns of formaldehyde and acetaldehyde emissions were comparable. Acetaldehydes are mostly produced during combustion when the properties of the butanol-biodiesel blend partially oxidize.



**Fig.5 Variation of acetaldehydes emissions in CC**

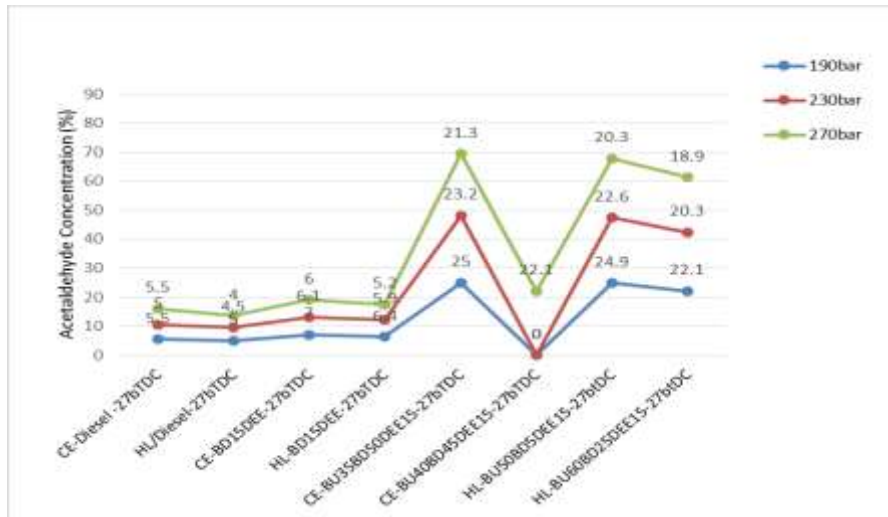
**ii. Air Gap Insulated Piston with Liner (IPL)**

Variations in formaldehyde emissions from heat-losing diesel engines with air-gap insulated pistons and liner using butanol-biodiesel with 15% diethyl ether are shown in Figure 6. Heat loss engine with a 50% increase in butanol induction displayed extremely high formaldehyde emissions in the exhaust and indicating a considerable decrease in heat loss engine. Reduce emissions of formaldehydes and intermediate compounds in heat loss engines by completing combustion processes caused by insulated pistons and liners.



**Fig.6 Variation of formaldehydes emissions in IPL**

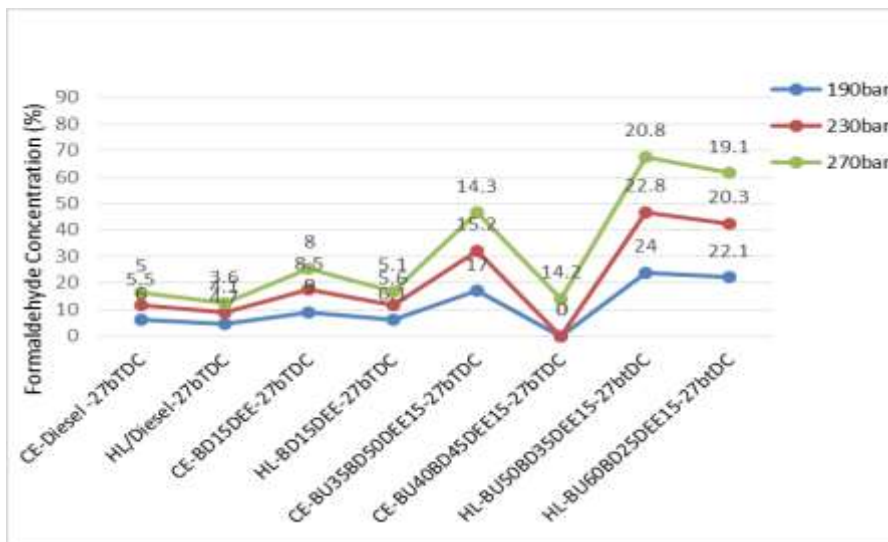
A heat loss diesel engine with an air-gap insulated piston with liner running on butanol-biodiesel containing 15% diethyl ether is shown to emit acetaldehyde emissions in Figure 7. The emission of acetaldehyde showed a similar pattern. The concentration of acetaldehyde is related with the exhaust temperature and fuel hydrogen-carbon ratio.



**Fig.7 Variation of acetaldehydes emissions in IPL**

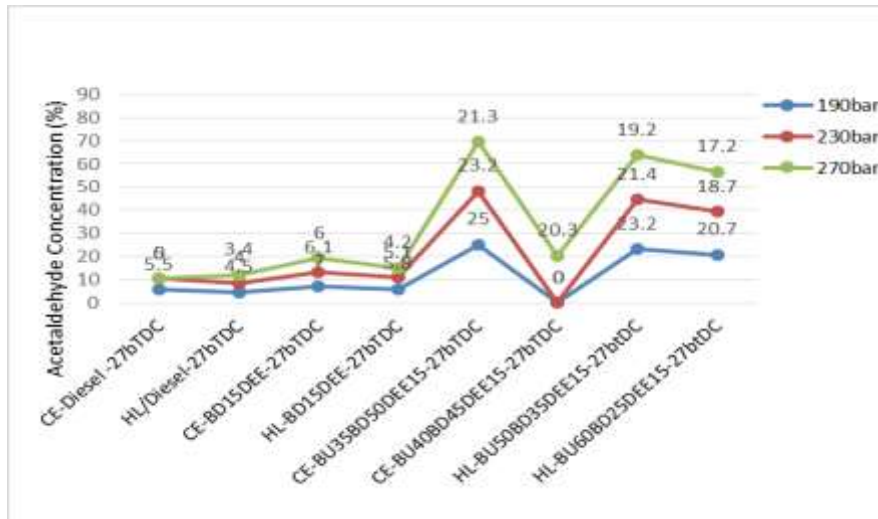
**iii. Cylinder head with ceramic coating, insulated piston, and lined (IPLC)**

A heat-loss diesel engine with a high degree of insulation (insulated piston, liner, and ceramic coating) will exhibit variations in formaldehyde emissions, as shown in Figure 8. Diesel engine heat loss was significantly reduced, as evidenced by the very high formaldehyde emissions from the exhaust of a conventional engine. Formaldehyde concentration decreased due to increased speed leads to better air-fuel mixing and atomization and faster mixing of hot cylinder gases at high injection pressure reduces the ignition delay. The hot atmosphere of the heat loss engine completed combustion reactions and minimized intermediate chemical and formaldehyde emissions. As a result, it was concluded that the heat loss engine was better suited to an alcohol engine running on pure diesel.



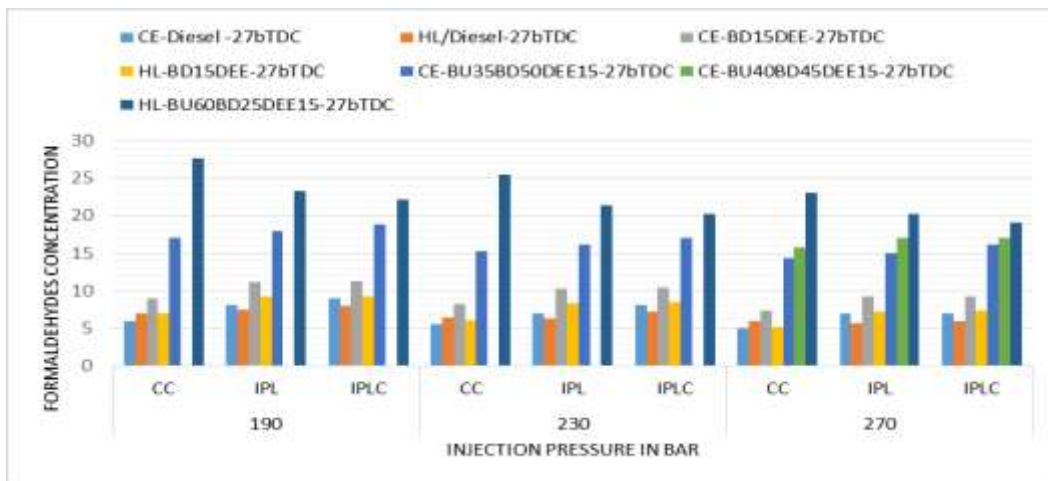
**Fig.8 Variation of formaldehyde emission in IPLC**

Figure 9 displays the variations in acetaldehyde in heat loss diesel with high degree insulation (insulated ceramic coated cylinder head, insulated liner, and insulated piston). Acetaldehyde emissions followed the same trends as formaldehyde emissions in heat loss engines. Acetaldehyde components were produced as reactive intermediate species, and then as combustion progressed. In high-temperature combustion, forward chemical reactions go more quickly. Acetaldehyde emissions decrease with increase of injection pressure due to fuel droplets injected in to hot combustion chamber and complete combustion reactions.



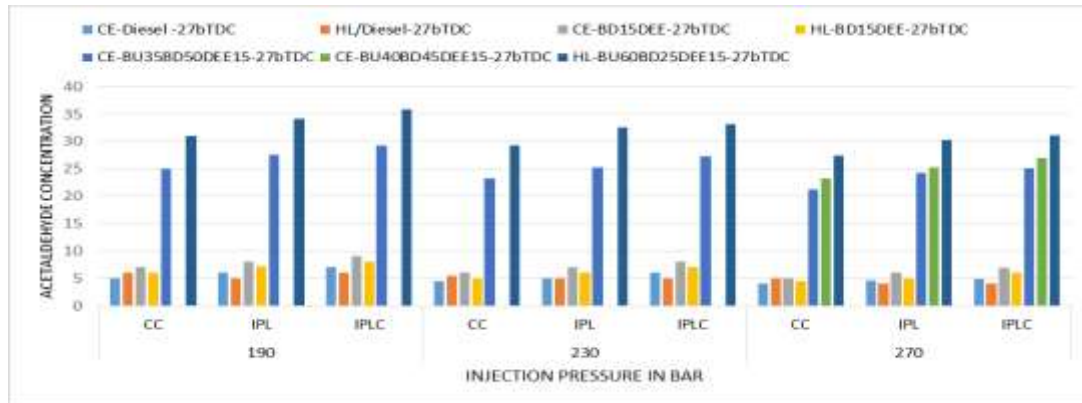
**Fig.9 Variation of acetaldehydes emissions IPLC**

With butanol-biodiesel blends containing 15% diethyl ether, Figure 10 illustrates the fluctuation in formaldehydes (CH<sub>2</sub>O) content in heat loss engines with varying degrees of insulation. Because enhanced injection qualities allowed fuel to be sprayed in to the combustion chamber walls, formaldehyde emissions dropped with increased injection pressure and varying degrees of combustion chamber insulation. Higher butanol blends lead to lower formaldehyde emissions due to butanol's lower reactivity and different combustion characteristics.



**Fig.10 Variation of formaldehydes emissions of Heat Loss diesel engine with different degree of insulation with butanol – biodiesel with 15% diethyl ether blends at maximum load operation.**

Figure 11 shows how the concentration of acetaldehydes (C<sub>2</sub>H<sub>4</sub>O) varies in heat loss engines with varying degrees of insulation when butanol-biodiesel blends with 15% diethyl ether are used. Acetaldehyde emissions decreases with increase of high degree of insulation engine. This was caused by the diesel fuel's lower viscosity and milder ignition delay as compared to biodiesel, which enhanced combustion and prevented the formation of intermediate fuel deposits such acetaldehydes. Increased injection pressure improves the heat loss engine's combustion performance while reducing acetaldehyde emissions in various heat loss engine types.



**Fig.11 Variation of acetaldehyde emissions of Heat Loss diesel engine with different degree of insulation with butanol – biodiesel with 15% diethyl ether blends at maximum load operation.**

## Conclusion

In a heat-loss diesel engine, formaldehyde and acetaldehyde emissions decrease with increasing insulation of heat loss engine. Increase in injection opening pressure caused a rise and fall in the proportion of induction aldehyde emissions in both butanol-biodiesel and diethyl ether engine with different insulations. When the percentage of butanol induction rises, acetaldehyde and formaldehyde emissions decrease in a diesel engine with heat loss, cylinder head with ceramic coating, insulated piston, and liner increase significantly. Formaldehyde emissions drop up to 14% and acetaldehyde emissions drop up to 15% when injection pressure rises from 190 to 270 bar in various insulation engine types.

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## References

1. Y.C. Sharma, B. Singh, D. Madhu, Fast synthesis of high quality biodiesel from 'waste fish oil' by single step transesterification, *Biofuel Res. J.* 3 (2014) 78–80.
2. Samat, Amira Farzana, Nor Amirah Safiah Muhamad, N. A. A. Rasib, Siti Aminah Mohd Hassan, Khairunissa Syairah Ahmad Sohaimi, and Nur Izzati Ibrahimi. "The potential of biodiesel production derived from fish waste." In *IOP Conf. Series: Mat. Sci. Eng.* (IOP Publishing), vol. 318, 012017, 2018.
3. M. Vijaya Kumar and S.Sai Gowtham Reddy Study on the performance and emissions of diesel engine by fish methyl ester and DEE additive in a diesel engine fuel" *Materials Today: Proceedings*, 2214-7853, 2021, [tps://doi.org/10.1016/j.matpr.2020.12.648](https://doi.org/10.1016/j.matpr.2020.12.648)
4. Jiaqiang, E., MinhHieu Pham, Yuanwang Deng, Tuanngghia Nguyen, VinhNguyen Duy, DucHieu Le, Wei Zuo, Qingguo Peng, and Zhiqing Zhang. "Effects of injection timing and injection pressure on performance and exhaust emissions of a common rail diesel engine fueled by various concentrations of fish-oil biodiesel blends." *Energy* 149, 2018, 979-989.
5. Arunprasad, S., & Balusamy, T. (2018). Experimental investigation on the performance and emission characteristics of a diesel engine by varying the injection pressure and injection timing using mixed biodiesel. *International Journal of Green Energy*, 15(6), 376–384. <https://doi.org/10.1080/15435075.2018.1464923>
6. Britto, R. F., & Martins, C. A. (2015). Emission analysis of a Diesel Engine Operating in Diesel-Ethanol Dual-Fuel mode. *Fuel*, 148, 191–201. <https://doi.org/10.1016/j.fuel.2015.01.008>
7. Ellappan, S., & Rajendran, S. (2020). Addition of diethyl ether on the LHR engine characteristics using biodiesel-eucalyptus blend. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*. <https://doi.org/10.1080/15567036.2020.1778138>
8. Fan, C., Song, C., Lv, G., Wang, G., Zhou, H., & Jing, X. (2018). Evaluation of carbonyl compound emissions from a non-road machinery diesel engine fueled with a methanol/diesel blend. *Applied Thermal Engineering*, 129, 1382–1391. <https://doi.org/10.1016/j.applthermaleng.2017.10.086>
9. Gillani, S. E., Ikhtlaq, M., Khan, M. U., Awan, D., & Hamza, A. (2021). Effects of butanol blending and fumigation with *Jatropha* biodiesel on combustion, performance, and emissions of diesel engine. *International Journal of Environmental Science and Technology*, 18(4), 819–834. <https://doi.org/10.1007/s13762-020-02898-4>
10. Hasan, A. O., Abu-Jrai, A., Al-Muhtaseb, A. H., Tsolakis, A., & Xu, H. (2016). Formaldehyde, acetaldehyde and other aldehyde emissions from HCCI/SI gasoline engine equipped with prototype catalyst. *Fuel*, 175, 249–256. <https://doi.org/10.1016/j.fuel.2016.02.005>
11. Jeevahan, J., Britto Joseph, G., Durairaj, R. B., Mageshwaran, G., & Sriram, V. (2021). Influence of diethyl ether on engine performance and emissions characteristics of blends of butanol, pentanol or biodiesel (neem oil methyl ester) in a single cylinder

- diesel engine. *International Journal of Ambient Energy*, 42(4), 435–443. <https://doi.org/10.1080/01430750.2018.1537938>
12. Kim, K. H., Choi, B., Park, S., Kim, E., & Chiramonti, D. (2019). Emission characteristics of compression ignition (CI) engine using diesel blended with hydrated butanol. *Fuel*, 257. <https://doi.org/10.1016/j.fuel.2019.116037>
13. Kotturi, R. K., Krishna, M. V. S. M., Kumar, B. S. P., & Ravi Chandra, M. (2021). Control of pollutants in supercharged partially adiabatic diesel engine with carburetted methanol and crude karanja oil blended with DEE. *International Journal of Ambient Energy*, 42(8), 867–879. <https://doi.org/10.1080/01430750.2019.1567587>
14. Krishna, M. V. S. M., Prakash, T. O., Ushasri, P., Janardhan, N., & Murthy, P. V. K. (2016). Experimental investigations on direct injection diesel engine with ceramic coated combustion chamber with carbureted alcohols and crude jatropha oil. In *Renewable and Sustainable Energy Reviews* (Vol. 53, pp. 606–628). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2015.09.011>
15. Kumar, M. V., & Reddy, S. S. G. (2021). Study on the performance and emissions of diesel engine by fish methyl ester and DEE additive in a diesel engine fuel. *Materials Today: Proceedings*, 45, 3323–3327. <https://doi.org/10.1016/j.matpr.2020.12.648>
16. Muthukumarasamy, S., Arun, S., Amirthalingam, P., Yogesh, P., & Baradhan, P. (2018). Performance and emission characteristics of biodiesel-butanol blended fuel in LHR engine. *Journal of Applied Fluid Mechanics*, 11(Specialissue), 1–5. <https://doi.org/10.36884/jafm.11.SI.29410>
17. Roy, M. M. (2009). Effect of fuel injection timing and injection pressure on combustion and odor emissions in DI diesel engines. *Journal of Energy Resources Technology, Transactions of the ASME*, 131(3), 0322011–0322018. <https://doi.org/10.1115/1.3185346>
18. Roy, M. M., Islam, M. S., & Alam, M. N. (2021). Biodiesel from crude tall oil and its nox and aldehydes emissions in a diesel engine fueled by biodiesel-diesel blends with water emulsions. *Processes*, 9(1), 1–20. <https://doi.org/10.3390/pr9010126>
19. Sakthivel, G. (2016). Prediction of CI engine performance, emission and combustion characteristics using fish oil as a biodiesel at different injection timing using fuzzy logic. *Fuel*, 183, 214–229. <https://doi.org/10.1016/j.fuel.2016.06.063>
20. Swaminathan, C., & Sarangan, J. (2012). Performance and exhaust emission characteristics of a CI engine fueled with biodiesel (fish oil) with DEE as additive. *Biomass and Bioenergy*, 39, 168–174. <https://doi.org/10.1016/j.biombioe.2012.01.001>
21. Tongroon, M., Saisirirat, P., Suebwong, A., Aunchaisri, J., Kananont, M., & Chollacoop, N. (2019). Combustion and emission characteristics investigation of diesel-ethanol-biodiesel blended fuels in a compression-ignition engine and benefit analysis. *Fuel*, 255. <https://doi.org/10.1016/j.fuel.2019.115728>
22. Tüccar, G., Özgür, T., & Aydin, K. (2014). Effect of diesel-microalgae biodiesel-butanol blends on performance and emissions of diesel engine. *Fuel*, 132, 47–52. <https://doi.org/10.1016/j.fuel.2014.04.074>
23. Yerrennagoudaru, H., Manjunatha, K., Raza, A., Kantharaj, B. R., Mujahed, A., & Irshad, K. (2018). Analysis and comparison of performance and emissions of compression ignition engine fuelled with diesel and different bio-fuels blended with Methanol. *Materials Today: Proceedings*, 5(2), 5175–5185. <https://doi.org/10.1016/j.matpr.2017.12.099>
24. Zarante, P. B., Da Silva, M. J., Valente, O. S., & Sodr , J. R. (2010). ALDEHYDE EMISSIONS FROM A STATIONARY DIESEL ENGINE OPERATING WITH CASTOR OIL BIODIESEL-DIESEL OIL BLENDS. In *Technology Engenharia T rmica (Thermal Engineering)* (Vol. 9).
25. Jacob, S., & Karikalan, L. (2020). Experimental studies on characteristics of C.I engine by using fish oil as an alternative fuel. *Materials Today: Proceedings*, 37(Part 2), 1079–1082. <https://doi.org/10.1016/j.matpr.2020.06.308>
26. Kumar, M. V., & Reddy, S. S. G. (2021). Study on the performance and emissions of diesel engine by fish methyl ester and DEE additive in a diesel engine fuel. *Materials Today: Proceedings*, 45, 3323–3327. <https://doi.org/10.1016/j.matpr.2020.12.648>
27. Trindade, W. R. da S., & Santos, R. G. dos. (2017). Review on the characteristics of butanol, its production and use as fuel in internal combustion engines. *Renewable and Sustainable Energy Reviews*, 69(October 2015), 642–651. <https://doi.org/10.1016/j.rser.2016.11.213>.
28. B Raja Narender, S Narasimha Kumar, B Hadya (2025) Determination Of Physical And Chemical Properties Of Fish Oil Methyl Ester, Diethyl Ether, And Butanol Blends IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 21, Issue 3 , PP 16-24.
29. B.Raja Narender , S.Narasimha Kumar ,B.Hadya (2024)Emission Control and Aldehyde Reduction Using Fish Oil Methyl Ester, Diethyl Ether, and Butanol Blends in CI Engines *Journal of Propulsion Technology* ISSN: 1001-4055 Vol. 45 No. 3 ,PP 2178-2190.
30. B Raja Narender , S Narasimha Kumar and B Hadya (2025) Impact of Fuel Injection Pressure and Timing on the Performance and Emissions of a Low Heat Rejection CI Engine with Fish Oil Methyl Ester, DEE and Butanol Blend *Journal of Engineering Research and Reports* Volume 27, Issue 1, Page 59-75.

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