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Analysis of metal concentration, performance and noise emissions of the CI engine

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Abstract: Biodiesel is a substitute for diesel fuel and is highly required to control global warming and reduce dependence on limited petroleum reserves. Replacement of diesel fuel is unavoidable due to the depletion of oil reserves and environmental threats to existing life on the earth. This study used single-cylinder, four-stroke Compression Ignition (CI) engines for experimental work. An endurance test was conducted on the engine using diesel fuel (D100) and biodiesel blended fuel for 105 hours at 1300 rpm. During the endurance test, a multi-elemental of lubricant oil was conducted. It was found that the average wear concentration in lubricant oil was lower in biodiesel blended fuel than in diesel fuel. In this regard, elemental reduction was observed as AL (38.8%), Cr (67.7%), Fe (58.2%) and Mn (17.89%), respectively. Besides this, higher viscosity and density of lubricant oil were observed on B30 compared to D100. Furthermore, engine performance was determined and resulted from low brake thermal efficiency in diesel compared to biodiesel. The engine's noise was also calculated during operating hours at various positions such as front, left and back. It was determined that it was reduced at the mentioned positions for B30 compared to D100.

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1. Introduction

The biodiesel is an alternative fuel for the diesel fuel and is manufactured from vegetable oil and animal fats through a different process. The transportation systems of the world are primarily dependent on diesel engine machinery. It encompasses all kinds of vehicles and machinery, such as heavy-duty transport vehicles, railway engines, agricultural-related machinery, construction machinery, power generation plants, etc. However, their emissions consist of distinct air pollutants that cause environmental and health repercussions (Ogunsola *et al.*, 2023; Martikainen *et al.*, 2023). Environmental consequences due to these emissions are the greenhouse effect, ozone layer depletion, acid rain, climate variations, etc. (Song *et al.*, 2023). Diesel fuel emissions are the most significant environmental pollutants that carry multiple Hydrocarbons (HC), Sulphur (S), and residues of crude oil (Azad *et al.*, 2023). Moreover, according to the US Department of Energy Report, the world's oil supply will reach its highest production and soon reach the point of depilation (Doppalapudi *et al.*, 2023). Concerning this, reserves of fossil fuels are depleting along with increasing raw fuel prices, indicating an alarming threat to the global economy owing to negative loads on the worldwide trade balances (Krishnan *et al.*, 2023). Therefore, energy security is a fundamental factor concerning the stability of the economy; its rising demand, rising world population, enhancing living standards, and extensive industrialisation have forced to utilise limited sources of wisdom and developing alternative non-petroleum fuels for a stable economy and environment (Biswas *et al.*, 2023a; b).

Initially, trans-esterified vegetable oil (biodiesel) was used in diesel engines in South Africa before World War II. After this, it is known as 'biodiesel' (Hossain *et al.*, 2023). Furthermore, biodiesel can be obtained from straight-chain vegetable oils, edible and non-edible cooking oil, and animal fat (Rajpoot *et al.*, 2023). Using vegetable oil is an old idea; Rudolf Diesel was the first to use peanut oil for combustion in diesel engines in 1910 (Simhadri *et al.*, 2023). In a brief period, the use of biodiesel fuel in the engine dropped due to the availability of petroleum oil worldwide. The eye-catching characteristics of biodiesel are high cetane number, biodegradability, negligible sulphur, non-toxic emissions, aromatic compounds, and excellent lubricity (Gowrishankar & Krishnasamy, 2023). Many fuels have been tested in CI 2 engines from time to time. All fuels were analysed regarding performance, exhaust emission and combustion due to their physical and chemical properties. These properties have solid relationships with their fatty acid composition due to the construction in oil that may influence some characteristics such as cetane number, fuel viscosity, fuel density, calorific value, and lower temperature (Mendiburu *et al.*, 2022). Besides, multiple experimental analyses on biodiesel fuel were conducted by scholars. They observed different results concerning power loss, declined torque, and enhanced brake-specific fuel consumption (BSCF). Besides this, they also got results of HC emissions, Carbon Monoxide (CO), Sulphur Oxides, Polycyclic Aromatic Hydrocarbons, and Nitric Polycyclic Aromatic Hydrocarbons. However, a small increment in nitrogen oxide emissions was also detected by many researchers (Lim *et al.*, 2022).

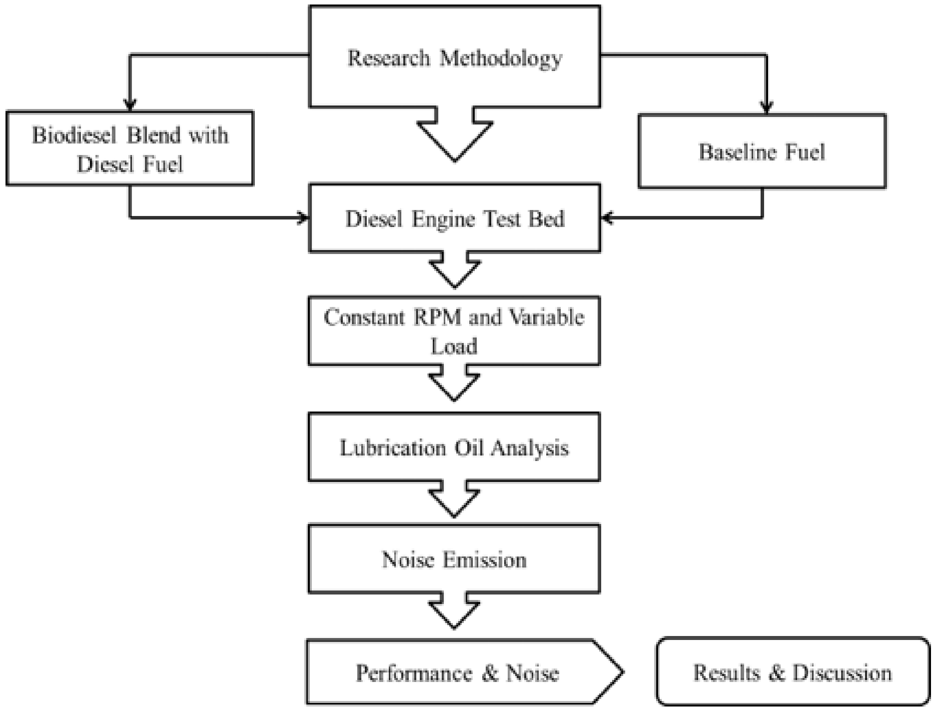
Additionally, it was reported from different research studies that biodiesel or blends in Compression Ignition (CI) engines have shown reduced trends in noise pollution and good noise quality (Doppalapudi *et al.*, 2023). Moreover, renewable fuels derived from vegetable oils have suitable engine performance; in other operations, some fuels can reduce performance, high carbon and lacquer deposition, and cause engine damage (Krishnan *et al.*, 2023). Deposit around the injector tip is due to high temperatures owing to the advanced diesel injection system (Madihi *et al.*, 2022). It is reported from different studies that a few properties of biodiesel, which are high viscosity, small volatility, and the reactivity of unsaturated hydrocarbon chains, can cause injector coking and trumpet creation on the injector, high carbon deposition occurs when the engine is run for a long time (Godiño *et al.*, 2022). According to various research reports, diesel oil has a significant share in aggrandising environmental pollution, having adverse health impacts on life. Noise pollution is another major problem that affects health. It is due to combustion produced by high-pressure changes during the fuel burning time (Bhangwar *et al.*, 2022).

The literature review reflects that significant studies have been carried out to investigate the performance and emissions of CI engines using different fuels; however, minimal studies have been reported in the literature to investigate CI parameters. Moreover, it was also not reported regarding the elemental analysis of lubricant oil of CI engine; therefore, an investigation of CI engine elemental analysis and noise emissions is very much needed to explore the performance and engine life better. The research aims to analyse the elemental analysis of lubricant oil and noise mission of CI engines using biodiesel blended fuel.

2. Research methodology

The research addressed objectives by examining two oil samples within a diesel engine. It investigated three primary aspects: elemental analysis, engine performance, and noise pollution assessment. Fuel properties were evaluated following ASTM standards. The fundamental analysis was performed consistently under stable load and speed conditions. Meanwhile, engine performance and sound pressure levels were assessed across different loads while maintaining a constant speed. For a comprehensive understanding of the research methodology, please refer to the detailed flow diagram illustrated in Figure 1.

Figure 1: Flow diagram of research methodology



2.1. Elemental analysis of lubricant oil

Conducting an endurance test for 105 hours on a CI engine using diesel and biodiesel blended fuel involves a rigorous evaluation of the engine's performance and the impact of fuel variations on its operation. The engine is operated continuously for 105 hours under specific conditions, including constant load and RPM. This extended operation assesses the engine's durability, performance, emissions, and overall behaviour using different fuel samples (in this case, diesel and biodiesel blends). The test divides the total duration (105 hours) into three segments of 35 hours each for diesel and biodiesel blended fuel. This allows for a comprehensive comparison between the two fuel types over equal durations.

After each 35-hour run on a particular fuel type, the lubricant oil used in the engine is extracted for analysis. This oil carries residues, contaminants, and by-products from combustion. These residues can provide insights into the engine's wear and tear and chemical interactions. Various methods of analysis, such as multi-element analysis, are conducted on the collected lubricant oil samples. Determining the presence and quantity of various elements in the oil might indicate wear on engine components or the combustion process’s impact on the oil.

2.2. Engine performance procedure

The engine test bed featured dual fuel tanks: one containing pure diesel (D100) and the other holding a B30 blend. Both fuels were supplied through a single pipeline, regulated by distinct valves. Table-1 outlines the evaluation of two fuel samples, D100 and B30, used in this research. The engine's performance metrics—engine torque, brake power, brake thermal efficiency, and brake-specific fuel consumption—were assessed under constant speed conditions while varying the load. The load varied between 0 and 2.0 Kg-m at an RPM of 1300. Initially, data was gathered while the engine was unloaded at a speed of 1300 rpm. The engine's stabilised condition was ensured for approximately 10 minutes before collating data on its performance metrics under varied loads.

Table-1: Biodiesel composition by volume

Sr No.	Composition Name	Composition by Volume
1	D100	Diesel 100%
2	B30	Diesel 70% Biodiesel 30%

2.3. Engine sound pressure level

The objective involved calculating the noise levels (sound pressure level) generated by the CI engine. Two fuels underwent testing to measure their sound pressure levels across various loading conditions and constant speeds. Measurements were taken from three directions: front, back, and left, as illustrated in Figure 2.

Three microphones were strategically positioned at distances of 1 meter from the test bed, placed at the locations specified earlier. The sound pressure levels were captured using a dB meter, as depicted in Figure 2. Comprehensive specifications in Table-2 are provided, outlining the detailed parameters used for these measurements.

Figure 2: Schematic diagram of measuring sound pressure level

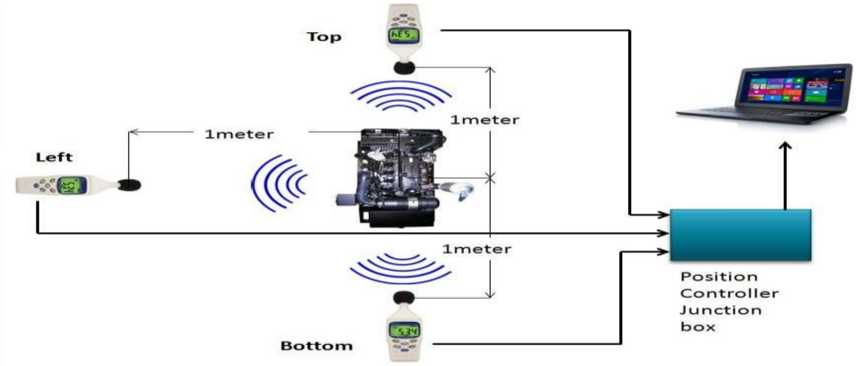


Table-2: Detailed specification of sound pressure level meter

Type	Electric condenser microphone
Range of dB Level	35dB to 150dB
Accuracy	± 1.5 dB
Resolution	0.1 dB
Microphone diameter	½ “
Dynamic Range	55dB

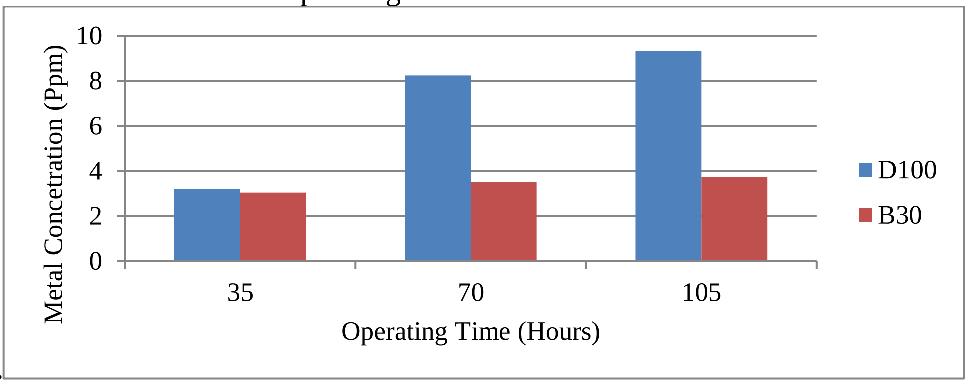
3. Results and discussion

3.1. Aluminium wear

Figure 3 illustrates the metal concentration of Aluminium (Al) in lubricant oil. The results indicate a lower metal concentration in biodiesel blended fuel B30 than in diesel fuel D100. This reduction is attributed to the superior lubricity found in biodiesel blends.

On average, aluminium concentration within the biodiesel blend is a notable decrease of 38.8%. The sources contributing to metal concentration in the lubricant oil include engine parts, such as the gearbox, piston rings, bearings, cylinder liners, and camshaft.

Figure 3: Concentration of Al vs operating time

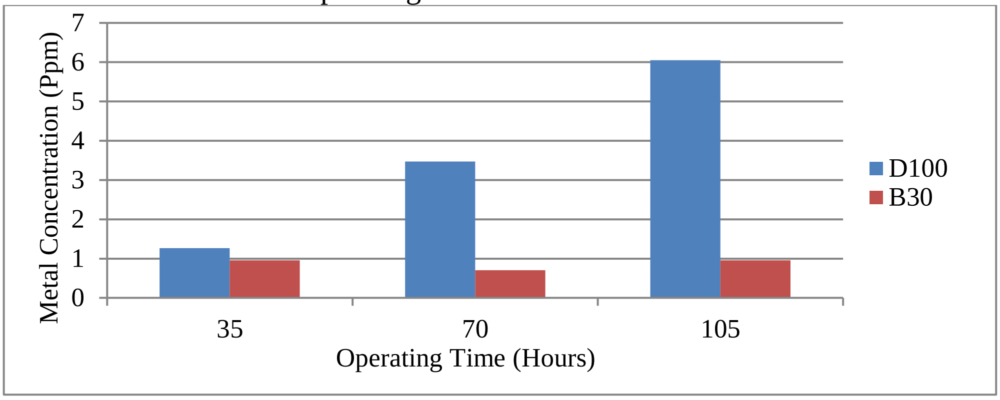


3.2. Chromium wears

Figure 4 displays the metal concentration of Chromium (Cr) in lubricant oil. Like the findings for Cr, the results show a lower concentration of Cr in biodiesel blended fuel B30 than in diesel fuel D100. This decline is attributed to the enhanced lubricating properties inherent in biodiesel blends (Bhangwar *et al.*, 2022a).

On average, there is a significant reduction of 67.6% in Cr concentration within the biodiesel blend. Various engine components, including the gearbox, piston rings, bearings, cylinder liners, and camshaft, contribute to the metal concentration in the lubricant oil.

Figure 4: Concentration of Cr vs operating time

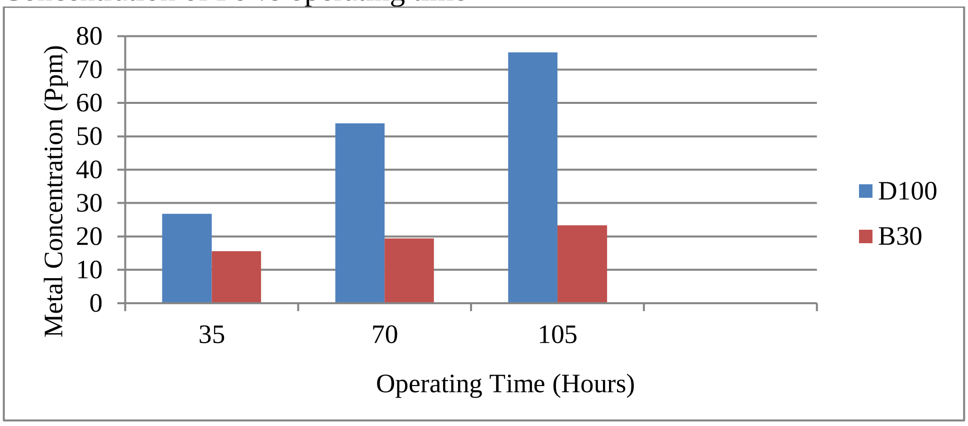


3.3. Iron wear

Figure 5 highlights the metal concentration of Iron wear in lubricant oil. Much like the outcomes observed for Chromium (Cr) and Aluminum (AI), the results demonstrate a lower concentration of Iron (Fe) wear in biodiesel blended fuel B30 compared to diesel fuel D100. This decrease is attributed to the improved lubricating properties of biodiesel blends.

On average, there is a notable reduction of 58.2% in the Fe wear concentration within the biodiesel blend. Several engine components, including the gearbox, piston rings, bearings, cylinder liners, and camshaft, contribute to the metal concentration in the lubricant oil (Memon, 2022).

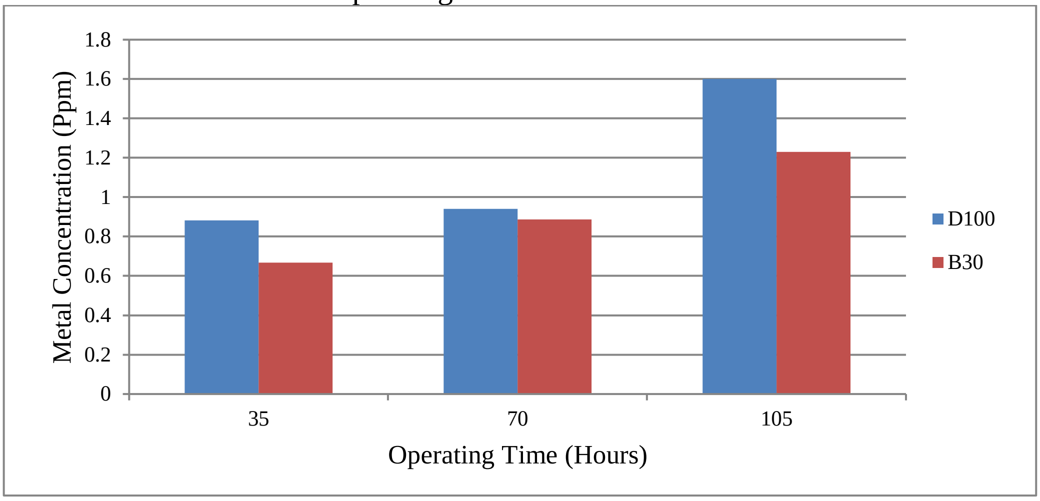
Figure 5: Concentration of Fe vs operating time



3.4. Manganese wears

Figure 6 shows the result of a metal concentration of Manganese (Mn) in lubricant oil. From the results, it has been found that the metal concentration of biodiesel blended fuel B30 is lower than that of diesel fuel D100. This is due to the maximum lubricity present in biodiesel-blended fuel (Memon, 2022). The average percentage is Mn (17.89%), respectively. The source of metal concentration in lubricant oil in various parts of the engine gearbox, piston ring, bearing, cylinder liner, camshaft, and valves. The wear produced during running hours of an engine is higher in diesel than in biodiesel blended fuel. Biodiesel blended fuel has superior quality lubricant inside the engine; that's why percentages of biodiesel blended fuel are more critical for engine lubricant oil and parts of the engine.

Figure 6: Concentration of Mn vs operating time

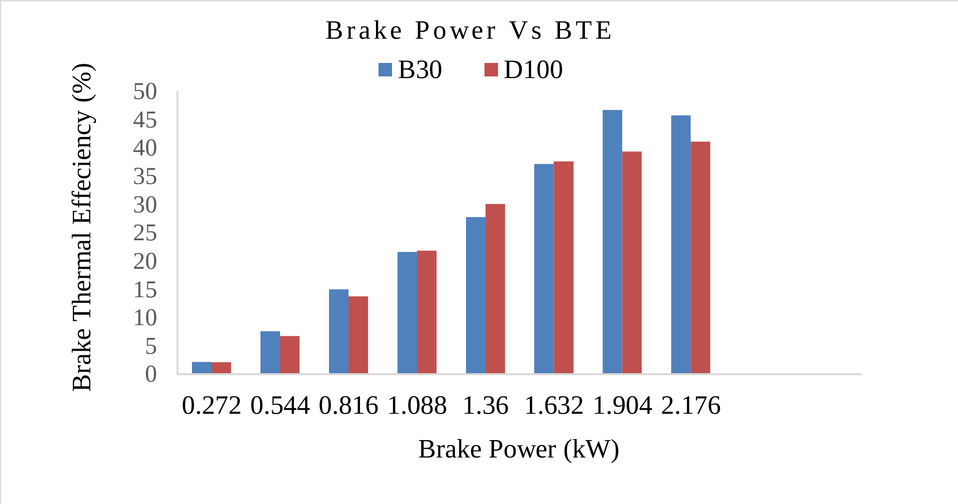


Overall, Figures 3 to 6 present the metal concentration of Al, Cr, Fe, and Mn in lubricant oil. A consistent trend emerges across these results: the metal concentration in biodiesel blended fuel B30 is notably lower than diesel fuel D100. This disparity can be attributed to the superior lubricating properties inherent in biodiesel blends. On average, there are significant reductions in metal concentrations: Al (38.8%), Cr (67.6%), Fe (58.2%), and Mn (17.89%) within the biodiesel blend. These metals originate from various engine components, including the gearbox, piston rings, bearings, cylinder liners, camshaft, and valves. The wear generated during the engine's operation is higher when using diesel than biodiesel blended fuel. Biodiesel blends possess high-quality lubricants that result in lower wear on engine parts. Therefore, the percentages of biodiesel blended fuel are crucial not just for the engine lubricant oil but also for the overall health and performance of the engine components (Sarwar *et al.*, 2023; Keshavarzi *et al.*, 2022). Lower metal concentrations signify reduced wear and tear, highlighting the importance of using biodiesel blends for engine longevity and optimal performance.

3.5. Brake Thermal Efficiency (BTE)

The BTE is the ratio of the thermal power available in the fuel to the power that the engine delivers to the crankshaft (Panithasan & Venkadesan, 2023). The brake thermal efficiency was observed at the B30 proportion of the biodiesel blend at variable loads, shown in Figure 7. The BTE of D100 is lower than that of B30. In Figure 7, at 1.9 kW, the maximum thermal efficiency value was observed at 46.68% on B30, and on D100, 36.4% was observed. The increased efficiency of the diesel fuel is 22% in comparison to the biodiesel fuel. The increased efficiency of B30 is 17.9% in comparison to D100. The difference in efficiency between the above is 4.1%.

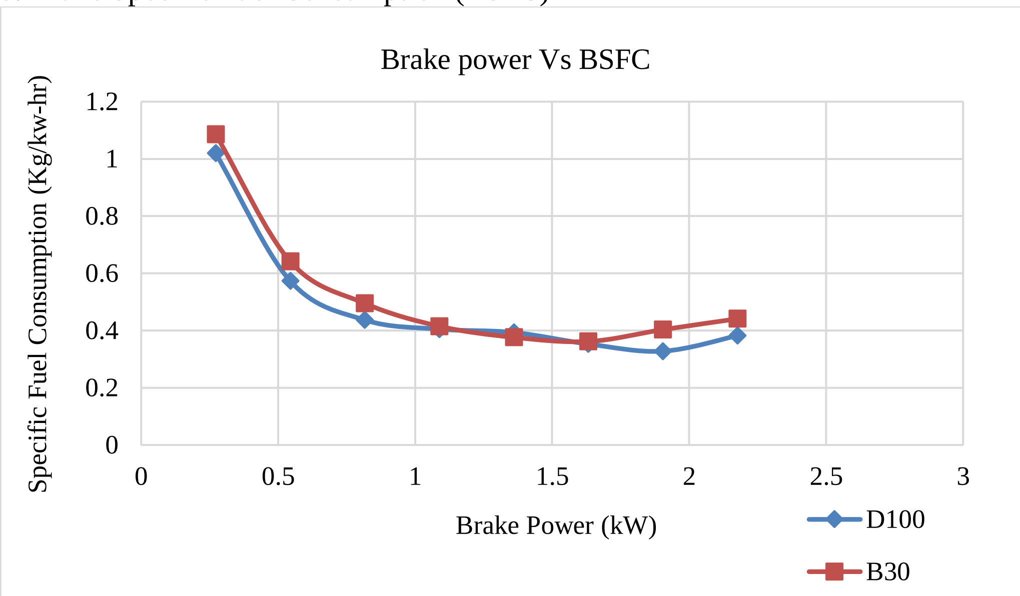
Figure 7: Result comparison of thermal efficiency D100 and B30



3.6. Brake Specific Fuel Consumption (BSFC)

The BSFC is an indicator of fuel consumption in an IC engine. It depends on the engine's speed, load, biodiesel blend ratio, and additives (Sarwar *et al.*, 2023). The diesel and biodiesel fuels are mentioned in Table-1. The results show that the BSFC of B30 is higher than D100 at unloading conditions, as shown in Figure 8. BSFC shows the engine's performance, and its unit is kg/kW-hr. The BSFC of biodiesel fuel is higher due to the maximum contents of oxygen, which results in a declined heating value. The fuels' lower densities and heating values require higher mass fuel for the same energy output from the engine. It has been reported that the density and calorific value impact the degree of unsaturation, and it has been noted that unsaturated esters with lower heating values have lower mass-energy content (MJ/kg) than saturated esters.

Figure 8: Brake Specific Fuel Consumption (BSFC)



3.7. Analysis of noise emission level

Results show the CI engine's Sound Pressure Level (SPL) at various load conditions using diesel fuel D100 and biodiesel blend B30. Three sides were selected to record noise levels at various positions. The front, back, and left sides were chosen at a 1m distance from the piston head, as shown in Figures 9 to 11. All comparative results demonstrate that the engine using diesel fuel D100 has higher noise emission than biodiesel B30 (Bhangwar *et al.*, 2022). Low-pressure sound levels are produced on the initial load, while a slight friction difference occurs when using biodiesel fuel on medium loads. Results clearly show that the biodiesel blend B30, which has larger oxygen contents than diesel fuel D100, reduces noise emission. The sound pressure level results were determined at variable brake loads and a constant rpm 1300. It can be observed from Figures 9 to 11 that the position of the front side showed a higher sound pressure level than the back and left sides.

Figure 9: Sound pressure level at front position

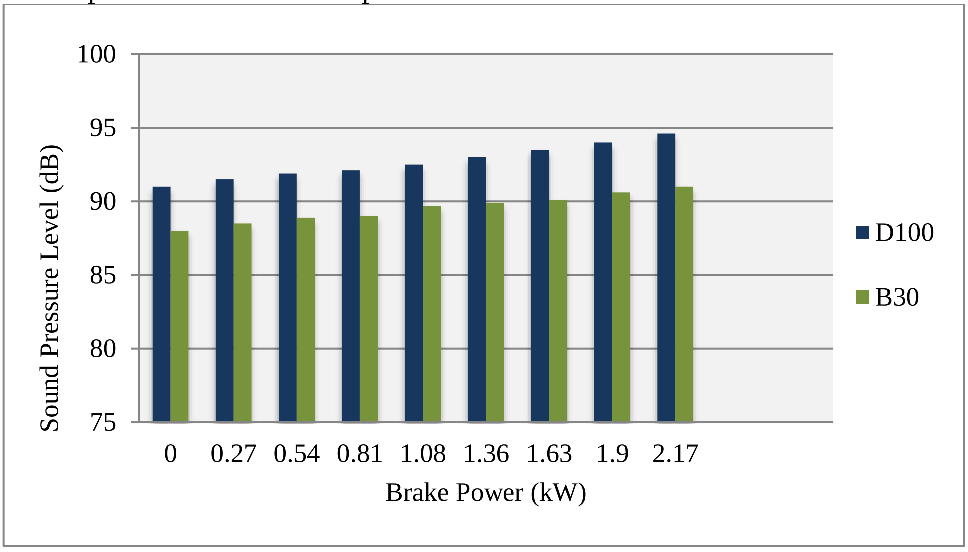


Figure 10: Sound pressure level at left position

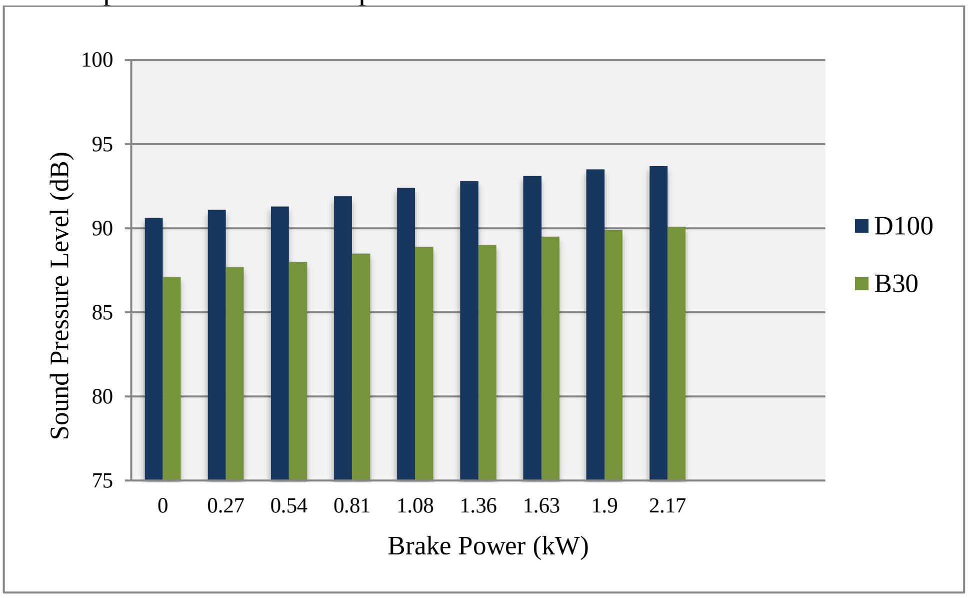
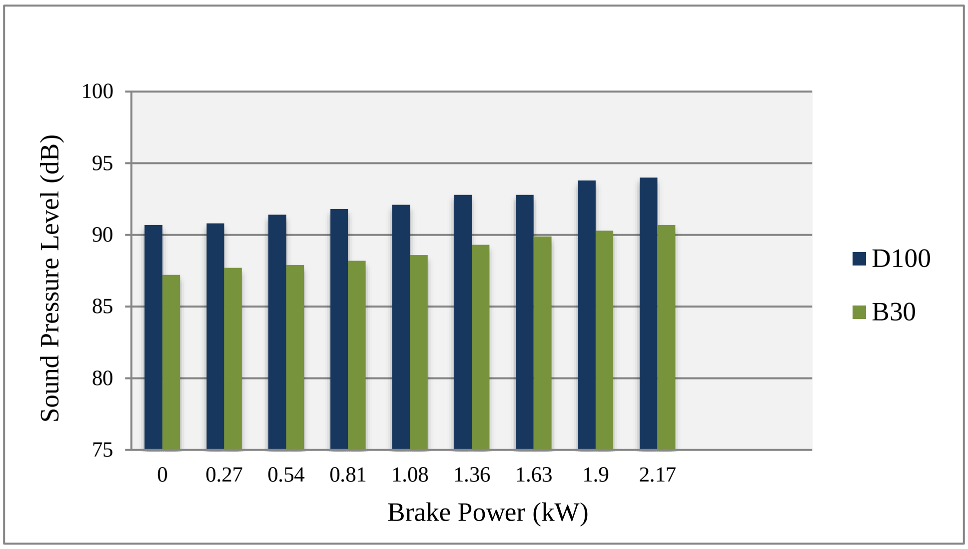


Figure 11: Sound pressure level at back position



4. Conclusions

The research objectives were to determine the multi-elemental analysis, engine performance, and sound pressure level test using diesel fuel D100 and B30 blends without any engine change. In this regard, only two samples were taken, the engine was operated at 105 hours to obtain the research objectives, and the proper research methodology was organised. It is based on the experimental results, which are stated as follows.

The multi-elemental analysis was performed at constant load and speed during lubricant oil analysis. All the elements such as Al, Cr, Fe, and Mn were found to be decreased for lubricant oil when the engine was fuelled with B30 as compared to D100 due to lubrication available in Biodiesel fuel. Moreover, the engine oil viscosity during the engine endurance test conducted on biodiesel blends resulted in higher than D100. The density of the engine oil during the endurance tests was observed to be higher using biodiesel fuel compared to D100. It is due to the combined effect of the wear on engine parts. During the engine performance test, engine torque, brake power, and brake thermal efficiency for bio-fuel blends were determined to be lower. At the same time, Brake-Specific Fuel Consumption (BSFC) was obtained higher for biofuel blends than D100. These results were determined due to lower heating values and higher density. Results of noise emission for B30 were obtained lower than D100. This happened due to the physical properties and richness of oxygen contents in biodiesel fuel.

This research focuses on analysing lubricant oil and evaluating the performance of a Compression Ignition (CI) engine using biodiesel-blended fuel. Additionally, the study analyses engine part deposition when biodiesel is utilised, exploring the effects of various antioxidants.

Declaration of conflict of interest

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