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Lubricant Oil Degradation in a Compression Ignition Engine Fueled with Biodiesel

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Abstract— Before biodiesel may be deployed on a greater scale in compression ignition engines, its long-term effects on lubricating oil properties and engine durability must be studied. This study examines the impact of a 20% chicken fat biodiesel-diesel mix on lubricating oil characteristics and engine longevity over a 512-hour endurance test compared to diesel. During the endurance test, lubricant characteristics were evaluated at regular intervals to see whether they exceeded the oil critical limits, and a modified oil change interval was calculated. The results demonstrated that biodiesel negatively affects lubricating oil performance and engine durability. However, the differences in attributes did not generate any significant operating issues. The kinematic viscosity and density variation was 6% and 13%, respectively. The biodiesel-fueled engine had a 5% lower flash-point, but the moisture content was 7% greater. Samples of lubricating fluid from both engines are analyzed by spectroscopy to identify engine component wear particles.

Index Terms— Engine test, Biofuel, Lubricating oil, Engine durability, Metal debris, Oil change Interval, Spectroscopy

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1 Introduction

India is one of the world's top five energy consumers, and its energy consumption is expanding fast. Due to its rapid economic expansion, up to 70 percent of its oil needs are met by imports. This situation has emphasized India's urgent need to concentrate on indigenous renewable energy sources, as outlined in the 2018 National Policy on Biofuels. The program intends to boost the use of biofuels in the energy and transportation sectors during the next decade, primarily via processing domestic feedstock into biofuels. Biodiesel is the best renewable alternative to mineral diesel, which remains the most popular transportation fuel. It is sustainable and renewable, and the manufacturing procedure is straightforward. It offers equivalent performance and reduced emissions to existing engines [1]. Concerns remain, however, about the long-term usage of biodiesel. Its significantly different chemical makeup from mineral diesel causes incompatibility concerns with engine component components and lubricants. These difficulties may result in varying amounts of diesel dilution in the lubricating oil, which should be evaluated for long-term engine use. [2]

The principal role of lube oil is to minimize friction and wear between mating components. Secondary functions include thermal dissipation, inhibiting corrosion, coating formation control, and impurity dispersal. Lubricant oil analysis provides a clear indicator of engine health and facilitates the early diagnosis of the failure. It is comparable to checking human blood for illness prevention and diagnosis. The excess accumulation of wear debris in the lube oil implies atypical wear of engine parts that may lead to a breakdown. Alterations in the essential characteristics of the lubricating oil may diminish its qualities and impair its performance. The primary sources of lubricant deterioration are oxidation, wear particle contamination and water. Evaluation of various oil properties and characteristics provides a measurement of oil deterioration. In addition, the measure of wear particle concentration in the oil aids in determining wear processes.[3]

It has been stated that used chicken fat may be used as a viable source of biodiesel as a potential substitute for vegetable oils.[4] Utilizing it reduces production costs, protects the environment, and reduces the effect on food security.[5] Researchers have conducted short-term experiments to evaluate the engine performance metrics and emission levels of biodiesel-fueled engines. Researchers have also published the lubricity properties of biodiesel and its blends. However, there is little information on how using biodiesel over time affects the lubricant properties and subsequent effects on engine component wear. In this study, a 512-hour endurance test examines the effects of biodiesel blends made from waste chicken fat on lubricating oil properties in a compression ignition engine. We collect and analyze lubricant samples at distinct periods during the test to learn how fuel composition affects lubricant degradation. The lubricant's service life is calculated, and the most important metric for gauging oil durability is identified. The concentration of metal particles in the engine's lubricating oil was measured to look for signs of abnormal wear.

2 Materials and Methods

The experimental investigation utilizes a compact, constant-speed, single-cylinder, water-cooled, direct-injection diesel engine. The technical specifications of the engine are given in Table 1. Chicken fat biodiesel is prepared from waste chicken fat feedstock by a two-step process; base-catalyzed esterification using methanol (30:1 molar ratio) and sulfuric acid (20%) followed by an acid-catalyzed transesterification with methanol (6:1 molar ratio) and KOH(0.8%). The optimal ester concentration in the biodiesel-diesel blend was obtained from background experiments involving performance, emission, and lubricity tests. Different blends were prepared with concentrations ranging from 0 percent (pure diesel) to 100 percent (pure biodiesel) through 10,15,20,25,30 and 50 percent. Performance, emission, and lubricity parameters were analyzed from the recorded data, and 20 percent biodiesel (CFB20) was selected as the optimum blend. The lubricant oil employed in the engine is of grade SAE 15W40, conforming to the engine manufacturer's specifications.

Table 1 Test Engine Specification

Make	Kirloskar AV1
No of Cylinders	Single (naturally aspirated)
Strokes per cycle	4
Ignition	Compression-Ignition
Type of Fuel Injection	Direct Injection
Cooling Method	Water Cooled
Maximum Power	3.7 kW/5HP @ 1500rpm
Bore x Stroke	80mm x110mm
Compression Ratio	16.5:1
Rated Speed	1500 rpm

A 512-hour endurance test (IS:10000 Part IX) is carried out in two stages to investigate the effects of CFB20 on the functionality of lubricating oils. First, 32 cycles (16 hours each) were run at rated speed on diesel to establish baseline data. Table 2 specifies the test cycle. After each round of testing, the engine was serviced to ensure proper functioning. The first stage concluded with replacing the piston, piston rings, liner, and bearings. During the second stage, instead of using neat diesel as the fuel, we utilized CFB20, with all other parameters being the same as the first. At 64-hour intervals throughout both stages, the engine's lubricant oil was sampled following protocol. In addition, several analyses were performed on lubricating oil samples to determine their components.

Table 2 Test Cycle for Endurance (IS:10000-Part 9)

Load	Running Time (min)
Full Load	240 (+30 min warm-up)
Half Load	240
10% Overload	60
No Load	30
Full Load	180
Half Load	210

3 Results and Discussion

The impact of the biodiesel-diesel blend on lubricant oil properties is critical in determining its compatibility with current engines. Therefore, numerous tests were performed on the lubricating oil to examine the possibility of oil degradation and engine durability issues

3.1 Viscosity

The high wear of component surfaces is directly attributable to viscosity fluctuations—an increase or decrease in viscosity damages the oil coating, a barrier between metallic components. Lube oil from diesel and CFB20 engines have different kinematic viscosities, as shown in Figs. 1 and 2. Filtering the oils, we use a Redwood viscometer to test the oils' viscosities at temperatures of 40^{0}C and 100^{0}C. (ASTM D445). The CFB20 engine oil samples had a greater reduction in viscosity than mineral diesel. The engine running on CFB20 may achieve up to 6% more viscosity reduction.

Fig.1 Lubricating oil viscosity at 40^{0}C

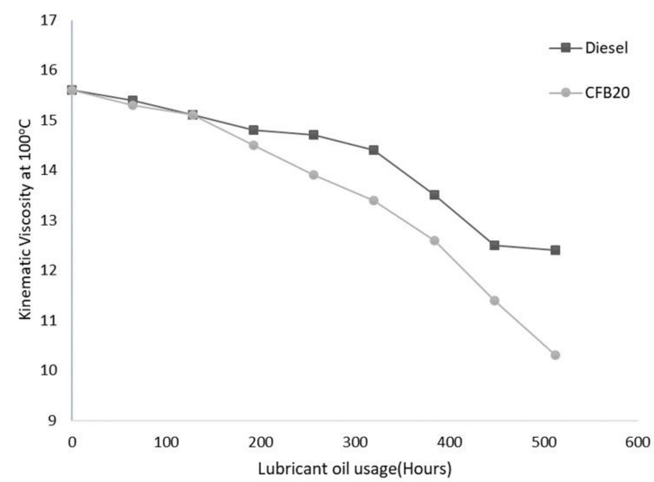

Fig.2 Lubricating oil viscosity at 100^{0}C

CFB20 fuel causes a more significant fall in lubricant viscosity, which may indicate fuel dilution in the crankcase. Due to fuel dilution, scientists have seen a comparable drop in lubricant viscosity in biodiesel-powered engines.[6] The dilution rates are based on the inflow and exit rates of the lubricating oil. Fuel is introduced into the crankcase at a faster pace for biodiesel than for petroleum diesel. Compared to pure diesel fuel, biodiesel has a higher surface tension, greater viscosity, and a higher density. Because of the bigger size and deeper penetration of biodiesel spray droplets from the fuel injector, there is a greater chance of fuel droplets striking the liner, a phenomenon known as wall wetting. Wetting the cylinder walls allows liquid fuel to seep past the piston rings and onto the sump, diluting the lubricating oil. In addition, biodiesel's higher boiling point makes it less volatile than diesel, resulting in less biodiesel evaporating from the crankcase. Therefore, biodiesel increases the total dilution rates since it accumulates in the crankcase oil more quickly than diesel and lingers in the lubricating oil. The viscosity modulation of the lubricant is further affected by the interactions between biodiesel components and lubricant components, in particular viscosity modifiers, throughout a wide temperature range.

3.2 Density

Density fluctuations point to fuel contaminants and wear debris in the lubrication oil, which dilutes the oil. Density variations of the lube oil specimens from both engines are shown in Fig. 3. As the test goes on, the lubricating oil gathered from both engines will get denser. However, the oil from the CFB20 fuelled engine suggests a more substantial density rise during the experiment's final half (up to 13% higher). More testing is needed to determine whether or not the increased rate is a result of increased wear debris formation or humidity accumulation in the biodiesel-fueled engine.

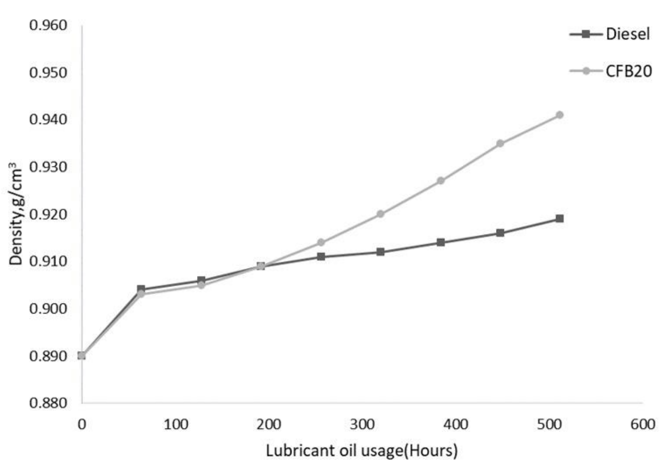

Fig. 3 Lubricating oil density

3.3 Flash Point

The flash point of a lubricant is the minimum temperature when an external ignition source will ignite its vapors. Both diesel and CFB20 fuel-powered engine oil samples showed a decreasing trend. Nonetheless, the CFB20-fueled engine's flash point dropped at a faster pace as the test duration increased. Here, diesel with a flash point of 170^{0}C is contrasted with biodiesel, which has a flash point of 71^{0}C. As shown in Fig. 4, the CFB20 engine has a lubricating oil flash point about 5% lower than the diesel fuelled engine during the last phase of the endurance test. This variation is because of a more diluted fuel mixture in the CFB20-fueled engine. Adding fuel to lubricating oil lowers its flash point because it weakens the bonds between oil molecules, requiring less heat to evaporate. Moreover, the biodiesel's flash point may be lowered even further with the addition of water.

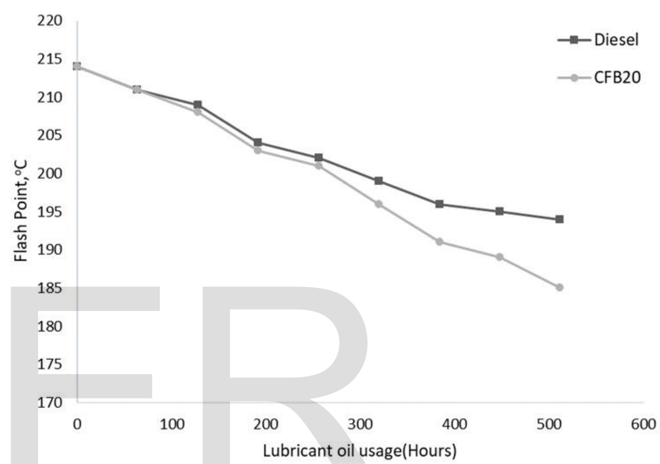

Fig. 4 Lubricant oil flash point

3.4 Moisture Content

There is a direct correlation between the amount of moisture in lube oil and how quickly the oil degrades. Moreover, when oil components interact with water, acidic by-products are produced that promote corrosion [7]. There is a stronger attraction between dissolved water molecules and other polar molecules, such as those found in lubricant additives. These additives have an affinity for each other, and when they separate from the lubricating oil, they may wreak havoc on an engine. Fig. 5 shows the moisture content in the lubricant oil, measured using a titration unit (ASTMD1744). A 7 percent increase in moisture was found in lubricant specimens from the CFB20-fueled engine. Oil dilution by biodiesel, which is naturally more hygroscopic, is responsible for this variance. Increased engine blow-by, which causes additional water to collect in the crankcase, may account for the more significant rise in moisture content after 400 hours of oil consumption.

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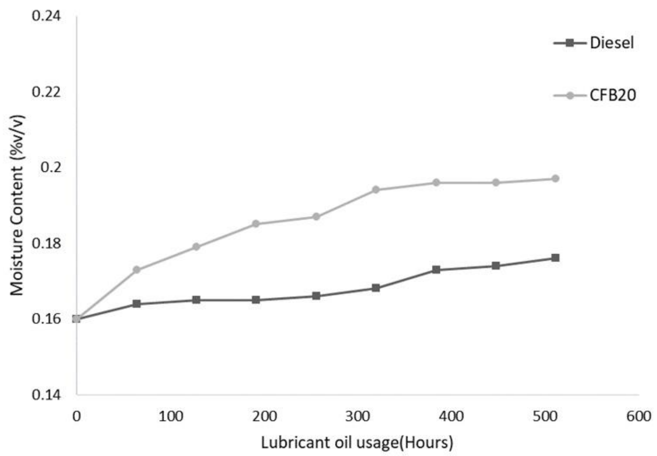

Fig. 5 Variation of Moisture Content

3.5 Solvent Insolubles

Lubricating oil will inevitably be tainted with oxidation by-products and wear debris. Pentane (an aliphatic solvent) is generally insoluble in oils, but benzene (an aromatic solvent) is soluble in oxidation products. Therefore, both pentane and benzene are often ineffective in dissolving wear debris and soot. The level of contamination and deterioration in the oil may be detected by performing an insoluble solvent test. It includes both a benzene insolubility test and a pentane insolubility test.

All impurities in the lubricating oil, from wear metal particles to solid contaminants to carbon residue to combustion and oxidation by-products, are accounted for in the insoluble pentane test. It is important to note that oxidation and combustion products in the oil are undetectable by the insoluble benzene test alone. Resin amount refers to the disparity between the two insoluble. Solvent insolubility in lubricating oil may be quantified using a submicron membrane filtering technique (ASTM D 4055). Toluene insoluble below pentane indicates that contamination is less severe than the chemical breakdown of the oil.

Figure 6 and Figure 7 show the insoluble relative to oil content. The CFB20 engine produces up to 16% more insoluble pentane than the tidy diesel engine. These variations indicate that the oil has degraded significantly owing to oxidation and has been contaminated with wear debris. Antiwear additives may have been depleted in CFB20-fueled engines because of the greater moisture content in lubricant samples, as previously noted. After 400 hours of operation, benzene insoluble from the biodiesel engine increased dramatically. Analysis of the wear metals in the engine's lubricating fluid supports the conclusion that considerable metallic component wear is the cause.

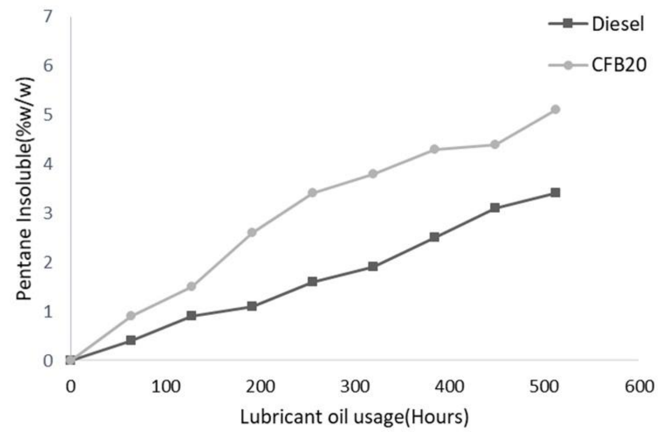

Fig. 6 Pentane insoluble vs. usage hours

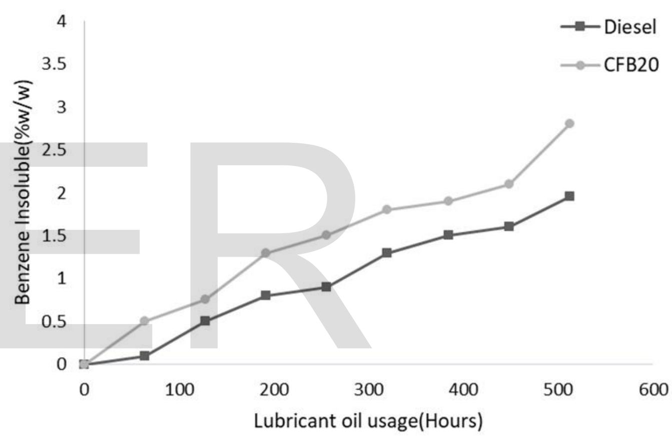

Fig. 7 Benzene insoluble vs. usage hours

3.6 Total Base Number(TBN)

For diesel engines, the accumulation of organic and inorganic acids in the lubricating oil as a by-product of combustion is neutralized using a base reserve additive, which TBN indicates. Corrosive engine wear may occur if strong acids build up without this alkalinity reserve. It is also a gauge of the oil's capacity to deal with the impurities and residues generated by the engine over time.

As shown in Fig. 8, TBN steadily reduced with biodiesel and mineral diesel throughout the operation. However, it fell more quickly during operation with the CFB20-fuelled engine. Oil should maintain its acid-neutralizing property during its service life to avoid corrosion of engine components. Thus, this quick decline is cause for worry. However, the TBN number alone cannot be used to predict how long a lubricant will last due to its acid-neutralizing capacity, particularly when fuel dilution alters the lubricant's chemistry. [8] TBN levels are calculated using a potentiometric titration method following the protocols specified in ASTM D2896.

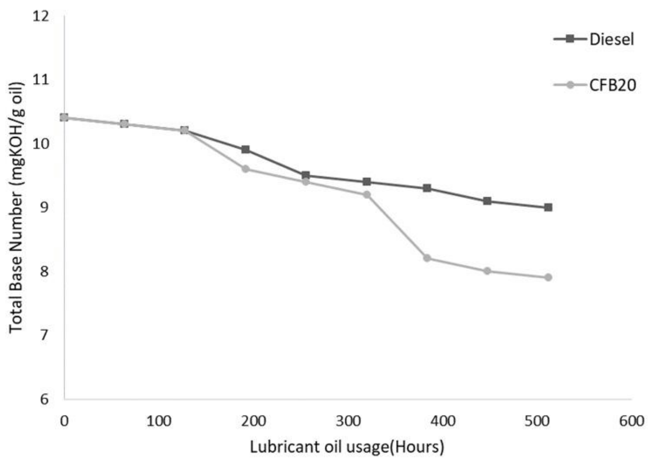

Fig. 8 Variation of Total base number with usage

3.7 Ash Content

The ash in engine oil is a by-product of engine parts' normal wear and tear and the introduction of outside contaminants like dirt and dust. Given their identical operating circumstances, the dissimilarity in ash concentration between petro diesel and CFB20 fuelled engines suggests the presence of metallic wear debris in the oil (Fig 9). Higher rates of component wear in the bio-diesel engine are indicated by a roughly 13% increase in ash content in the lubricating oil (as measured by ASTM D482). The results of a metal analysis on the motor oil support these claims.

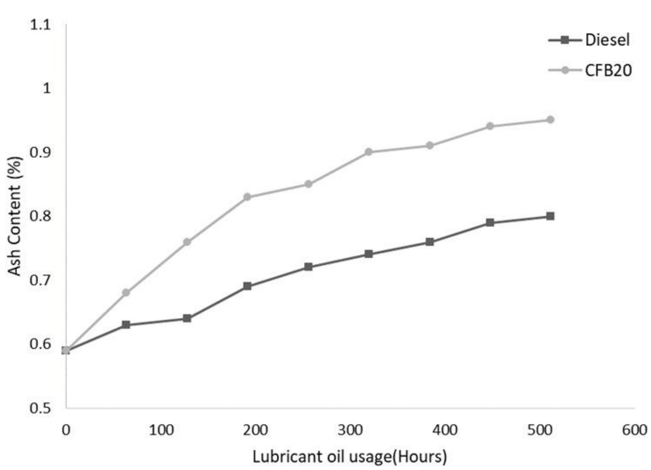

Fig. 9 Variation of ash content with usage

3.8. Critical Limits of Lubricant Oil Properties

Standard operating limits for lubricating oil condition monitoring are shown in Table 4. The test engine has a suggested oil change frequency of 500 hours. However, only the kinematic viscosity and flash-point (about 460 and 480 hours, respectively) exceed the prescribed restriction parameters.

Therefore, a modified lubricant replacement frequency of 450 hours is suggested to account for this. This is reasonable since viscosity changes result from several events, including fuel mixing, moisture accumulation, and wear.

3.9. Estimation of Metallic Debris in Oil

The lubricant collects metal wear particles released by engine parts. This means that metal particles in oil are indicators of engine component wear [9]. Inductively coupled plasma spectroscopy analyses samples of mineral diesel and CFB20 lubricating oil for their wear metal content.

Iron concentration in a biodiesel-fueled engine is lesser during the first 200 hours of operation. (Fig. 10(a)). However, as the endurance test progresses, it slowly rises to a much greater value than plain diesel. (26% more) In the first part of the test, the quantity of iron debris was significantly reduced when the lubricating oil was diluted with trace quantities of biodiesel [10]. Fig. 10 (b) shows the relative concentration of copper wear debris in an engine running on CFB20 fuel. It shows a gradual gain throughout most of the test, with a sharper increase at the end.

Fig. 10 (c). displays nickel debris from CFB20 and diesel engines. Throughout the experiment, nickel particles in both engines rose. However, their concentration was slightly greater in the biodiesel engine. Fig. 10 (d). illustrates the variation in the oil's lead wear particles. There was a significant increase in lead concentration in the biodiesel-powered engine's lubricating oil. Throughout the experiment, diesel and biodiesel-powered engines produced similar levels of aluminium particles. (Fig. 10 (f)).

CFB20-fueled engines had a larger chromium content (Fig. 10(h)), although having lower amounts of total wear debris. Since biodiesel is more acidic and corrosive than regular fuel, it accelerates the deterioration of precious metals like chromium.

Zinc and magnesium concentrations in diesel and biodiesel engines are shown in Figures 10(e) and 10(g). Higher evaporative losses or lower additive depletion explain the rising trend in certain places, whereas the opposite is true for declining trends over extended periods.

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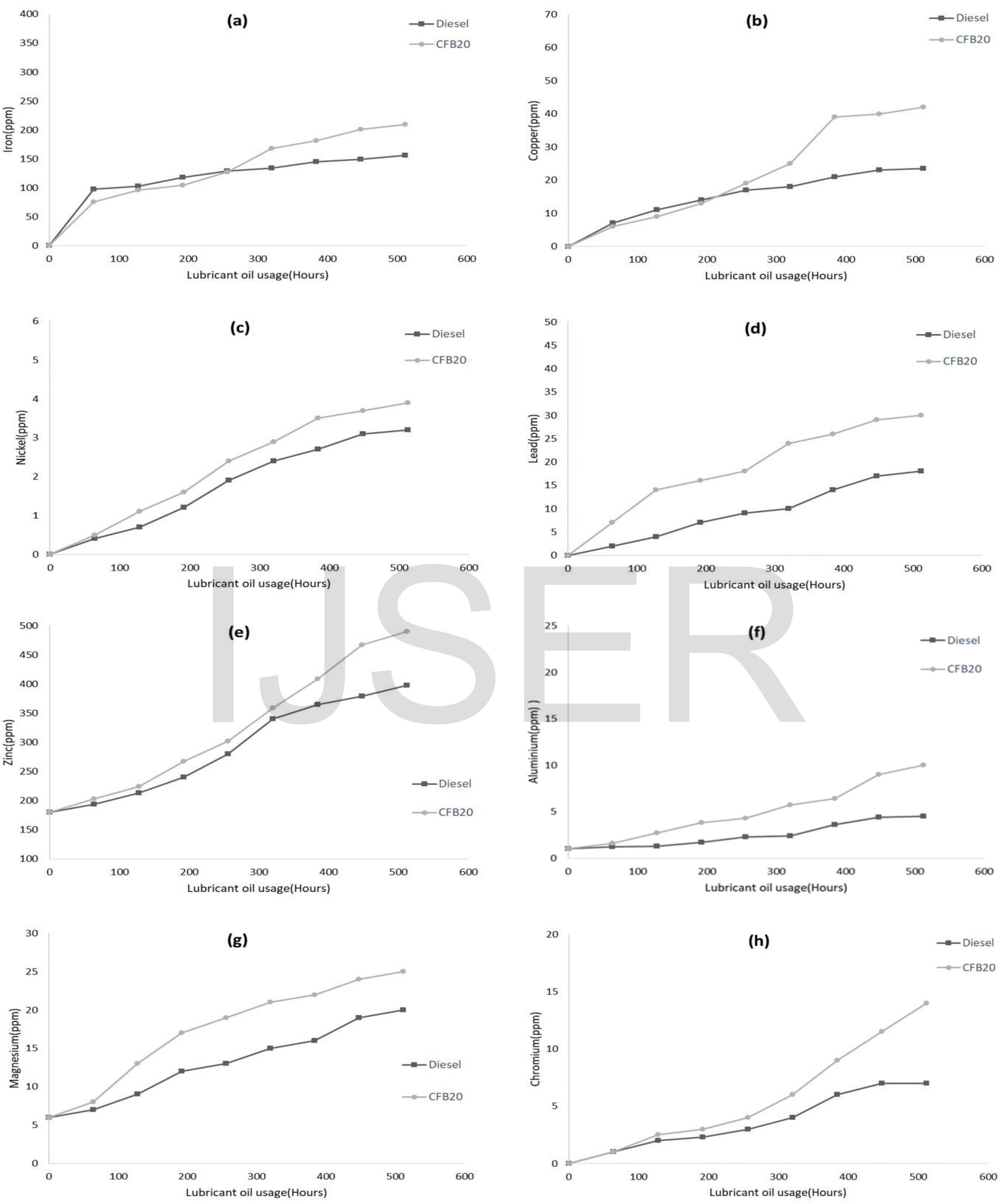

Fig. 10 Metallic particles (ppm)vs Hours of Usage (a) iron, (b) copper, (c) nickel, (d) lead, (e) zinc, (f) aluminium, (g) magnesium, and (h) chromium**.**

4. Conclusions

The influence of CFB20 on lubricating oil deterioration and engine durability was compared to diesel in a single-cylinder CI engine. The vast array of data acquired during the endurance test led to many conclusions.

A 13% higher density for the lubricant oil samples from the biodiesel-fueled engine can be attributed to increased wear debris formation and humidity accumulation. Wear debris also results in higher ash content and solvent insoluble in the lubricant oil from the CFB20 engine. In addition, more significant wear elements such as iron, copper, aluminium, and chromium were discovered in the CFB20-fuelled engine's lubricant samples, particularly in the later phases of the endurance test, indicating oil deterioration.

The significant decrease in the viscosity of lube samples from the CFB20-fueled engine showed increased impurities in the sump oil and fuel entry into the lubricant oil. In addition, a decrease in the flash point also proves the presence of fuel in the lubricant oil.

Due to fuel dilution, additive depletion, and lubricant oil oxidation, blends of biodiesel made from waste chicken fat cause increased engine component wear and lubricant oil deterioration. However, none of these problems resulted in a breakdown of the engine operations. Thus, appropriate reformulation of the lubricating oil will permit widespread use of biodiesel blends in current compression engines.

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