

Investigation of Lubricating Oil and Exhaust Valve Deposit Formation Using Blend Fuels in CI Engine

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ABSTRACT

Based on the findings of short-term research, biofuels are determined to be an acceptable replacement for petroleum diesel fuel. Extended research using these kinds of oils as fuel identified issues with engine wear and upkeep. A 200-hour test was conducted on a single-cylinder compression ignition engine to examine the effects of fueling on engine longevity. This research work was carried out to investigate the long-term endurance test of DF100 (diesel fuel) as the base fuel, and blended fuels: DF95WCO5 (5% waste cooking oil and 95% DF), and DF65WCO20Pe15 (20% waste cooking oil, 65% DF, and 15% n-pentanol) through single-cylinder compression ignition (CI) engine. Further, the effects of DF100, DF95WCO5 and DF65WCO20Pe15 on exhaust valve surface deposits were also investigated. The SEM and EDS analysis showed that DF95WCO5 has a higher concentration of carbon deposits around the exhaust valve surface as compared to DF100 and DF65WCO20Pe15. Further, ternary blend fuel had minimal carbon deposits on the exhaust valve as compared to as compared to remaining both. This evidenced that the addition of pentanol significantly reduced the carbon deposition on the exhaust valve surface. About DF, DF95WCO5, and DF65WCO20Pe15, the percentage of carbon layer on exhaust valve surfaces is 44.67%, 45.42%, and 16.01%, respectively. For the fuel DF65WCO20Pe15, there was very little exhaust valve deposit formation during experimental examination. The ternary blend fuel also observed less concentration of Iron, Copper, Nickel and wear debris concentration as compared to DF100 and DF95WCO5.

Keywords: Waste cooking oil; exhaust valve deposition; viscosity; density; wear analysis

INTRODUCTION

As the need for fuel rises and environmental rules tighten, researchers are starting to look into the term “alternative fuels”. (Ponnusamy, Ramani et al. 2021). Diesel engines are essential in the locomotive, agricultural, construction, and industrial sectors because of their unparalleled efficiency in turning fuel into power, reliability, durability, and torque capacity (Dillikannan, Sathiyagnanam et al.

2018). Their widespread usage increases dependency on fossil fuels, leaving developing countries like India primarily reliant on imports to meet their fuel requirements, which has a severe impact on their economies (Rajesh Kumar and Saravanan 2016, Rajesh Kumar, Saravanan et al. 2016). Diesel engines are widely recognized for their high NO_x and smoke emissions, which are harmful to the environment and living things (Kaliyaperumal, Sathiyagnanam et al. 2018).

The economy and the ecology will benefit if even a small amount of fossil fuel is replaced with renewable biofuel (Depoures et al. 2018). One essential component of attaining environmental sustainability is recycling. Globally, many billion gallons of used cooking oil are thrown away each year (Hribernik and Kegl 2009). Utilizing used cooking oil in various forms in CI engines is the subject of much study (Can 2014; Hwang, Qi et al. 2014). Furthermore, transesterification is the most extensively used technique for creating biodiesel from leftover cooking oil and producing oil with properties equivalent to diesel oil (Man, Cheung et al. 2016, Ulusoy, Arslan et al. 2018). However, the challenges involved in converting waste cooking oil with a high acid content to biodiesel are complicated, thus a workable solution is needed to use waste cooking oil as the fuel oil (Chen, Lee et al. 2017). Modern diesel engines might have various issues when using vegetable oil directly, including increased engine wear, fuel filter clogging, injector coking, and heavy carbon deposits in engine components, piston ring sticking, and lubricating oil gelling (Utlu and Koçak 2008, Hribernik and Kegl 2009, Lin, Hsu et al. 2011, Awad, Varuvel et al. 2014).

Due to its high viscosity, using cooking oil directly in CI engines results in poor atomization, which raises soot concentration (Masimalai and Mayakrishnan 2014). Researchers have recently become interested in reformulating WCO with alcohols because it is an easy, practical, and affordable way to reduce the viscosity of vegetable oils (Bari, Yu et al. 2002, Kalam, Masjuki et al. 2011). The effects of combining n-pentanol with used cooking oil and diesel mixture under various load circumstances were studied by Ravi Kumar and Saravanan (Capuano, Costa et al. 2017). The wear particles remain suspended in the lubrication system of fluids. Variations in the concentrations of metallic particles included in the

lubricating oil may be studied and investigated after a given period of operation to provide enough information about the element source, wear rate, and engine condition (Atmanli, Yüksel et al. 2013).

Effective harvesting requires at least two factors, namely effective harvesting tools and sufficient harvesters, to produce the optimum output within the recommended harvesting cycles (Ahmad 2023).

In diesel engines, common wear items include the cam shaft, valve system, crankshaft, cylinder liner, pistons, bearings, piston pins, tappet, and so on (Sharon, Jai Shiva Ram et al. 2013). As a result, direct signs of engine wear and condition can be discovered by analyzing the lubrication oil (Lujaji, Lukacs et al. 2011). As per (Krishnamoorthy, Dhanasekaran et al. 2018), it can be deduced from the extant literature that a ternary blend D50-WCO30-Pe20 of waste cooking oil, which is blended with diesel and alcohol, would be a feasible substitute for fueling diesel engines. Pentanol added to biodiesel or diesel enhanced performance and emissions, particularly at low/medium loads, as demonstrated by (Li, Wang et al. 2015) Excellent combustion was achieved with a ternary blend that contained 40% diesel, 30% biodiesel, and 30% pentanol. The research mentioned above used short-term endurance tests.

The aim of this research work is to evaluate the effects of “diesel”, “used cooking oil”, and “pentanol” fuel in one-cylinder engines having same fuel injection pump pistons and with similar exhaust valve specifications is performed. After 200 hours of operation at 1300 rpm, the exhaust valves were examined and compared using SEM and EDS analysis. The primary goal of this work is to conduct a comparative analysis of the exhaust valve surface deposits, lubricating oil analysis and wear debris for DF, DF05WCO5, and DF65WCO20Pe15 blends, respectively.

Nomenclature

CI	Compression ignition
Cu	Copper
CIDI	Compression ignition direct injection
ASTM	American society for testing and materials
DF	Diesel fuel
DI	Direct injection
DF95WCO5	Diesel fuel 95% + Waste cooking oil 5%
DF65WCO20-Pe15	Diesel fuel 65% + Waste cooking oil 20% + n-pentanol 15%
EDX / EDS	Energy dispersive X-ray spectroscopy
Fe	Iron
IC	Internal combustion
Ni	Nickel
O	Oxygen
SEM	Scanning electron microscopy
Ni	Nickel
WCO	Waste cooking oil

MATERIALS AND METHODOLOGY

FORMULATION OF FUELS

Waste cooking oil used primarily for frying at temperatures between 130 and 180 degrees celsius was obtained reputed

restaurant. Before blending the oil, the oil was strained and heated it to remove sediments and water particles. This was done to adjust the strengths of the combinations because diesel is water repellent and water may cause phase separation over period of time.

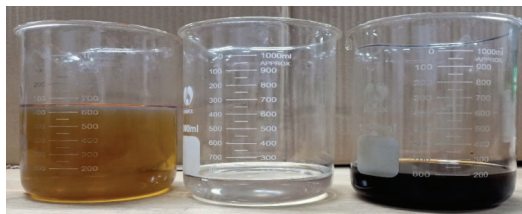


FIGURE 1. Appearance of selected fuels for experiments

A 4 μ m filter was utilized for WCO filtration. Before fueling the engine, each test fuel mixture (% vol) was prepared. Using a mechanical homogenizer at 4000 revolutions per minute and 30 minutes of splash blending, the test fuels were blended. No cetane refiners were present and surfactants were added. Figure1 depicts the physical position of fuel prior to combining.

The diesel fuel (DF100) was considered as base fuel, and two blended fuels such as binary fuel: DF95WCO5 ratio as: diesel fuel-95%vol + WCO-5%vol, and ternary blended fuel: D65-WCO20-Pe15 ratio as: diesel fuel-65%vol + WCO-20%vol + nPe-15%vol were formulated, and their characteristics are shown in Table 1.

TABLE 1. Characteristics of DF100, DF95WCO05 and DF65WCO20Pe15.

Properties	DF100	D95WCO5	D65WCO15Pe15	Test Method
Density g/ml	0.85	0.89	0.84	ASTM D-7042
Calorific value MJ/Kg	42.5	39	40	ASTM D-5468
Viscosity 40 °C Cst	2.28	2.34	1.95	ASTM D-7042
Cetane number	50	53	55.5	ASTM D-6890
Flash point °C	78	85	94	ASTM D-93

TESTING BED OF ENGINE

A single-cylinder, four-stroke, compression ignition engine that is water-cooled and connected to an eddy current

dynamometer was used for the experiments. Figure 2 displays the engine's schematic diagram. Moreover, the compression ignition engine major specifications are tabulated in the Table 2.

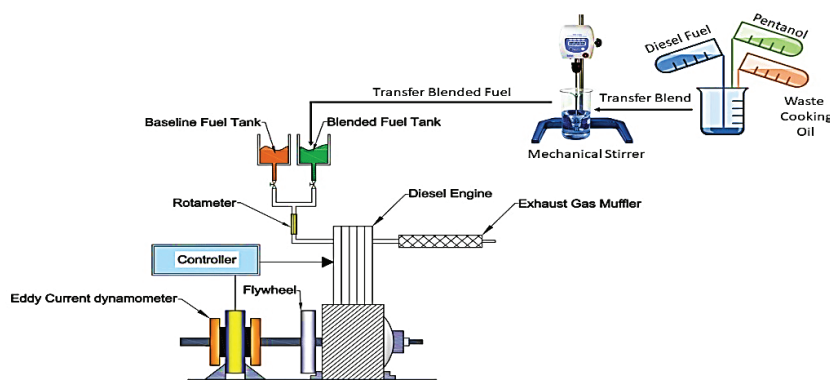


FIGURE 2. Experimental setup

TABLE 2. Engine specifications

Model	Single-Cylinder, Horizontal, water cooled four stroke pre-combustion chamber
Stroke	80mm
Bore	75mm
Displacement	0.353L
Output (12 hours rating)	4.4kW/2600r/min
Injection pressure	14.2 + 0.5 MPa
Compression ratio	21-23
Specific fuel consumption	278.8 g/kW h
Cooling water consumption	1360 g/kW h
Specific oil consumption	4.08 g/kW h
Maximum engine power	7.7 kW
Valves clearance	Inlet valve 0.15-0.25mm
Maximum engine torque	80 Nm

On each fuel sample, a 200-hour endurance test was conducted as part of the research. Following the disassembly of the engine to obtain the exhaust valve for examination, the three remaining test fuels were utilized in the same manner. Finally, energy dispersive X-ray spectroscopy (EDS) and scanning electron microscopy (SEM) were used to examine each sample of exhaust valve that had been collected. Deposits that are macro- and submicron-scale can be examined using SEM. The elemental analysis of microscopic deposits can be done using EDS in conjunction with this technique. For visual evaluation of the exhaust valve, photographs were taken at 0 h (Fresh) and after 200 h endurance testing of each fuel sample. During the investigation of DF100, DF95WCO5, and DF65WCO20Pe15 mixtures on engine oil, lubricant oil samples were collected every 20 hours for each fuel sample during the engine endurance test. The viscosities of lubricant oil samples were determined using a Saybolt viscometer (Two-tube type), and the density was measured using a Glass pycnometer. During the endurance test, an atomic absorption spectrophotometer was used at the conclusion to determine engine attrition.

RESULTS AND DISCUSSION

EXHAUST VALVE VISUAL INSPECTION

During a 200-hour endurance test on DF100, DF95WCO5, and DF65WCO20Pe15, photographs were taken of the exhaust valve as depicted in Figure 3. The visual examination of the liners of the exhaust valve surfaces of both fuel samples conducted after varying hours of operation disclosed the accumulation of deposits, as seen in Fig. However, the valve surface running on DF100 and DF65WCO20Pe15 was cleaner than the injector running on DF95WCO5. Reksowardojo et al. (Atmanli, Ileri et al. 2014) reported comparable findings. In another study, Birgel et al. (Atmanli, Ileri et al. 2014) observed that biodiesel caused an increased accumulation of deposits in the injector nozzle. Additionally, DF100 and DF95WCO5-run valve surfaces showed greasy/oily deposits, while DF65WCO20Pe15-run valve surfaces showed dry deposits.

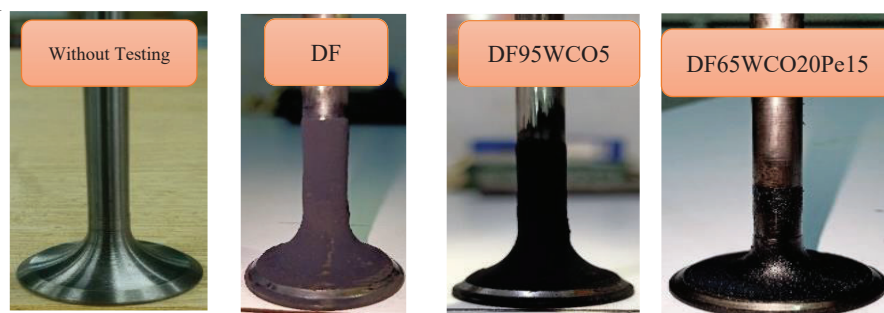


FIGURE 3. Photographic view of engine valves during endurance test

SEM AND EDX ANALYSIS

Deposits, or carbon deposits, in diesel engine combustion chambers are heterogeneous combinations of carbon debris, soot, and oxygenated material leftovers (Atmanli, Ileri et al. 2015). The deposition in combustion chamber maybe increased due to the effect of unburnt fuel in combination with low wall temperature (Atmanli 2016). On the cylinder head are the intake and exhaust valves, components of the engine mechanism. The purpose of these valves is to control the flow of fluids and gases into and out of the combustion chamber (Özgür, Tosun et al. 2017). WCO is a combination of diesel fuel and unmodified waste cooking oil. This combination was used to power a single-cylinder diesel engine during a long-term durability test. It has been reported that it is possible to determine the thickness of deposits by monitoring the temperature of the

wall of the combustion chamber as well as the area where fuel is impinging (Agarwal 2007, Ravikumar and Saravanan 2017). Advanced diesel injection systems are characterized by higher temperatures in the area of the head depositions that can lead to particularly stubborn deposits (Solangi, Memon et al. 2024). It is possible for there to be greater deposit formation in the engine chamber if the wall temperature is low and there is unburned gasoline present. After the long-term endurance test of 200 hours had been completed on DF100, DF95WCO5, and the DF65WCO20Pe15 mix, the engine was partially disassembled so that deposit formation on each exhaust valve surface could be investigated. Higher temperatures in the vicinity of the injector tip, which are characteristic of advanced diesel injection systems, can cause deposits that are particularly resistant to removal at the injector tip and in the surrounding area (Basinger, Reding et al. 2010, Haseeb, M. A et al. 2011).

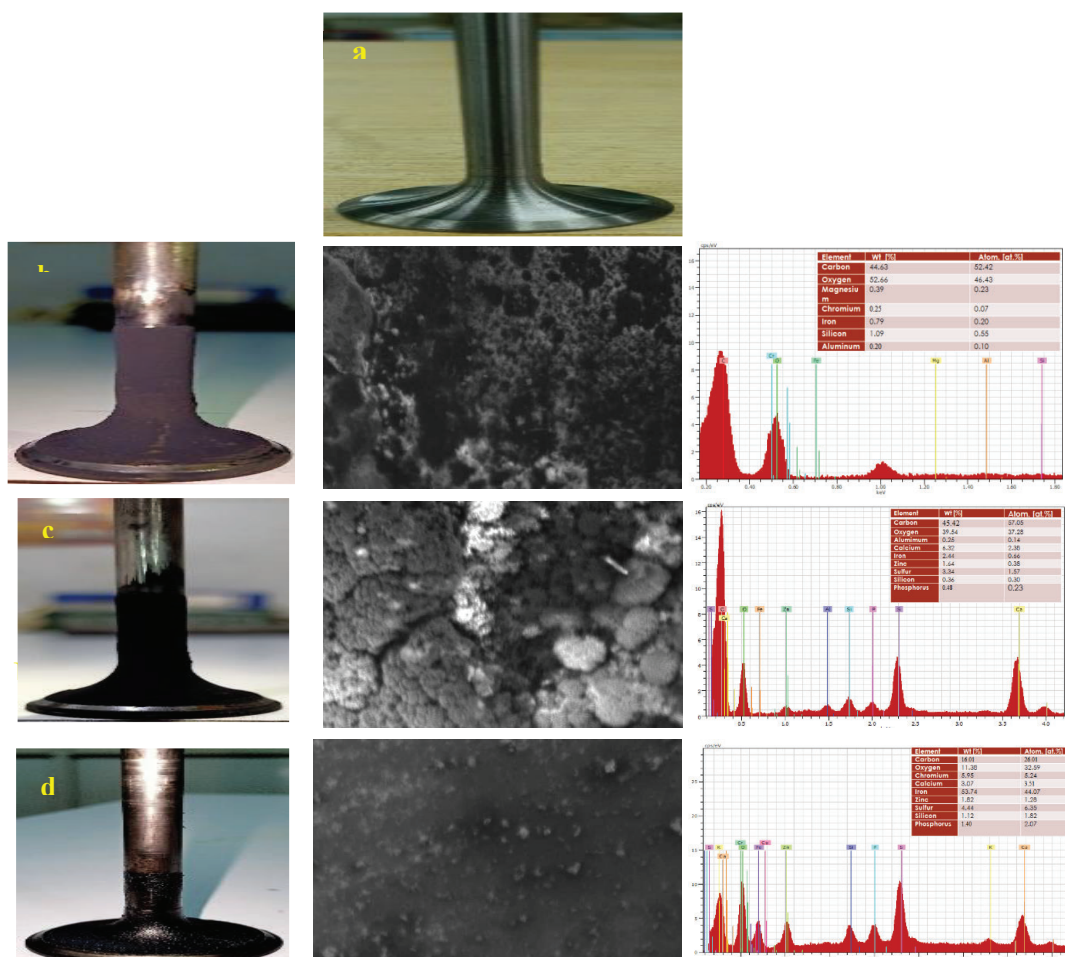


FIGURE 4. SEM and EDX Analysis of (a): Without Testing, (b): DF100, (c): DF95WCO5 and (d): DF65WCO20Pe15

Figures (a), (b), (c) and (d) show the SEM micrographs at 25X magnifications in conjunction with EDS of deposits on exhaust valve fuelled with three blend fuels and compared to base line fuel respectively. Figure 3 (d) clearly indicated less deposition for DF60WCO20Pe20 as compared to DF100 and DF95WCO02. Figure 3 (b) shows higher concentration of deposition on the top layer of exhaust valve, which evidences the amount of oxygen (O) as 52.66% (through EDS analysis). Nonetheless, in case of DF95WCO05, the concentration of oxygen is around 39.54 (through EDS analysis), and at the same location of exhaust valve (SEM image). However, the concentration of carbon (C) in these 44.63 % and 45.42 %, respectively. The deposited valves fuelled with DF60WCO20Pe15 on the surfaces show comparatively lesser concentration of carbon (16.01 %) and reduced concentrations of oxygen (6.86). This indicates that accumulation layer has a reduced concentration of carbon. On the other hand, the presence of base metal iron (Fe) in case of all test fuels are: 0.79, 2.44, 53.74 which shows that ternary blends have rather than a higher amount of iron. As mentioned previously, the amount of carbon depositions for DF60WCO20Pe15 blend fuels are comparatively lower than that of DF100. In case of DF95WCO05 binary blend fuel shows grain like different phases on the deposition. This could be due to the presence of verity of carbon and oxygenated compounds. Finally, the presence and deposition of Sulfur (S) and zinc (Zn) in all tested fuels may be linked to engine fuel system hardware, and lubricant contamination.

LUBRICATING OIL ANALYSIS

Lubricating oil is a crucial component of IC (internal combustion) engines. It combines basic oils with additives and is made up of a complicated blend of hydrocarbons. Lubricants serve as detergents, dispersion agents, antioxidants, viscosity modifiers, and other cleaning agents in addition to reducing friction and wear on various sliding and rotating engine components (Diaby, Sablier et al. 2009, Solangi, Memon et al. 2022). After every 20 hours of operation, lubricating oil samples were taken in order to examine the impact on the engine oil during the endurance tests conducted on the DF100, DF95WCO5, and DF65WCO20Pe15 mix. The following parts provide the investigation's findings.

VISCOSITY

It was supposed that the viscosity measured at 100°C was quite close to the typical oil temperature during engine running (Solangi, Memon et al. 2024). Kinematic viscosity is a critical feature of engine lubricating lubricants. While a drop often denotes lubrication fluid dilution, a rise in viscosity typically suggests that the lubricant is degrading due to contamination or oxidation (Suryantoro, Sugiarto et al. 2016). Kinematic viscosity measurements were made at 40°C and 100°C, and the results are depicted in Figures 5 and 6, respectively. The experimental results depicted that throughout the endurance test, the kinematic viscosity of all blended fuels and base fuel dropped for 40°C and 100°C. The most likely cause of this drop in lubricating oil viscosity is gasoline dilution of the crankcase oil. Viscosity was significantly reduced during the first 20-hour operation, as can be observed. Lubricants contain variety of chemicals, including antioxidants and anticorrosion agents, and it is expected that various additives could be activated (form protective coatings) due to combine effect of pressure and temperature with the passage of time of operation (Yaman and Yesilyurt 2021). The lubricant first passes through various tribochemical processes rather of forming the protective coating, which causes viscosity degradation to occur more quickly than it would for the remainder of the working time (Goldsworthy 2006). However, DF65WCO20Pe15 demonstrated a more significant decline in engine lubricating oil viscosity in comparison to DF100 and DF95WCO5 during the engine endurance test.

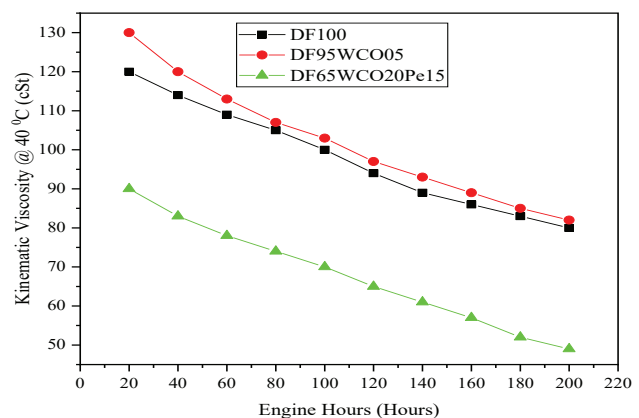


FIGURE 5. Kinematic viscosity at 40°C of Diesel and Blended Fuels.

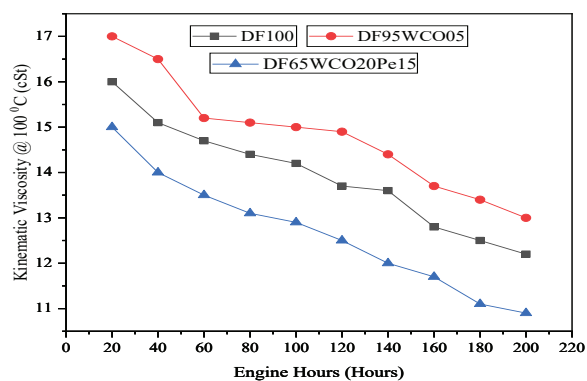


FIGURE 6. Kinematic viscosity at 100°C of diesel and blended fuels

The engine life may be shortened by increased wear on the moving components caused by the engine oil samples' reduced viscosity during the endurance test (Solangi, Memon et al. 2024). According to some reports, unburned biodiesel mix that enters the crankcase over time may weaken the viscosity of the lubricating oil, lowering the thickness of the lubricant coating and eventually accelerating component wear in the oil (Li, Wenbin et al. 2021). Similarly, according to Gramstad et al. (Dandu and Nanthagopal 2021), insufficient atomization and larger droplet sizes from the injectors as a result of the biodiesel fuel's higher viscosity, surface tension, and specific gravity in combination with a lower volatility led to the fuel's incomplete combustion, and the leftover unburned fuel on the cylinder walls is scraped into the crankcase by the piston rings. Additionally, this unburned gasoline dissolves in the engine oil, degrading it. As a result, biodiesel fuel builds up in the crankcase, diluting the engine oil further. Additionally, excessive engine oil dilution has the potential to lead to a number of issues, including catalyst poisoning and decreased oil performance and durability. Considering the aforementioned information, it can be shown in Figs. 5 and 6 that using DF65WCO20Pe15 as engine fuel resulted in a higher drop in lubricating oil viscosity than using DF100, DF95WCO5.

DENSITY

The density of the engine lubricating oil may be measured, and this information is crucial for determining if the oil has been contaminated by wear metals or diluted with gasoline. As a result, the presence of wear particles, diluted gasoline, and increased moisture content cause the density of used engine oil to rise.

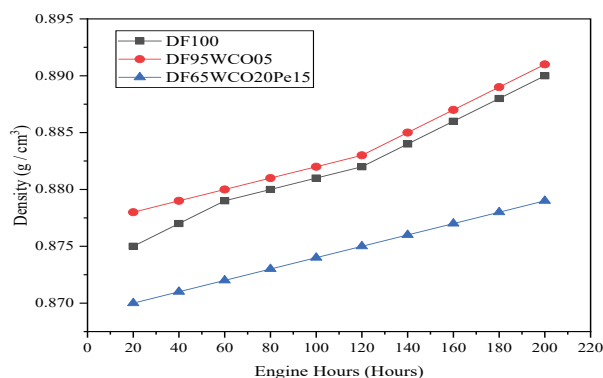


FIGURE 7. Density of diesel and blended fuels

According to Figure 7, there is an upward trend in the density of the engine oil samples as they are used. First, the engine parts begin to wear more quickly, and gasoline dilution also begins. As a result, the combined impact of these factors has a greater impact on the rate of rise in the density of the engine oil when the engine is operating with the DF65WCO20Pe15 mix than when it is running with DF100, DF95WCO5. The first 20 hours of operation was when the density increased the most, as can be shown. Density increases are consistent with explanations for kinematic viscosity decrease.

ENGINE WEAR

During engine endurance testing, the concentration of metallic particles in engine oil provides critical information on the rate of wear as well as the source of the elements. Therefore, doing a metal analysis on the engine's lubricating oil can provide a reasonable estimate of the amount of wear that has occurred on the essential components of the engine. As a result, it is possible to forecast the condition of the engine at that point, and is that the chromium (Cr) maybe produced from crankshaft and cylinder liner, copper (Cu) comes from the bearings and bushings, aluminum (Al) comes from the piston or ingested dust, lead (Pb) comes from the bearings, paints, and grease, and magnesium (Mg) comes from the bearings, bushings, and lubricants. The wear rate, element source, and engine condition can all be accurately predicted in a diesel engine through an examination of the quantity of metallic particles in the lubricating fluid. Lubricating oil often contains iron (Fe), copper (Cu), and nickel (Ni) after engine use (Dandu and Nanthagopal 2021). An Atomic Absorption Spectrophotometer (AAS) was set up by placing Hollow cathode lamps of each element independently in order to determine the engine analysis wear/debris. Iron (Fe), copper (Cu), and nickel (Ni) were

among the elements in standard solutions that were created. When the engine was fueled with either DF100, DF95WCO5, or DF65WCO20Pe15 during the endurance testing. Figure 8 illustrates the varied wear particles that were present in the engine lubrication oil. It can be noticed that DF95WCO5 has a greater metal concentration than DF100 and DF65WCO20Pe15. According to research, fuels containing additives may produce less exhaust emissions, but they may also because more wear than fuels containing a high sulphur concentration. When oxygen and unsaturated fatty acids in N-pentanol come into contact with metal surfaces, a chemical reaction occurs that might result in oxidation and wear. Additionally, there is a chance that a trace amount of metal contaminants may exist. As a result, the lubricant for DF95WCO5 contains more wear debris or metals breaking off of surfaces. This is especially clear where there are high amounts of Fe, Cu, and Ni. Later on, the wear rate is significantly reduced. Different types

of additives, such as antioxidant additives and anti-corrosion compounds, are used in the lubricant composition. Instead of generating a protective film right away, the lubricant initially engages in a variety of tribochemical reactions with metals depending on the type and purpose of foreign matter. It takes time for the participating additives to neutralize (or participate) in the metal debris that was blown into the lubricant.

IRON (FE)

The wear of several engine parts, including the crankshaft, bearing, piston rings, gears, corrosion, cylinder liner, valves, and their guides, is the cause of the iron metal particles that have accumulated in the old lubricating oil of the engine sump (Dandu and Nanthagopal 2021).

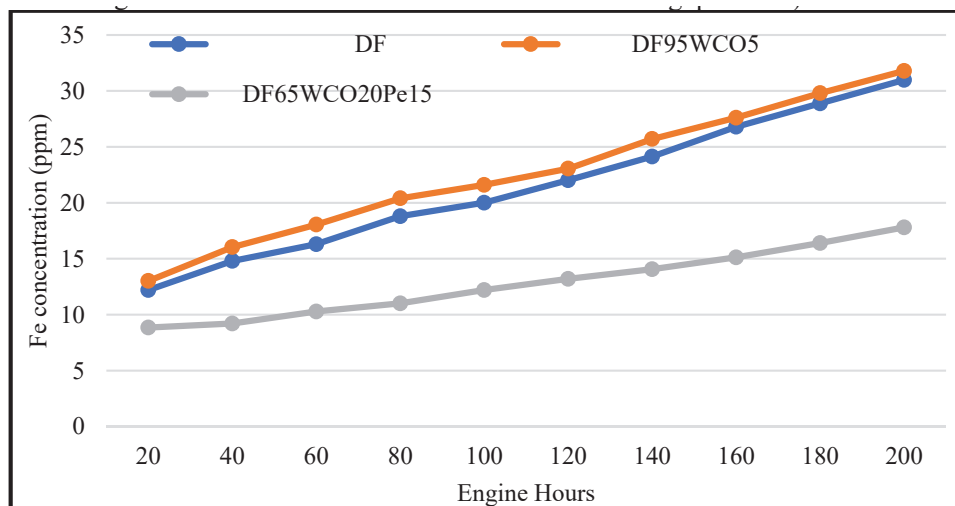


FIGURE 8. Iron concentration V/s engine hours

Figure 8 makes it evident that the rate of growth for iron is larger for DF95WCO5 and DF100 fuel. The lubrication oil that was drained from the engine that was powered by the mix fuel DF65WCO20Pe15 showed less iron concentration than the engine that was powered by diesel. In Figure 8, the diesel-fueled engine had less iron wear than the blend-fuel engines. The binary blend DF95WCO5 and the ternary blend DF65WCO20Pe20 converted to DF100, respectively, had the highest levels of iron concentration.

COPPER (CU)

Bearing and bushing are the most typical sources of copper concentration (Kadir, Yahya et al. 2016). Based on the examination of wear debris. The concentration of copper in binary and ternary blends of pure diesel, such as DF95WCO5 and DF65WCO20Pe20 fueled engines, was depicted in Figure 9 with respect to the number of lubricating oil consumption hours after every 20 hours. The figure made it abundantly evident that a binary blend results in a higher proportion of copper. In contrast to diesel fuel, however, the addition of n-Pentanol as a ternary blend only little altered the engine.

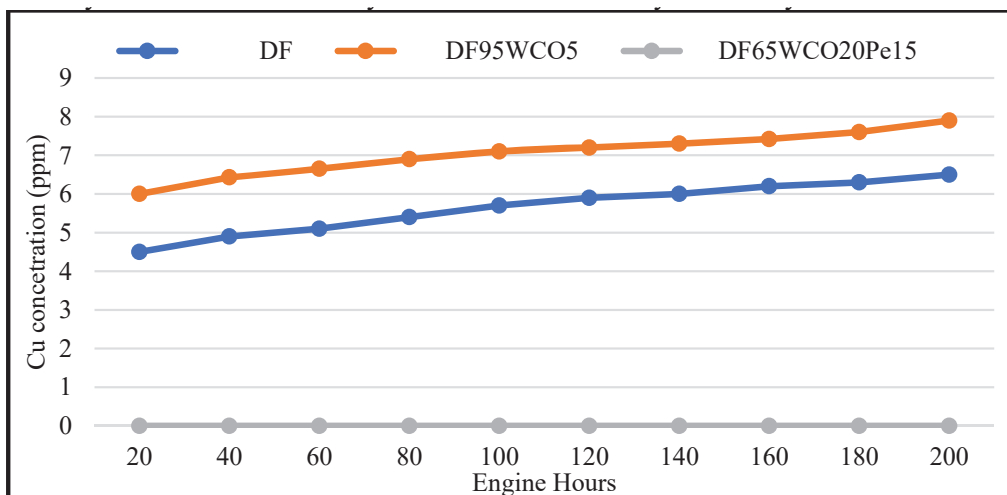


FIGURE 9. Iron concentration V/s engine hours

Figure 9 shows less copper wear in the ternary fuel blend. The binary DF95WCO5 and DF100 combination has the highest concentration of copper. The computer, however, regarded the ternary mixes DF65WCO20Pe20 as non-detective since they had very low concentrations or negligible concentrations.

NICKEL (NI)

Shafts, cams, rods, springs, valves, and valve guides are some of the components where nickel is concentrated (Ramalingam, V et al. 2015). The results are shown in Figure 10 in relation to the concentration of nickel metal dominating in the lubricating oil.

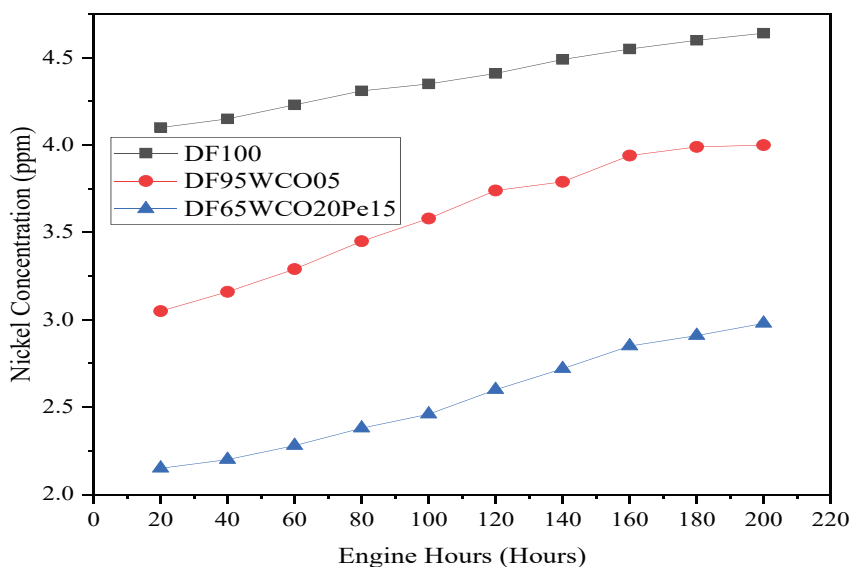


FIGURE 10. Nickel concentration V/s engine hours

The figure shows that when an engine is powered by a ternary blend of DF60WCO20Pe15 and diesel fuel, the

amount of nickel element is only slightly found to be at its lowest level. However, binary blend (DF95WCO5) was found to be superior to diesel fuel in this circumstance.

CONCLUSIONS

In this investigation, a 200-hour endurance test was used to examine how DF100, DF95WCO5, and DF65WCO20Pe15 mix fuels affected valve surface deposits, lubricating oil, fuel efficiency, and exhaust emissions. In this regard, the following conclusions might be made in light of the experimental findings:

1. Visual inspection revealed some deposit buildup in the exhaust valve when it was operating on either fuel (DF100, DF95WCO5, or DF65WCO20Pe15). Nevertheless, it was discovered that the exhaust valve operating with DF95WCO5 was dirtier than the valve operating with DF and DF65WCO20Pe15.
2. While the engine was fueled with DF65WCO20Pe15, dry deposits were seen on the exhaust valve as opposed to oily/greasy deposits while running with DF100 and DF95WCO5.
3. At the conclusion of the endurance test, SEM and EDX examination revealed that the amount of valve surface deposits was significantly lower with DF100 and DF65WCO20Pe15 than with the DF95WCO5 blend. The carbon layer wasn't consistently thick due to the deposition.
4. On the other hand, SEM and EDX tests revealed dense and dry deposits on and around the exhaust valve area when the engine was run on the DF95WCO5 blend, and the same deposits were virtually covered or otherwise obstructing the area. The dark regions showed a higher carbon concentration.
5. The viscosity of the lubricating oil was lowered with regard to engine running time at 40 °C and 100 °C when the engine was fuelled with DF and DF95WCO5 instead of DF65WCO20Pe15. In
6. comparison to DF100 and DF95WCO5, DF65WCO20Pe15 shown a greater reduction in engine lubricating oil viscosity when used.

The endurance test of the engine oil for the density rose during the endurance testing with both fuels. The increase in engine oil density was greater when the engine was run on the DF65WCO20Pe15 mix.

During the engine endurance testing, there were more metallic particles in the engine oil when the engine was operating on DF95WCO5 rather than DF100 and DF65WCO20Pe15.

The higher the inclusion rate of waste cooking oil, the more deposits formed on engine components, particularly the valves and injector tip.

By increasing WCO inclusion rate, a tendency toward increased ring sticking was observed.

DF95WCO5 fuel led to a large amount of deposits. More specifically, the use of DF95WCO5 showed excessive wetness in the exhaust valve. This could be ascribed to the fact that the injected fuel hitting on the valve surface wall would fail to dry, thus making the DF95WCO5 caused deposits tend to be wet and brittle. Future Scope Compared to binary mixes of diesel and waste cooking oil, ternary blends of diesel, waste cooking oil, and n-pentanol offer superior performance and emission characteristics. Less exhaust emissions were produced when n-pentanol was added compared to the binary blend and diesel fuel. Therefore, more study on ternary n-pentanol blends is necessary before various biofuels can be employed in CI engines in the future.

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DECLARATION OF COMPETING INTEREST

None.

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