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RESEARCH

Study of Lubricating Oil Degradation of CI Engine Fueled with Diesel-Ethanol Blend

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A B S T R A C T

The study of lube oil is useful in scheduled maintenance activity, determining the oil replacement time for engines, to increase the engine life and ensure the maximum performance. Investigation of engine oil can reduce maintenance cost and promises higher design efficiency. Experiments were carried out on a mono cylinder compression ignition engine fueled with diesel-ethanol blended, which is operated at a constant rated speed of 1500 rpm for 100 hours. The lube oil samples were subjected to wear metal tests, chemical and physical tests. The quantity of wear metal in the engine oil was observed using the atomic absorption spectrometer. The total base number and total acid number were measured by the titration method according to ASTM code ASTM D6654 and ASTM2896, respectively. The viscosity was determined using the Stab Viscometer, SVM3000, by the ASTM D445 method at 40°C temperature. Iron and copper concertation was increased with an increase in usage time. However, TBN decreased, and TAN increased with the usage time. Viscosity and density decrease with the increase in usage time. The lube oil shows that the engine can be operated for an extended time with the same lube oil since all the measured parameters are within the limit.

1. INTRODUCTION

With the continuous depletion of fossil fuels and day-by-day, increment in the demand of fuel as well as increasingly stringent emissions regulations, stances a challenge to current internal combustion design and technologies. With the advancement during recent years and increasing technological involvement to utilize biomass for biofuel production, the bioenergy business sector has been grown to manifolds. Thus, providing an effective way to deal with rapidly increasing fuel demands. Biodiesel is biodegradable, renewable, and has properties similar to fossil diesel fuel. Biodiesel consists of a long-chain alkyl ester produced by transesterification of animal fats and vegetable oil; it is a chemical reaction which may or may not use a catalyst, that works to replace the glycerol with molecules of methanol, thus giving molecules of methyl ester in the vegetable oil [1]. Some researchers found that biodiesel provides adequate lubricating characteristics. Now a day's considerable focus had been shifted on alternate fuel development sources such as alcohol and bio CNG. Butanol, Ethanol, Methanol, and propanol are some of the alcoholic fuel, researched extensively to overcome disadvantages associated with the Physico-chemical properties of these alternative fuels. Methanol is the simplest alcohol, which consists of a methyl group, linked to a hydroxyl group and is highly immiscible in a diesel-biodiesel blend; however, available emulsion significantly increases the cost of fuel, which in turn becomes uneconomical to deploy blended fuel as a viable commercial alternate of diesel fuel. However, Ethanol is a good selection as an alternative fuel. Ethanol is one of the extensively used alternate fuels since it is possible to produce ethanol from a bio-based and renewable resource. Moreover, it quickly gets miscible with diesel, bioethanol contents up to 10 % volume/volume, which can be used in a diesel engine without any hardware modification if water contamination is controlled. The commercial viability of E-diesel is very well established, wherein 7 % bioethanol is blended with diesel [2]. M. Al-Hassan et al. operated the engine using E-diesel blends with varying ethanol concentration from 5 to 20 %, and biodiesel is fixed at 10% on a v/v ratio [3]. They found that the E-diesel blend is not stable after 9, 3, and 1 day for 10, 15, and 20 % ethanol concentration, respectively.

It has been found that when the CI engine is fueled by highly aerated ethanol, it led to a reduction in particulate emissions. Ethanol may be produced from non-renewable resources (hydrocarbon), mainly natural gas and biomass. It is also synthesized from CO_2 and H_2 gas. It can also be produced by several biomasses such as corn, cassava, sugarcane, barley, sorghum, and sugar beets. It is a biomass-based renewable fuel, and it has advantages of clean combustion characteristics and high-octane rating [3]. The major problem of blending sometimes occurs due to the water content, which not only makes blend unstable but it also affects the combustion characteristics and the durability of the fuel injection system components [4]. To stabilize the blend at desired level two methods are proposed; addition of an emulsifier-it suspends small driblets of ethanol within blend fuel, the addition of a co-solvent (such as biodiesel) that acts as a bridging agent between molecules [5]. Sharma et al. have examined the emission of a four-cylinder direct injection diesel engine fueled with 0, 10, and 30 % ethanol at 1700 rpm. They found that the increase in vol.% of ethanol in the E-diesel blend leads to a reduction in emissions of smoke, NOx, CO_2, whereas CO increases. Yilmaz et al have examined diesel engine emission with varying ethanol of 3, 5, 15, and 25 % while keeping equal volume of diesel and biodiesel in the different blends. They found higher exhaust gas temperature for ethanol blended fuel than the diesel due to high latent heat of vaporization, hence higher ignition delay. Higher CO (carbon monoxide) emission due to incomplete combustion of ethanol. NO or NOx (oxides of nitrogen) emissions was reduced due to cooling effect of the ethanol in the blends compared to diesel. Reduction of unburnt hydrocarbon at low concentration of ethanol while increased with more concentration of ethanol [6]. Kuszewski has examined the auto ignition properties of blends of ethanol with diesel up to 14 % maintaining constant volume environment and found that the, ignition time increases with increase in ethanol [7]. Pinzi et al have studied the properties (solubility, kinematic viscosity, and heating value) of ternary blend of castor oil, ethanol and diesel. They found ricinoleic acid advances the polarity of the oil, improve the miscibility of ethanol in diesel, and showed good ignitability [8]. Another study by Jamrozik in diesel engine with diesel ethanol (up to 40 %) blended fuel. They found improved thermal efficiency and no change in indicated mean effective pressure and reduced the carbon monoxide [9]. Toongroon et al. have investigated the diesel engine fueled with ethanol diesel blend with biodiesel as co-solvent, called diesohol. They used ethanol 5 %, 5 % and 10 % in three blends. They found that the more biodiesel is required with increased ethanol in the blends. Also, power and torque was reduced with increase in ethanol. The cylinder pressure reduced due to high heat of vaporization of ethanol, long ignition delay. Hydrocarbon and NOx are increased [10]. Pradelle et al. had performed the experimentation to validate the stability of the ethanol- biodiesel-diesel blend for the use in CI engines. The use of cetane improver is essential to avoid the misbehaviour like detonation or misfire of an engine at the high proportion of ethanol percentage [11]. Nour et al. had examined the engine characteristics of single cylinder, constant rpm (1500) CI engine running on ternary blends. Two ternary blends were tested, namely, octanol-ethanol and diesel and pentanol-ethanol diesel. Both the blends showed improved blend stability & solubility and decrement in smoke, NO_x, CO by 73, 33 and 83 % respectively [12]. Saksham Arya et al have conclude in their review that tyre pyrolysis oil can be used as an alternative fuel for diesel engine [13]. Abhishek Sharma et al. performed interesting study and found Distilled Used Engine Oil (DULO) blended with jatropha biodiesel showed promising alternate of diesel fuel. [14]. Saleh et al. have also investigated the ternary blend on single cylinder direct injection CI engine. In this approach, ternary blend jajoba methyl ester (JME) was used as a primary fuel. It was made by using optimized proportion of jajoba oil and ethanol. Ternary blend was made of JME-diesel and ethanol. It has found that 10 % of ethanol and of 10 % JME and 80 % diesel blend has provided the improved results of emissions from the CI engine. Increase in the percentage of JME was resulted increase in BSFC [15]. Paul et al. have investigated the diesel- ethanol blend performance with CNG enrichment through intake manifold in the CI engine. The two blends of diesel-ethanol were chosen for the experiments. 5%E-95% diesel and 10%E-90% diesel with low and high enrichment of CNG. It has found that increase in ethanol percentage decreases the brake thermal efficiency of an engine and also creates the phase separation of diesel ethanol. 5E-D95 with low CNG enrichment has shown improved results of NO_x and smoke opacity than the other combinations used in the investigation [16]. An endurance study of wear of diesel engine, lube oil from the engine, subjected to AAS analysis, they found that biodiesel fueled engine showed lesser wear rate of iron, copper, and chromium than that of diesel-fueled [17]. Another similar study of 100 hours run of diesel engines showed that less wear on piston rings of B20 fueled engine as compared to diesel-fueled [18].

Further, the analysis showed lead and aluminum was slightly higher for (B20) fueled engine than the diesel-fueled engine. The other study of wear of diesel engine after 512 hours run showed less wear in case of biodiesel (made of Karanja oil) blended fuel than that of diesel fuel [19]. Similarly, a study on a diesel engine runs for 100 hours. The engine was fueled with Karanja biodiesel, the lube oil was subjected to wear metal concentration test and noted that the iron, copper aluminum and chromium wear was 35 % less in the biodiesel fueled engine than that of diesel-fueled [20]. The viscosity of lube oil plays [21] significant role in engine lubrication and reduce the wear of engine component by making a protective layer to separate the mating surfaces. There is a close relationship between wear and lube oil oiliness. There are several engine components which are having direct metal-to-metal contact while engine is running, such as piston rings and cylinder liner, bearing and crankshaft surface, crankshaft and valve they can contribute the wear metal in the lube oil. During the operation of the engine, the composition of lube oil changes as the concentration of engine oil additives changes due to wear of engine components (such as piston, piston ring, connecting rod, etc.). In an analytical method, an investigation is done on the change in the constituent's percentage of lube oil throughout and after operation; the degradation of lube oil is mainly due to worn-out metal and chemical reactions. For the detection of wear particles formed due to additive depletion, contamination, component wear; wear element spectrometric analysis technique is used. Monitoring of ethanol blended fueled engine health is very less. During the operation of the engine, the constituent composition of lube oil changes as the concentration of engine oil additives changes due to the wear of engine components (such as piston, piston ring, connecting rod, etc.). In an analytical method, an investigation is done on the change in the constituent's percentage of lube oil throughout and after the process; the degradation of lube oil is mainly due to worn-out metal and chemical reactions.

The main objective of this paper is to monitor engine health through engine oil analysis and helps to determine the periodic time interval for oil replacement. The monitoring of engine oil is done by wear particles and chemical/physical changes. Hence, this article is dedicated to probing lube oil depletion using ethanol blends.

2. METHODOLOGY OF EXPERIMENTATION

2.1 Blend preparation

For this study, a blend of ethanol, biodiesel, and diesel was set on a volume-to-volume basis with the percentage composition. In this work, a blend with a lesser concentration of ethanol was considered. Stability tests were conducted for the miscibility of ethanol-diesel and biodiesel of different samples, with varying concentrations of diesel, ethanol and biodiesel. It was observed that all the blends are stable and no phase separation was found up to 24 hrs. To increase the stability of the Ethanol-diesel mixture, 10 % biodiesel is added in the 80 % diesel and 10 % ethanol blend. Biodiesel is mixed as a surfactant which improves the miscibility of the diesel and ethanol.

2.2 Physical and chemical properties of the blend

The properties of diesel, biodiesel, ethanol, and blend are deduced according to the ASTM standard. The density measured by hydrometer at room temperature and then converted into at 40°C using a standard table. Viscosity is measured using stab viscometer, SVM3000, by the ASTMD445 method. Flashpoint, pour point, and sulphur are also determined for blend and constituents of the blend. The properties and comparison of diesel, biodiesel, ethanol and the blend are listed in Table 1.

Table 1. Properties of blend and blend constituents.

Property	Diesel	Biodiesel	Ethanol	Blend
Density (kg/m^3) @ 15 °C	819.8	851.1	796.0	818.8
Density (kg/m^3) @ 40 °C	802.0	833.8	777.6	801.0
Viscosity (cSt) @ 40 °C	2.721	6.064	1.113	2.413
Viscosity (cP) @ 40 °C	2.182	5.056	0.865	1,932
Flash Point (°C)	42.0	114.0	-	9.5
Pour Point (°C)	-9	6	-	-
Sulphur (ppm)	23	15	<0	11

2.3 Test rig

The experiment has been performed on a Greaves Kirloskar engine of 5 HP at 1500 rpm; four-stroke water-cooled single-cylinder compression ignition diesel engine with the bore, stroke length, orifice diameter of 80mm, 110mm and 20mm respectively; having compression ratio 16.7:1. The load on the engine is provided by an eddy current dynamometer of 5 HP at 1500 rpm, water-cooled using tyre coupling; spring balance for load measurement. Figure 1 shows the engine test ring and Fig. 2 shows a schematic of the test rig.

Fig. 1. Experimental test engine rig.

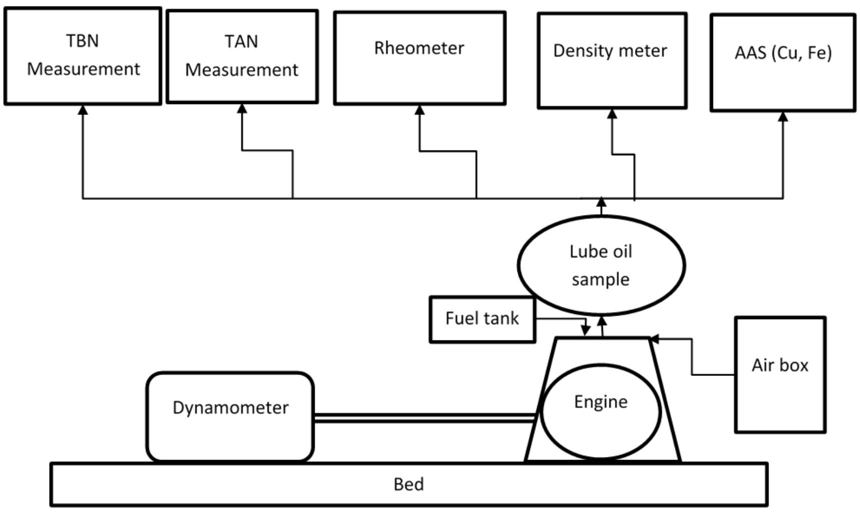

Fig. 2. Schematic diagram of the test rig.

2.4 Testing plan

The different load conditions and rated speed is shown in Table 2. For this experiment, the engine was ON for 100 hrs and lube oil was sampled after 20, 40, 60, 80, and 100 hours of the test time.

Table 2. Test cycle plan.

Loading (% of rated load)	Run time (hours)
100	2 (comprising 0.33 hrs of warm-up)
50	2
110	0.5
No Load (idling)	0.25
100	1.5
50	1.75

The loading condition is adopted from the IS:10000 [22] code of endurance test of diesel engine. The sequence of loading is given to replicate from no load to severe loading of the engine. Samples are collected very carefully just after stopping the engine to ensure the homogeneity of lube oil and stored in airtight containers. Further, these samples are subjected to oil analysis.

2.5 Sampling of lube oil

During the experimental run, samples were collected every 20 hours. The engine oil used was SAE20W-40, and the quantity taken out for the sampling was 100 ml. The oil sump was regularly replenished with an appropriate amount of remaining oil to maintain the levels of sump oil and to avoid the starvation of oil. However, the addition of the new oil of small quantity will not affect the property significantly. The samples were collected at 20, 40, 60, 80 and 100 hours of the run. The sampling method comprised of using a syringe and pipe to suck out the engine oil after proper mixing. After this, the sample was stored in appropriate containers

2.6. Engine oil analysis

For the condition monitoring of the lube oil, there can be two ways viz. chemical & physical characteristics change and metal concentration in the sample taken. Property change has been observed in terms of TAN, TBN, density & viscosity. The metal concentration was found in terms of two materials (iron & copper).

Total base number

The total base number is the measurement of oil alkalinity, which is measured in milligrams of equivalent KOH required per gram of oil sample. Alkalinity is the capacity of the oil to prevent the corrosion resulted from oxidation. Alkaline nullifies the acids produced while performing the engine operation. During the operation, when the engine undergoes different operating conditions, i.e., loading conditions, environmental changes, stress, etc., this property of lube oil shows its depletion. Higher the TBN, higher is the stability of that lube oil to counter the acid produced for a more extended period. The TBN can be calculated by Potentiometric titration (ASTM2896). In this method, the lube oil sample is made to dissolve in a blend of chloroform, alcoholic 2-propanol, toluene, and water, which is then treated with alcoholic HCl acid solution. Results of the method are found by performing titrations by continually increasing the HCl concentration with a constant time interval. The final point of the titration reaction is then measured using the titration curve.

Total acid number

The total Acid number is the measurement of oil acidity, which is quantified in milligrams of KOH required to neutralize the solution per gram of oil specimen. It determines the overall value of the acids present in the sample. Commonly, the ASTM D664 standard is followed to measure TAN by Potentiometric titration. The sample is dissolved in water, isopropanol, and toluene, and then it is titrated using alcoholic potassium hydroxide. The endpoint of the titration is reached when an inflection point is reached.

Density of engine oil

Density is the main property of lubricants and all other fluids. It is the amount of the mass of a substance relative to a recognized volume. Lubricants generally have a lesser density than water. The object with lower density than the water will float in water. The moisture content in the lube settles down to the beneath of the sump, and it comes out first while draining of lubricant. This property is used to calculate the kinematic viscosity of the fluid. Kinematic viscosity is the ratio of absolute viscosity to the density value. That means, whenever the density of lubricant changes due to any reason, an error occurs in the calculation of both viscosities. Generally, the density of the fluid is given concerning specific gravity, which is the relationship of density to water. The density of engine oil changes with the temperature; when the temperature increases the density of oil decreases. Whenever the engine oil takes part in the operation of the engine, it subjected to high thermal stress leading to a decrease in density. The fuel dilution in the engine oil is also responsible for the lowering of the density.

Viscosity

Lubrication is one of the prime functions of the engine oil. Viscosity is involved in the lubrication, which reduces the wear and friction between the two metal components during the operation of the engine. Viscosity is a measure of the resistance offered by the fluid of one layer to the adjacent layer. Therefore, the engine oil of higher viscosity produces more resistance between the fluid layers, and hence the higher shear force and relative movement are required to get the hydrodynamic lubrication. However, higher viscosity provides a higher load-bearing capacity.

2.7 Wear analysis

Atomic absorption spectroscopy

The spectroscopic analysis majorly constitutes of two methods viz. atomic and emission spectroscopy. According to the basics of atom physics, an atom responds to a certain wavelength by either emitting or absorbing light within the visible region and ultraviolet region in the spectrum of energy. An oxy-acetylene flame is used for the atomization of metallic constituents in the atomic absorption spectroscopy process. The portion of the wavelength of the light provided on the sample, that is absorbed by the elements is measured and detected using the process of spectroscopy. During this process, the prepared sample is evaporated into vapour that contain unbounded atoms. The characteristics of radiation of metal constituent, which is being tested, are analyzed using a source emitting light, which is made to pass through the vapour-phased sample. The suspended free atoms present in the vapour phase absorb a quantified amount of radiation, which results in a reduction in emerging radiation from the source. This decrement is quantified using an absorbance detector at the endpoint. The actual concentration of the element is now measured using the absorbance value obtained by extrapolating the calibration graph. Cylinder liner, shaft, camshaft valve are the primary source of the iron, while copper may be contributed by the bearings.

3. RESULT AND DISCUSSION

3.1 Wear analysis

The quantification of wear particle in the used engine oil is helpful to monitor health and determine oil replace time. It is also helpful to take early remedial work of the engine [23] Iron may be contributed by the wearing of cylinder liner, camshaft or valve they are made of iron and alloys in the engine oil. Figure 3 shows the presence of iron in lube oil. The iron in a blended fueled engine is higher than that of the diesel-fueled and is increasing with the running period of engine for both engines. The cylinder liner and piston ring become together in direct contact, which produces the iron concertation significantly in the lube oil. Due to the presence of ethanol and high temperature of cylinder, there is oil thinning hence the viscosity of lube oil reduces and unable to lubricate the mating surface, it results the cylinder wear. Santosh Kumar Kurre et al., in his research found that the concentration of iron increases with the running period [24]. Abhishek Sharma et al. had found that the iron and copper wear increases as compared to diesel when engine fueled with JMETP20 (80 % Jatropha methyl-ester +20 % tyre pyrolysis oil after the 100 hours durability test [22].

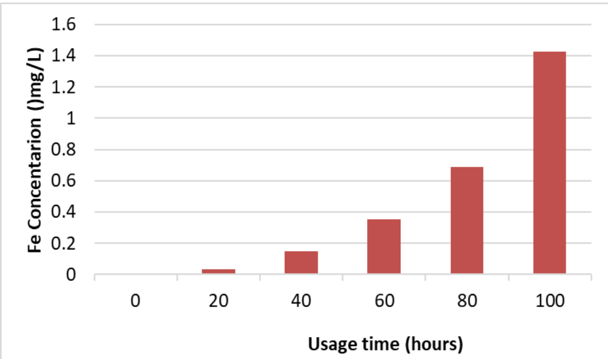

Fig. 3. Iron (Fe) variation with usage time.

Copper concentration in the engine oil is due to bearing wear. Figure 4 shows that the quantity of copper in the engine is increasing with the running period of the engine. Acidic compounds and ions may be attracted and melt in water.

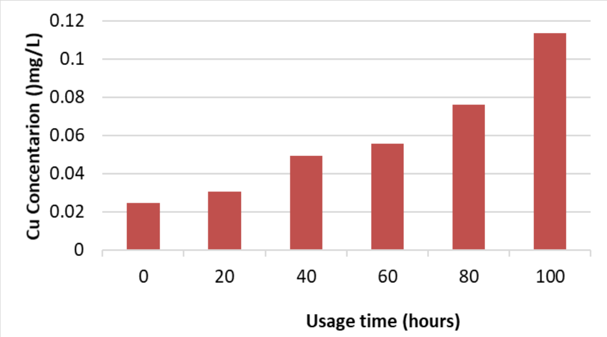

Fig. 4. Copper (Cu) variation with usage time.

Hence, corrosive wear occurs to the bearings. The piston liner and the piston ring experience the maximum loading and temperature of combustion. The sliding contact between the piston rings and liner undergoes all the lubrication conditions such as hydrodynamic, boundary, and mixed lubrication. In boundary lubrication, there is metal surface contact between the components, thus initiation of wear occurs from this lubrication. Further, the wear particles are imported in the sump with lubricant from the engine components. In hydrodynamic lubrication; once the wear generated in the lubricant and recirculated to the engine, the wear particles interact between the mating surface and it creates the three-body abrasive wear, which further increases the wear.

3.2. Total acid number (TAN)

TAN is showing variation, as shown in Figure 5. TAN is increasing with the running time, and it is due to oxidation of the lube oil, the inclusion of wear particles, and the inclusion of some emission gases into lube oil.

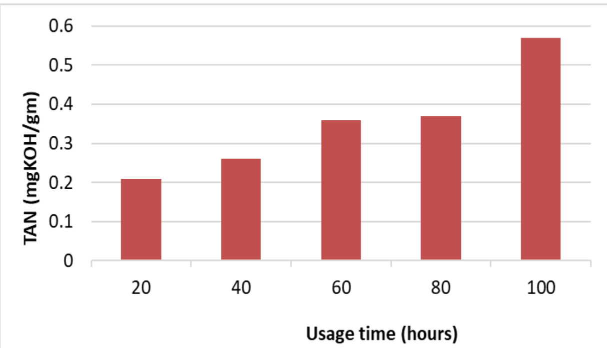

Fig. 5. Total acid number (TAN) variation with usage time.

The base oil, the lubricating oil is oxidized, during operation, produced the weak acids. Weak acids to be neutralized by the base of lubricating oil, and if not, it becomes as TAN. Some acids may be generated by combustion blow-by, which is not neutralized by detergent, remain in the lubricant and TAN increased [25] . The limit value of TAN is (TAN of fresh lubricant + 3mgKOH/g). It is also observed that engine oil can be used further as the highest value of TAN is 0.5 mgKOH/g.

3.3 Total base number (TBN)

TBN is showing decreasing variation, as shown in Fig. 6. The total base number is a measure of the ability of lube oil to counter the acid attacks generated during the operation. The total base number is provided in the lube oil to resist the acid formation or to neutralize the acid and prevent the engine component from the corrosive wear. Corrosive wear occurs due to the oxidation of the oil when it comes into the contact of high temperature generated in the engine at the time of combustion. This is due to the fact the alcohol possesses acidic property and hygroscopic. Moisture promotes the rust formation and corrosion of the engine component. And, also it produces an adverse effect on the additive material by precipitating the additive. Ethanol promotes the oxidation of lubricating oil and reduces the load capacity of oil. Hakan Kaleli [26] also found in his work that the TBN decreases with the running period of the engine. The general consideration of changing engine oil; whenever the TBN goes down 50 % of its original value [27]. From Fig. 6, one can see that the oil need not replace after 100 hours of the run.

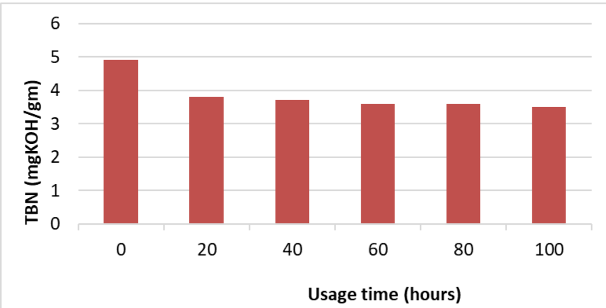

Fig. 6. Total base number (TBN) variation with usage time.

3.4 Density

The density of engine oil @ 40 ^oC is reducing with the time of usage for engine oil as shown in Fig. 7.

Density of engine oil changes with the temperature; generally, when the temperature increases, the density decreases. One can see from the Fig. 7 density decreased very slightly (0.23 %).

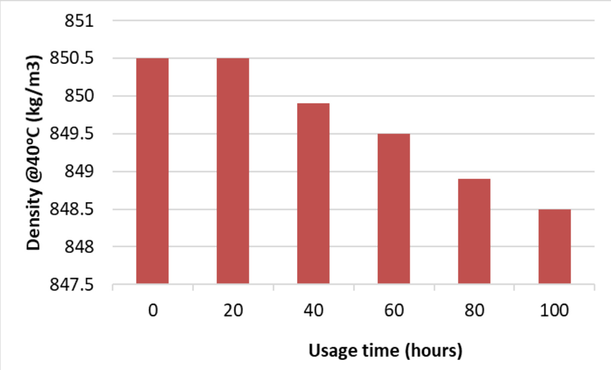

Fig. 7. Density variation with usage time.

Whenever the engine oil takes part in the operation of the engine, it subjected to high thermal stress leading to a reduction in density. The fuel dilution in the engine oil is also responsible for the lowering of the density. The alcohol and the biodiesel both are oxygenated fuel, which provides the oxygen for proper burning of the fuel. Thus, temperature increases as lubricant gets closer to the high-temperature zone of the engine, it losses the density due to high heat. At the same time, some parts of the biodiesel remains unburnt due to its high heat of vaporization as compared to the diesel, thus unburned biodiesel and ethanol mixed in the sump engine oil, which increases the density of the oil. However, the thinning proper of ethanol reduces the viscosity hence, density reduced. The overall effect seems the decrease in density.

3.5. Viscosity

The reduction of the viscosity of engine oil may be noted easily from Fig. 8. It is also due to the thinning of lube oil with the running time the lube oil film thickness reduces. During the operation of the engine, the cylinder temperature, and pressure increases, at high-temperature lubricants, higher chain hydrocarbons convert into the small chain. The fuel dilution in the engine may degrade viscosity. Besides, the additive depletion occurs in the long time use of lube oil, resulting in lower viscosity. It is a general consideration that whenever the viscosity increase or decreases by 25 % of the unused oil viscosity, the oil must be replaced by new engine oil [27]. Thermal oxidation and fuel dilution are responsible for the decrease in viscosity. Ethanol remains unburnt due to its high heat of vaporisation and incomplete combustion, which is scraped by the piston ring to engine oil.

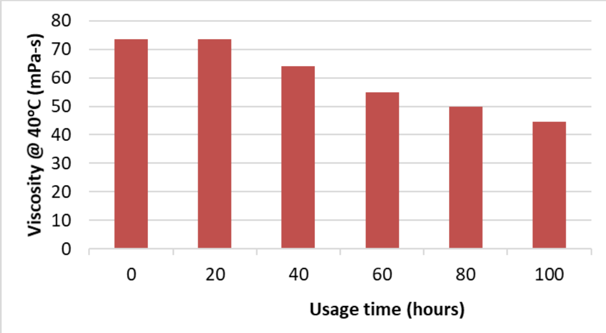

Fig. 8. Viscosity variation with usage time.

Also, it can be mixed through the crevice of piston and ring and blow-by. The unburnt ethanol may dilute the lubricating oil. The viscosity of oil reduced 39.5 % after 100 hours of the run. This can provide the thin film lubrication to the engine component and reduce the friction that occurs due to fluid itself.

4. CONCLUSION

Based on the results of the research work, 100 hours run, it has been concluded:

- From atomic absorption spectroscopy results, it is observed that the concentration of Fe and Cu is increased by 38.9 % and 3.6 % respectively in the engine oil with usage time. The reaction of ethanol produces the corrosive wear.
- From the viscosity and density test, it is observed that both are decreasing with the engine oil usage time. Density decreased very slightly 0.23 % and viscosity decreased 39.5 %. Density decreased with Ethanol dilutes the lubricating oil. Hence, the viscosity reduces. Because of the thinning of the lubricating, the protective layer of lubricant depleted, which increases the wear of components.
- TBN is decreasing with a running period of engine by 28.5 %. Ethanol has acidic property. When unburnt ethanol mixed with engine oil the lubricant additive losses it neutralization capability. Hence, TBN decreases.
- TAN is increasing with a running period of engine by 63 %. During the operation of the engine, high heat is generated, and lubricant

oxidized because of the oxidation number of acids produced. As the TBN reduces, the concentration of the acid increases, thus TAN increased. Finally, it has been found that ethanol has the potential to be used as an alternative fuel in the diesel engine from the lubricating oil degradation perspective.

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