Degradation analysis of gear oil SAE 90 used in load haul dumper machine

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Abstract: Lubricant degradation is the main cause for low performance of the machine such as heavy engineering machines, mining machinery etc. Lubricants are used for smooth running of gears and they also avoid friction and noise. Its performance is affected by high temperature and shearing, due to high temperature viscosity of oil changes and due to shearing its physical property changed or degraded. This paper analyses the failure behaviour of gear oil used in Load Haul Dumper (Model No: Eimco Elecon – 811MK). Gear oil degradation was measured by oil analysis in two sections: (i) fluid properties and (ii) contamination in the oil. Fluid properties were analysed by Viscometer, Rheometer whereas contamination analysis was done by Fourier Transform Infrared spectrometer (FTIR). All tests were performed carefully and their graphs were plotted. Results show that temperature and shearing were two of the several causes for degradation of oil. Viscosity analysis clearly presents that viscosity of oil exponentially decreases with temperature. Viscosity is also decreasing with shear rate at different temperatures. FTIR analysis confirmed that contamination is increasing with continuous use of oil. Temperature and oxidation are the main reasons for degradation. Different composition forming in used gear oil and those were confirmed by infrared spectroscopy absorption table.

1. Introduction
Lube Oil degradation is one of the major problems for the low performance of the gear. Degradation is taking place in the gear oil due to various causes such as contamination, metal wear particles, and oxidation [1]. Surface contacts occur between running parts, due to that surface roughness took place. Surface roughness generates friction, deformation, ploughing, adhesion, abrasion, delamination in it [2]. All these happen in lube oil due to long use of oil. The thermal breakdown is also occurred in lube oil [3]. Lubricating oil forms a fluid film between the mating surfaces and reduces direct contact of material and it also maintained a proper distance between the surfaces. Lubricating oil helps in reducing friction & wear of contacting surfaces, heat removal as well as removing contaminations and also improve performance and service life of all moving parts [4]. The main properties of lubricating oil are viscosity, anti-wear properties, extreme pressure properties, rust & corrosion inhibiting properties, thermal stability [5]. To increase service life and improve lubrication properties, additives such as anti-wear, anti-oxidant, corrosion inhibitors, extreme pressure additives are added to base oil [4]. All of these additives are added in an appropriate amount so that required property of oil for lubrication could be gained. Modern and advanced techniques are used for extracting health of a machine by performing oil analysis.

During meshing, gears have rolled and sliding contacts except at pitch point. This would generate frictional heating at tooth contacts and increase the temperature of gear assembly & gearbox [6]. This rise in the temperature of oil will accelerate degradation of oil, changes viscosity, oxidation and it also reduces film thickness between gear surfaces appreciably [7]. Viscosity of oil is dependent on the operating temperature and running hours of the machine. Oil viscosity changes with ageing due to...
contaminants generated, oxidation of oil, consumption of additives added to improve properties [8].

Shearing action of oil is one of the reasons for the degradation of oil [9]. Specific additives are added to the base oil to improve viscosity, generally containing double and triple bonded carbon atoms as poly(methyl methacrylate) (PMMA), olefin copolymer (OCP) and hydrogenated styrene-diene copolymer (SDP) [10]. After shearing of oil, some additives are deformed and formed different types of compound. These compounds change density of lubricant and fluid film thickness, therefore friction or wear took place between contacting surfaces [11].

Gears have elastohydrodynamic lubrication (EHL) due to relative motion between them. It maintains the gap between surfaces by an elastohydrodynamic (EHD) fluid film [12]. It helps in changing nearby surface of gear during EHD film formation [6]. Between EHL gap, small particles are pushed away and moved with the film whereas large particles are easily trapped in the vicinity of lubricant. Large particles accumulate together and generate solid frictional effects. These further produce fluid starvations because of accumulation of debris particles in the area of EHD film, which leads to scuffing [13]. Further, crushing of particles inside an EHD zone induces scratching on the surface during severe sliding [14]. Failures in gear occur due to degraded lube oil in circulation. These lead to occurrence of many types of wear such as micro pitting, pitting, scuffing, squeezing on the surface of gear teeth [7, 15].

This paper presents analysis of gear oil using different ways such as fluid analysis and contamination analysis.

2. Load Haul Dumper Machine

LHD machine is used in mining industries for loading purposes. It uses high torque for movement of machine and transportation of materials. A view is shown in figure 1. It is an electric power-driven machine and requires 550 Voltage and 37.5 KW of power.

![Figure 1. Load Haul Dumper Machine](image1)

![Figure 2. Planet gear of LHD machine](image2)

2.1. Specifications of LHD

Bucket capacity of 1.5 m³ of 1.3 tonne. Payload of 2250 kg. Weight of LHD: 7100 kg. height-1.95-2 m, length: 6.30 m, width: 1.5 m. running speed: 3.8-12.2 kmph.

2.2. Gear System

Differential planetary gear system is used for providing high torque requirement to drive LHD in rough terrain with loads. This gear consists of sun gear, planet gear and gear box for high torque conversion. Planetary gear is shown in figure 2.

3. Material & Methods

3.1 Lubricants:

Gear oil SAE 90 was selected from LHD machine. Oils were collected just after stopping of engine otherwise contaminants may be settling down. Samples were collected in a neat, clean and airtight storage bottle. Fresh oil was also taken as a reference for used oil from the same lot which was added to the gearbox. Two used oils were selected from the machine at an interval of 200 hrs from initial
position so, at 200hrs and 400hrs. A picture of all three samples is shown in figure 3. It is clearly visible that colour of the oil is changed and sample 3 is the darkest in colour. A detailed Flowchart (figure 4) is given below which provides complete information of lubricant had been analysed.

### 3.2 Methods:

![Gear Oil Samples](image1)

**Figure 3.** Gear Oil Samples

![Steps for Oil Analysis](image2)

**Figure 4.** Steps for Oil Analysis

Sample 1: Fresh gear oil. Sample 2: Used gear oil 200 Hrs. Sample 3: Used gear oil 400 Hrs.

#### 3.2.1 Viscometer:
Viscosity of samples was measured using Stabinger Viscometer (Model No. SVM 3000) and it should be according to ASTM D7042 method [16]. First, the instrument was cleaned with toluene/acetone for avoiding any previously tested oil. Then 10ml of a sample was taken in a syringe and put into viscometer. A temperature ranges from 40 °C to 100 °C was fixed for testing. It will provide all data like dynamic viscosity, kinematic viscosity, and density at the different temperature. These processes were repeated for all samples. Viscosity was measured in mPas.

#### 3.2.2 Air Bearing Rheometer:
Shear strain occurring inside the oil and it is measured by rheometer (Model No. AR 2000) and test is conducted according to ASTM D4440 method. A pressure of 3 bar is supplied to rheometer from air compressor to maintain a minimum distance between bearing and surface. Now, a cup & bob type geometrical measuring instrument (figure 5) is used for measurement for liquid samples with Newtonian & non-Newtonian behaviour [17]. A quantity of 50ml of each sample was taken for the testing purpose. Now, the sample was kept in the measuring geometry and temperature range of 60-100 OC was fixed for testing. Shear strain is varied between 0.01 & 1000 1/s to get viscosity variation at different temperatures. Viscosity was measured in mPas.

![Geometrical Measuring Instrument](image3)

**Figure 5.** Geometrical Measuring Instrument

#### 3.2.3 Fourier Transform Infrared Spectroscopy:
Transmittance change occurring inside the oil molecules and it is measured by FTIR spectrometer (Model No. Cary 600) and test is conducted according to ASTM E168. First, isopropyl alcohol was used to clean the disc surface and background scan was taken. Now, Lube oil is placed on highly reliable, chemically inert diamond ATR fixed on a disc & a metallic needle and pressed to ensure good contact between diamond ATR and sample [18]. This spectrometer for FTIR was run for analysis which uses wavenumber between 4000-400 cm-1. Computer generated a graphical plot between transmittance percentage and wave number.
4. Results and Discussion

4.1. Variation of Viscosity with Temperature and Time

It can be seen in figure 6 that the viscosity of all samples is varying. It is high for fresh oil (224.82 mPas). It is decreasing exponentially with increase in temperature for all oils and follows Reynold's equation [11]. Also, it is decreasing with running hours. This is taking place due to additives deterioration. Also, there were wear particles formation, oxidation, contaminations occurred in oil. It will lead to overheating, accelerated wear, and ultimately failure of the gear component. In table 1. presents the detailed value of constant, viscosity index and correlation coefficient.

\[ \mu = A \cdot e^{-BT} \]

Reynold’s equation

where,
\[ \mu = \text{Dynamic viscosity in mPas}, \quad T = \text{Temperature in °C}, \quad A = \text{Constant in mPas}, \quad B = \text{Constant in 1/°C}. \]

| Gear Oil   | A (mPas) | B (1/ °C) | Viscom \( R^2 \) | Correlation Coefficient (\( R^2 \) value) |
|------------|----------|-----------|------------------|-----------------------------------------|
| Fresh Oil  | 1079.4   | 0.042     | 100              | 0.9878                                  |
| 200 Hrs    | 818.33   | 0.041     | 87               | 0.9951                                  |
| Used Oil   | 592.99   | 0.040     | 84               | 0.9895                                  |

Table 1. Correlation coefficient and VI of Gear Oil

![Figure 6. Viscosity variation with temperature](image1)

![Figure 7. viscosity vs shear rate at 60 °C](image2)

4.2. Shear Rate Test with Temperature and Time.

From the figures (7, 8, 9, 10 and 11) of viscosity vs shear rate, it is clearly visible that viscosity decreases with shear rate increase. For figures 7 & 8, the viscosity of oil at 60 °C and 70 °C almost constant with respect to shear rate. At 80 °C, decrease in viscosity slightly increases (figure 9). From figures 10 & 11, it can be analysed at 90 °C and 100 °C decrease in viscosity with shear rate increases and it is maximum for used gear oil.

From the graph shown, it is clear that shear thinning is occurring in the oil as the increase in shear rate at higher temperature. It is mainly caused by breaking of bonds between molecules of additives added specifically for viscosity improvement. Viscosity at 60 °C is concentrated at about 50 mPas reduced to about 25 mPas at 100 °C. That means the temperature is also affecting viscosity with shear rate. Thus from references, it can be concluded that initially at low temperature fluid behaves as a Newtonian fluid but at later case of higher temperature, it is behaving as non-Newtonian fluid [19].

![Figure 7. viscosity vs shear rate at 60 °C](image3)

![Figure 8. viscosity vs shear rate at 70 °C.](image4)
4.3 Fourier Transform Infrared Radiation Analysis

Gear oil is made of paraffin, aromatic compounds, long chain hydrocarbon, branched chain hydrocarbon and other organo-compounds [5]. Most common degradation processes are oxidation and shearing of oil with increase in temperature. These compounds are degraded and form other by-products [20]. From the figure 12, it can be concluded that.

**Region A:** In the wavenumber range between 4000-3000 cm$^{-1}$, alcohols (-OH), amines(-NH), carboxylic acids (-COOH), alkane (-CH) groups have increasing transmittance so there is depletion of additives in the oils. It is suggesting that aging of oil is occurring after long use of oil. Additives having anti-oxidation properties, rust & corrosion inhibiting properties are consumed with aging.

**Region B:** In the wavenumber range between 3000-2000 cm$^{-1}$, Thiols(-SH) and alkynes(-C≡C-) groups have risen transmittance level, results from depletion of additives. These means that these compounds are consumed while changes in thermal and shear properties.

**Region C:** In the wavenumber range between 2000-1400 cm$^{-1}$, aromatic compounds have shown decrease in transmittance level. They are forming after a long duration of use of oil. These shows braking of organo-compounds is happening. **Region D:** In wavenumber range between 1400-1000 cm$^{-1}$, oxidised sulphur compounds, alkyl ethers, esters present, and oxidation has taken place in the used oil samples. Here, no additives are found. Oxidation of oils forms carbonyls, hydroxy compounds. **Region E:** Similarly, in wavenumber range between 1000-600 cm$^{-1}$, Substituted carbon chain is decreasing which clearly shows the breaking of bonds of additives.

### 5. Conclusion

5.1. Viscosity of gear oil is decreasing with increase in temperature. This happens due to contamination in oil, oxidation and various causes. Oxidation is responsible for degradation of gear oil.

5.2. Temperature is not only the cause of viscosity loss of lubricating oil but also due to shearing phenomena. Shearing is occurring in gear oil due to breaking of molecular bonds.
5.3. FTIR results clearly show the formation of oxidation by-products like carbonyl oxidation products, sulphur oxidation products, nitrogen oxidation products and many more.

6. References
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