

Role of Lubricants in Industry: A Review

Narendra A. Gokarn^{1*} and K. N. Kiran²

1. Consultant, 204 Mantri Kinara, Bhau Patil Road, Bopodi, Pune 411020

2. Himasai Srinidhim, Janapriya Utopia, Attaour, Hyderabad, 500048

Email: ngokarn@yahoo.com

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Abstract:

Lubricants are available in our daily lives for functioning as coolants, to dissipate heat and lubricate different surfaces which can be either in solid, liquid or gaseous forms. It reduces friction by the formation of thin film between two surfaces in contact and by improving efficiency and reducing wear. For any system to work efficiently and effectively appropriate lubricant is needed.

Fresh lubricating oil needs to meet specifications of Original Equipment Manufacturers (OEMs). Applying lubricant regularly on tool increases life on usage and durability but a situation comes when the oil starts degrading may be due to depletion of additives or tool break down. Degraded oil is tested by using different physicochemical properties and also by employing different sophisticated analytical techniques like infrared spectroscopy (FTIR), Gas chromatography (GC), Inductively coupled plasma atomic emission spectroscopy (ICPAES), etc.

In this article, we shall discuss some basics of lubrication, different lubrication regimes and various kinds of lubricants used for various industrial and automotive applications. Some case studies of oil and also their representative formulations, testing and interpretation of results is being presented for understanding of various lubricants.

Key words: Lubricant, lubrication, Analytical techniques

Introduction:

Lubricant assists in reducing friction between two surfaces in contact and thereby lowers the heat generated by cooling immediately. They are also referred as lubes. These can function by

removing the metal debris (metal particles removed due to two moving contacts abrading each other or by additive depletion).

Lubricants have a great impact on reliability by increase in shelf life of equipment, energy efficiency, thereby reduction of different machinery wear¹ and by friction. Lubricants can also function as a tool for heat dissipation. These exotic chemicals are applied on surfaces of substances which are referred to as substrate. They can be either as phases like lubricating oil in liquid or grease in semi solid state. These can be applied on substrate to minimize friction, wear, heat and cooling and allowing smooth functioning of part and are often referred as lubricity².

Basics of Lubrication

Lubrication is a process of reducing friction and wear between two surfaces that move relative to each other^{1,3,4}. This is done by introducing a substance called lubricant between two surfaces to build an oil film separating them and prevent these metals from contacting each other. Lubricants can be in the form of a lubricating oil or grease¹.

In the case of boundary lubrication (BL) condition, metal surfaces are usually in contact and load is carried by the surface asperities. In mixed lubrication (ML) the load is carried by both the lubricant film and the asperities in contact whereas in the case of hydrodynamic lubrication (HL), a full film of lubricant carries the load and the surfaces are not in contact. The contact occurs at the peaks of the surfaces called asperities and amount of extent of the asperity contact depends on many factors like surface roughness, fluid film pressure, normal load, hardness, elasticity of the asperities, etc⁵.

Boundary Lubrication

When there is a metal-to-metal contact taking place between two sliding surfaces we can say boundary lubrication exists. In this regime the lubricant film is worn away and there is severe contact between the two metal asperities which takes place usually during the start or shut down of equipment.

Mixed Lubrication

Mixed lubrication regime is referred to the stage when the metal-to-metal contact between the two asperities substantially reduces along with coefficient of friction. This is due to the fact that a lubricant film between the surfaces in motion has been created reducing the friction. Here there is minimal metal to metal contact taking place.

Hydrodynamic (HD) Lubrication

Here the metal contacting surfaces are not in contact with each other. An oil film of 1-micron thick exists between the two metal surfaces and metal slides over the oil film. Here the coefficient of friction is the least when compared to the three regimes. There should be a geometric conformity between machine moving parts and low contact pressure (100 to 300 psi in industrial journal bearings) between the moving parts⁶.

Elastohydrodynamic lubrication conditions occurs when there is a no contact between the moving components. This regime is considered to operate on a full fluid film and oil thickness is about 1 micron.

The different lubrication regimes are shown in Fig. 1

Generally, lubricants can be formulated by using class of base oils which can be either mineral oil base or synthetic base. Mineral base oils are usually natural in origin whereas synthetics are prepared artificially. Mineral base oils are found to be containing elements of carbon and hydrogen called hydrocarbons of different molecular structure and molecular weights distribution, chain length. Mineral lubricants are complex mixture of paraffin based, naphthenic and aromatic hydrocarbons of 20 to 50 carbon atoms. This being obtained naturally also may contain small fraction of nitrogen, oxygen and sulphur⁷.

Mineral base stocks are used for making industrial lubricants whereas combination of mineral and synthetic base stocks or only mineral base oils are used for formulating automotive lubricants.

Looking at the nature of the base oil, which is the key to lubricants, they are classified as mineral oil which are derived from petroleum resources, synthetic oil (eg., polyalphaolefins, polyalkylene glycols, synthetic esters, silicones, etc.) Synthetic base oils can be manufactured by using different small moieties which can be used as building blocks for further use. Molecular weight and viscosities of these oils can be tailor made as per requirement of supplier and are also stereo specific in nature⁷.

Base oils are divided into 5 broad categories and are listed in Table 1

Usually mineral base oil is obtained by distillation of petroleum crude by different fractions. They are further processed using different procedures. Base oils of different groups as per API

classification with different reactivity levels and concentration of sulphur can be obtained as per distillation procedure employed and so does the viscosity index of different group of base oils changes.

Use of mineral and synthetic base stocks has grown up exponentially in the last few decades. These are used for making different automotive lubricants like motor oils, gear oils, marine, railroad lubricants and for various industrial lubricants like compressor, gear, hydraulic oils, etc³. Synthetic base oils are usually used for manufacturing high end products.

Lot of crisis are going on as the petroleum crude is getting depleted fast due to its limited availability. So the synthetic base oils prepared chemically have come into existence. Mineral base oils obtained from crude are not biodegradable whereas synthetic base stocks prepared artificially are partially biodegradable and due to which recent trend shows a shift towards the use of biodegradable and low toxic synthetic lubricants^{3,4,8}. Mineral lubricants have poor biodegradability. Vegetable oils have low ecotoxicity and are biodegradable⁹.

Nanolubricants is another important class of lubricants wherein nanoparticles either are imparted in the lubricating oil in small dosages to form suspensions or are employed in lubricating oil in the form of friction modifiers and have to be dispersed uniformly. Effect of addition of nanoparticles is seen in the lubricating oil by the decrease in the coefficient of friction compared to lubricants with no nanoparticle additives. Examples of nanoparticles used in lubricating oils include titanium dioxide, graphene, zinc oxide, molybdenum disulfide, etc.¹⁰. Nanotechnology is an emerging field and a potential source to enhance the tribology performance of different lubrication system¹¹.

Biobased lubricants are the substitutes to mineral based oil and are found to exhibit superior lubricating properties over mineral oil. These are biodegradable to water and carbon dioxide. One of the limitations of bio based lubricant is low temperature characteristics and oxidative stability which can be overcome by incorporating proper additive package in the bio based lubricant¹².

Lubricants are a mixture of oil and additives. It can have from 90 to 100 % oil and 0 to 30 percent additives. Common lubricants include engine oils, gear oils, compressor oils, hydraulic oils, turbine oils, transformer oils, stamping oils, wind turbine oils and many more to name a few.

Additives can be in the form of antioxidants, antiwear agents, extreme pressure agents, detergents, dispersants, foaming agents, etc.

Lubricants can also be in the form of semi solid which is grease. Grease can be thought of sponge oil and consists of three fundamental components: a lubricating base fluid, a thickener and additives. It can have from 80 to 90 % oil, 7 to 15 % thickener and 0 to 10 percent additives.

Chronology of Lubrication:

Viscosity of a fluid can be referred to as resistance to flow of liquid. There are two kinds of viscosities which are kinematic and dynamic viscosities and the units are centistokes and centipoise respectively. Newton's law of viscosity says the shear stress is directly proportional to the velocity gradient. The friction responsible for creating viscosity is responsible for both molecular and mechanical stresses.

Tribology is the science which usually deals with friction and wear of material covering lubricants as one of the major field of study. This subject also covers design of bearings and science of interaction of surfaces in relative motion. It is an interesting and interdisciplinary science covering physics, chemistry, materials science and engineering and also chemical thermodynamics.

A brief history covering this wonderful subject is presented in the below in Table 2.

Various physico-chemical properties like kinematic and dynamic viscosities, moisture content, density, volatility, iodine number, saponification number, functional groups, carbon length distribution, elements, etc are used to find out some qualitative analysis and quantitative estimation of the base oils and finished lubricants¹⁶. Further some analytical sophisticated precise techniques like Fourier Transform Infrared Spectroscopy, Gas Chromatography, Inductively Coupled Plasma Atomic Emission Spectroscopy etc. are used for further information like purity, carbon chain length, predicting molecular structure.

Typical properties of Lubricating oil are given in Table 3:

In the present manuscript, we shall cover few case studies of lubricating oil along with their testing methods and their interpretation for the same (for fresh and used lubricating oils) using various sophisticated analytical techniques.

Properties of Oil

Viscosity

Oil analysis is needed to know the life, condition used in particular instrument.

In the case of gear oil, viscosity is generally tested in terms of kinematic viscosity at two different temperatures (40 °C and 100 °C) and having the units in centistokes (cSt). Dynamic viscosity is recorded at 25 °C and having units in centipoise (cps).

Kinematic viscosity is measured by knowing the time lubricant flows through a capillary at a defined temperature. Viscosity for the oil could be affected due to insolubles present in the lubricant, soot and oxidation of the lubricant.

Viscosity Index

Viscosity Index is a value calculated from the two measurements of viscosity at 100°C and 40°C or some typical two temperatures and describes the viscosity-temperature relationship of the oil. Higher value of Viscosity Index indicates small change of viscosity with temperature.

Moisture

Water ingress will increase the viscosity of the lubricating oil. Water content of fresh and used lubricating oil is measured by Karl-Fischer titration (either potentiometric or coulometric) method or by infrared spectroscopy method. When moisture content is greater than 50 ppm potentiometric method is used and when moisture content in the lubricating oil is less than 50 ppm coulometric titration is the preferred method.

Total Acid Number

Acid number in a lubricating oil specifies the amount of acidic components in the oil and is calculated by titration either manually or automatically determined by Volumetric Titration using KOH. Acid number could be starting point to detect the oxidation content in the oil.

Flash Point

Flash point of a lubricant oil is determined at which vapor may cease to burn when source of ignition is removed. Open cup and closed cup are commonly methods used for Flash point determination of lubricating oils. Lubricating oil with greater viscosity tend to have a higher flash point¹⁷.

Pour Point

Pour point is determined by temperature at which oil becomes semi solid and loses its flow characteristics. Lubricating oil with greater viscosity tend to have a low pour point.

Some brief method of description of sophisticated instrumentation techniques used is presented below -

FT-IR Spectroscopy

Fourier Transform Infrared Spectroscopy (FT-IR) also referred as infrared spectroscopy is an experimental analysis technique which is used to detect functional groups of organic material. The nature of carbon as aromatic, paraffinic and naphthenic in lubricating oil along with their proportion can be estimated. This method is also used for finger printing of functional groups present in the material.

FTIR spectroscopy is a technique for determining molecular structure by assigning each absorbance band to a specific functional group¹⁸. FTIR spectroscopy allows to quantify the total carboxylic compounds generated during the thermal oxidation of the lubricating oil. One can also find out purity of the material.

Ageing of oil leads to oxidation, nitration and sulphonation. This is seen by observing a shift in bonds in the used oil and correction is applied with respect to blank referred to as fresh oil. Some of the advantages of the FT-IR technique over the other conventional systems are ease of sampling and sample preparation, quick and reliable results and robust nature of equipment. Exposure of operator to minimum quantity of solvents¹⁹.

20 mg of solid in case solid (nujol), 1 drop of oil is needed in case of ATR to cover the crystal.

Inductively Coupled Plasma Spectroscopy

Initially AAS (Atomic Absorption Spectroscopy) was used for rapid trace metal analysis but it had limitations as only single metal could be analyzed at a time and it is cumbersome and time consuming. Detector used in AAS is a Photomultiplier tube and the same tube is commonly used as detector in AAS and electron multiplier for ICP.

Inductively coupled plasma atomic emission spectrometry (ICP-AES) is a multi elemental, rapid, simple technique for the determination of trace level analytes¹⁸. This method can detect elements of low concentrations at ppm and ppb for metals as well for as non-metals. ICP uses inductively coupled plasma to ionize the sample and creates atomic ions which are detected after the sample is atomized.

Sample weight varies as per concentration of metals and non-metals present. Multiple samples of different concentrations can be tested together with ease. Accurate determinations for Al, Ba, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Ni, Pb, Si, Ti, V, Zn, P, S, Na, B and S can be acquired by analysis for fresh and aged oils²⁰.

Low viscosity oil sample are used as such whereas high viscosity samples are diluted and then used. Liquid samples can be detected after diluting with suitable solvent like xylenes, petroleum ethers or any low volatile solvents which can instantly form aerosols on injection and solid samples which are to be digested and then used. Argon is usually used as carrier gas which assists in the formation of aerosols (propagating tiny droplet samples) across plasma which is maintained at a very high temperature²¹. Solid samples are digested in aqua regia.

The oil samples is diluted and 5 μ L sample volume injected into an air carrier stream leading to a conventional pneumatic concentric nebulizer which gives rise to a signal or peak.

Gas Chromatography

Gas chromatography is a tool used for separating and analyzing compounds. Gas chromatography can be used for testing purity of a substance.

Sample being tested should be thermally stable, be soluble in desired solvent and have different boiling points. Gas chromatography coupled with mass spectrometry (GCMS) can be utilized to check fresh and used lubricating oil and also to predict the probable molecular structure of oil. Oil analysis is used to find out shelf life and residual life of the oil after service.

Packed column holds the stationary phase which is made of steel or glass tube whereas capillary column is made of silica. GC usually uses different types of detectors like GC-FID, GC-TCD, etc. GC-FID (GC Chromatography Flame Ionization Detector) respond to wide range of hydrocarbons. GC-TCD (Gas Chromatography Thermal Conductivity Detector) detector can detect air, hydrogen, carbon monoxide, nitrogen, sulfur oxide, inorganic gases and many other compounds. GC-ECD (GC Chromatography Electron Capture Detector) is used to detect atoms and molecules in a gas. Of these, GC-FID is used for lubricating oil.

For GC, few microliters of sample is sufficient when using GC-FID, GC-TCD

Gas Chromatography separates organic compounds in mixture based on boiling point and retention time and carbon chain length distribution. Process is carried out by injecting liquid sample consisting of sample with carbon disulphide used as solvent and n-decane as standard using different carrier gas²².

Usually GC analysis has two phases which are stationary and a mobile phase. A stationary phase would absorb the sample and release them whereas, a mobile phase is a stream of carrier

gas used for carrying the sample from the injection port to column and finally to detector²³. Detector is a device which gives signal response with respect to counts and detect as a peak.

Some of the findings observed by previous workers are discussed below as case Studies Reig²⁴ studied an used oil and tested using FTIR by placing one to two drops of the oil sample between the two potassium bromide crystal windows using a spacer. Intense heating of the lubricating oil led to formation of carboxylic compounds. Triglyceride esters have a strong absorption band at 1743 cm^{-1} due to stretching of carbonyl group. Aldehydes and ketones have an absorption band at 1725 cm^{-1} and 1715 cm^{-1} respectively.

Infrared spectroscopy is used to measure the oxidation of the lubricating oil. The oxidation peak is usually observed at 1710 cm^{-1} wavenumber measured by infrared spectroscopy. Oxidation products within the oil reacts with hydrocarbon molecules forming insoluble carbonaceous residues and resins.

Nitration is due to lubricant oil degradation and results from the reaction of the oil with NO_x. The nitration peak is usually observed at 1620 cm^{-1} wavenumber measured by infrared spectroscopy.

Sulphation give an indication of the degree of degradation of the lubricant which are typically from sulfur based additives. Sulphation is measured by infrared spectroscopy at an infrared wavenumber of 1150 cm^{-1} .

Lubricating oil when fresh is devoid of any oxidation, sulphation and meets the specification and ready to be used in machine. It is observed that when fresh lubricant oil is depleted in additive content then oxidation of the oil takes place or in another scenario viscosity of the oil can increase due to wear of metal debris from the walls of the instrument in running condition. Wear metal which are worn out from the walls of the machine tend to mix with the fresh oil making them dark in color increasing their viscosity and making them not suitable for further usage.

Common cases for increase in viscosity is by the oxidation, nitration and sulphation of the lubricating oil.

Oxidation occurs when there is availability of oxygen and is dependant on temperature and contamination. As the temperature of the lubricating oil increases, wear metal content increases, oxidation of the oil also increases.

Martinez et al²⁰ analyzed the elemental content of vegetable oils through inductively coupled plasma optical emission spectroscopy (ICP-OES). ICP-OES can be used for multielemental analysis for elements from Lithium to Uranium at ppm and ppb levels². We have mentioned

above a few critical parameters used in the interpretations of lubricating oil. It is essential to interpret the fresh and used lubricating oil samples. Whenever used lubricating oil is sampled it is compared to the fresh lubricating oil and then an inference is drawn.

Todorova et al²⁵ had carried out analysis using distilled lavender oil with GCMS.

They had used Bruker BR-5 MS fused silica capillary make column. Standards were utilized to optimize various parameters of the instrument. Distilled lavender was diluted with hexane and was analyzed using GCMS. GCMS using internal libraries revealed that the oil of lavender contained 35 compounds, which represent 94.13% of the total oil. A total of 50 volatile compounds were found in lavender oil. These studies were useful to conclude the essential oil content and quality of the commercial products with respect to the standards.

Typical specification of an oil is given in Table 4 and elemental content for fresh and used oil is given in Table 5.

Table 4 is just a representative example of an oil. Fresh oil meets the specification and is without contamination. When an oil is used for its application, it lubricates the internal components of machine and a stage is reached where the fresh oil which is transparent in color becomes darkish. This is the stage we need to test the darkish oil. Fresh oil is used as a standard and being compared to the used darkish oil.

From Table 4 we can infer that, Viscosity at 40 °C and 100 °C has increased in the used lubricating oil as compared to the fresh oil. This is due to the oxidation of the used oil as compared to the fresh oil, increase in Acid Value of the oil and few system component elements which gets worn out mixing with the lubricating oil.

Acid number gets increased due to oxidation of the used lubricating oil and depletion of additives (antioxidants and antiwear).

Table 5 represents the elemental contents for the fresh and used Lubricating Oil. Fresh oil contains higher contents of Silicon, Phosphorous and Sulfur which are due to the additives. Elemental Phosphorous is an antiwear additive, Silicon is from the antifoaming agent. We can infer from the Table 5 that increase in Aluminum and Iron content in the used lubricant as compared to the fresh lubricant is due to wear of metals from different machine components during its operation. Wear metals once worn off mix with the lubricating oil leading to increase its viscosity.

Yan et al²⁶ have reported the analysis data for oils derived from 35,000 km of regular oil monitoring for an E-axle used in a truck oil. Oil used was 75W/90. Oil test data was based on a reliability road test data on a test gourd at Chongqing, China. Oil samples were tested for the physical and chemical properties after the road test which predicted the deterioration of oil, additive depletion and oxidation of the oil. Wear was in the form of iron debris from transmission gear, the rolling bearing, etc. When E- axle is operational, worn-out iron debris mixes with the oil causing abrasive wear of the E-axle. Iron in the oil will act as catalyst leading to the increase in debris concentration and finally degradation of the oil. Oxidation of the oil is tested by FTIR, additive depletion of the wear elements in the used oil was measured by ICP-AES.

Conclusions:

In this review, basics of lubricant and lubrication are discussed in brief. This is followed by description of various different types of lubricants used in industry which are mineral, synthetic (biodegradable), etc and brief history of lubrication. The application of different analytical techniques, namely, FT-IR, ICP-AES, GC in lubricant industry including different regimes are discussed at the end along with some case studies.

Figure:

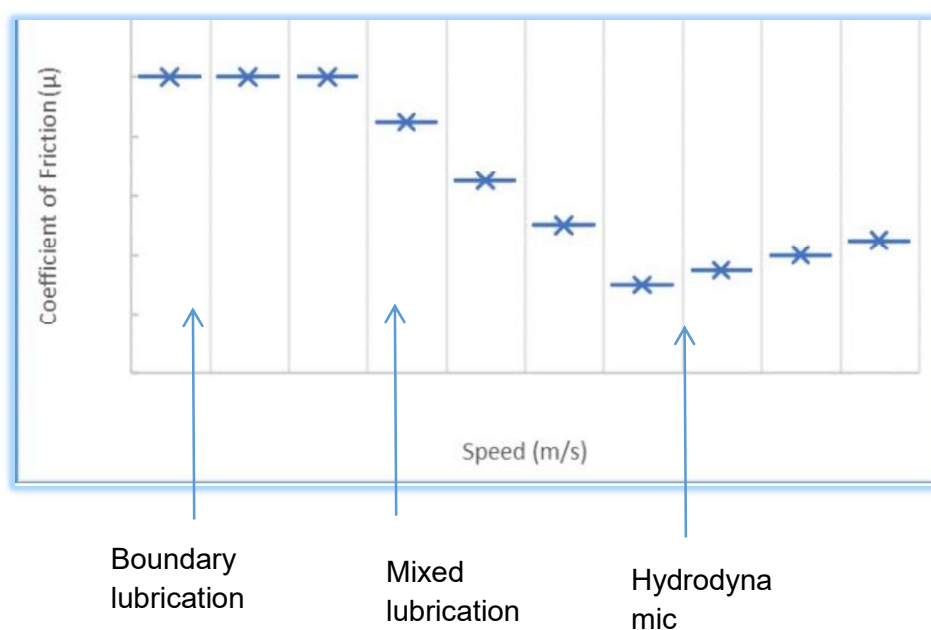


Figure 1: Lubrication regimes

Tables:

Table 1: Base oil Categories

| Base Oil Category | Percent Saturates | | Percent Sulfur | Viscosity Index | Types |
|-------------------|--|----------|----------------|-----------------|-----------------------------|
| Group I | < 90 | and / or | > 0.03 | 80 to 119 | Mineral Oil composed of Wax |
| Group II | ≥ 90 | and | ≤ 0.03 | 80 to 119 | Hydrotreated mineral oil |
| Group III | ≥ 90 | and | ≤ 0.03 | ≥ 120 | Naphthenic Oils |
| Group IV | Polyalphaolefins | | | | Polyalphaolefins |
| Group V | Anything not covered in Groups I to IV | | | | Polyol Esters Synthetic Oil |

Table 2: Brief history of Lubrication

| Year | Details |
|---|--|
| 1400 BC | Greases were made from calcium and fats used to lubricate chariot wheels. |
| 1450 AD | Herodotus described pits observed in Iraq as containing three different kinds of substances like asphalt, soil and oil which were in different forms like Asphalt and soil are solid and oil is liquid. |
| 1596 AD | First use of petroleum products was evolved in Egypt. Piny and Pedanius described Sicilian oil which was burnt for illumination during beginning of Christian era. Walter Rayleigh discovered deposits of bitumen in Trinidad in 1596. |
| 1629 AD | Joseph Roche of Cuba found petroleum being used medicinally and to bind pigments which were used in body adornments. |
| 17 th to 18 th Centuries AD | John Theophilus developed a tribology model of cohesion and adhesion on friction ¹³ . Molecules of a liquid experience friction having like behaviour when flowing due to molecular interaction within. |
| 1769 AD | James Watts was responsible for development of practical steam engine ¹⁴ . |
| 1833 AD | Benjamin Sillmann described petroleum sold in Eastern states under name of Senaca Oil found to be brown in color present between tar and molasses and its degree of consistency was not matching to temperature ¹⁴ . |
| 1859 AD | W.A. Smith, a blacksmith and brine well driller, began drilling |

| | |
|-----------------------------|--|
| | and went down 69.5 ft and was discovered on drilling an incredible quantity of 20 barrels of oil a day can be obtained ¹⁵ . |
| 1850 to 1875 AD | Between 1850 to 1875 period products of petroleum distillation and also an investigation of substitutes for vegetable and animal oils were found out. |
| 1900 AD | In 1900 crude oil demand increased due to importance in gasoline ¹⁵ . |
| 1910–1918 AD | Lubricants started being used in mechanical equipments like turbines and automobiles. |
| 1930 to 1940 AD | Additives started gaining importance in 1930s covering corrosion inhibitors, pour point depressants, viscosity index improvers, etc to be used in lubricants in 1940s ¹⁵ . |
| 1950 AD | Esters were produced in 1950 by US and British researchers which were the same in engines of jet aircrafts ¹⁴ . |
| 1970 to 1980 | Process of hydrocracking started in 1970s and 1980s. |
| 1990s AD | Isomerization became common in 1990s ¹³ . Hydroisomerization technique was used to basically remove the wax from Group I (solvent extracted) base oils and converted them into oil without wax (mostly Group I) |
| 21 st century AD | Evolution of mechanical lubrication progressed with oil / grease products with more productivity leading to advances in industry ¹³ . |

Table 3: Properties of Lubricating Oil

| Instrument | Testing method followed | Tests performed | Detection Limits | Details |
|-------------------|-------------------------|------------------------------------|-------------------|---|
| Viscosity | ASTM D445 | Viscosity and Viscosity Index | 2 cSt to 1000 cSt | Viscosity is measured at 2 temperatures, 40 °C and 100 °C |
| Moisture Content | ASTM E1064 | Trace Level Moisture in lubricants | < 10 ppm | Determined by potentiometric / coulometric titration using the Karl Fisher Reaction |
| Total Acid Number | ASTM 974 | Calculates Acidity in lubricants | 0.01 mg KOH g/oil | Determined by Volumetric Titration using KOH |
| Flash Point | ASTM D92 | Flash Point | | Determined by the point at which |

| | | | | |
|---|------------|--|--|--|
| | | determination in oils | | vapor may cease to burn when source of ignition is removed (25 to 250 °C) |
| Pour Point | ASTM D97 | Pour Point determination for oils | | Determination by temperature at which oil becomes semi solid and loses its flow characteristics (25 to -50 °C) |
| Fourier Transform Infrared Spectroscopy | | Detection of functional groups in oils, greases, polymers and gels | | Used to obtain infrared spectrum of solid or liquid |
| Inductively Coupled Plasma AES | ASTM D5185 | Determination of elemental contents in oils | | Used to determine additive concentrations in oils. |

Table 4: Representative example of Lubricating oil (Fresh and Used)

| Parameter | Fresh Oil | Used Oil |
|-------------------------------|-----------|----------|
| Viscosity, Kinematic @ 40 °C | 162 | 178 |
| Viscosity, Kinematic @ 100 °C | 19 | 24 |
| Viscosity Index | 135 | 165 |
| Flash Point, °C | 210 | 220 |
| Pour Point, °C | -36 | -35 |
| Acid Value, mg KOH g/ oil | 0.1 | 2.5 |
| Moisture, ppm | 100 | 500 |

Table 5: Elemental content for fresh and used Oil.

| Elements → | Al | B | Cu | Fe | Na | Si | S | Mn | Mo | Mg | P |
|-------------------|-------|----|----|-----|----|-----|-----|----|----|----|------|
| Fresh Mineral Oil | <1 | 10 | <1 | <1 | <1 | 500 | 300 | <1 | <1 | <1 | 2000 |
| Used Mineral Oil | 11000 | 5 | <1 | 500 | <1 | 200 | 500 | <1 | <1 | <1 | 20 |

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