

Monitoring Engine Health by Lubricating Oil Analysis- A Review

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ABSTRACT: This paper is a review on the methods of analysis suitable for lubricating oil in order to monitor the health of an engine. As an engine is subjected to very high temperature and pressure during combustion of fuel to produce mechanical power, lubrication of engines is an extremely important aspect of engine operations. A good lubricating system results in more efficient engines and increases their longevity. Lubricating oil can be analyzed to obtain thorough knowledge of the health of most of the components of an engine. Engine moving parts are lubricated to help in smooth operation of engine and to reduce the operating temperatures. The lube oil can be tested for its contaminants and wear debris and analyzed to predict the engine parts failure in advance, so we can avoid catastrophic failure. Various methods are used by investigators to analyze used lubricant properties to determine the engine condition.

KEYWORDS: Condition monitoring, oil analysis, wear debris, catastrophic failure, oil contaminants.

I. INTRODUCTION

The internal combustion engine is one of the greatest inventions of this century, but experts realized soon enough that friction creates a problem between two relatively moving parts affecting the engine's operation, performance and its life span. If a thin oil film or layer is introduced between the relatively moving parts to avoid heat production, wear and tear due to friction. This oil is called as lubricating oil, which sticks to the surface of moving parts and prevents direct contact between the relatively moving parts. Just as human blood flows in an animal's body, lubricating oil also flows inside the engine not only to provide lubrication between moving parts but also helps in transferring energy, transferring heat from mechanical components i.e., helps in dissipating the heat from the engine head and piston crown as soon as possible, provide a cushioning effect by absorbing sudden shocks or vibrations, preventing corrosion and contamination control by sealing engine components.

Engine lubricating oil exercises direct influence on overall engine operation, performance, efficiency, emission and life span. Therefore, lubricating oil monitoring helps to maintain the engine health by predicting engine status and adapting precautionary steps to avoid catastrophic failure. This process of oil monitoring is called as Condition Based Monitoring (CBM). CBM helps to monitor the oil level, wear and tear, and other oil parameters like viscosity, moisture content etc., These parameters are monitored by analyzing oil and measuring the physical-mechanical, chemical, optical, electrical and other properties of engine lubricant. In an engine, the beginning of a breakdown occurs thousands of miles or hundreds of hours before the breakdown itself. Signs of potential trouble usually appear first in the lubricant, the engine's bloodline. Just as a human blood samples can reveal much about an individual's health, lubricant monitoring can afford critical insight not only on the optimum point at which lubricants should be changed, but when repairs might be necessary. Identifying and measuring the amount of contaminants helps to diagnose the part which might have significant wear on it. The percentage of metal debris found in the oil helps to decide the severity of damage.

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CBM is a planned maintenance which comes under preventive maintenance and involves various techniques such as visual monitoring, performance monitoring, vibration monitoring and wear debris analysis. Some of the advantages of CBM are:

- An early knowledge of impending failure.
- Actual condition knowledge and accurate failure prediction.
- Diagnostic potential- CBM can pinpoint impending component failure together with the cause of that failure.
- Flexibility.
- Helps to replace the damaged parts at the earliest before damaging any other parts.

The applications of CBM can be extended to any mechanical system which are using lubrication system i.e., CNC, NC machines, wind mills, pumps, motors, generators, hydraulic systems etc., And can also be used in many industries in their maintenance programs to perform an accurate monitoring job on machinery equipment with lubrication system. Paper is organized as follows. Section II describes the various testing methods to analyse the used lubricating oil. Section III presents the conclusion and finally Section IV highlights the future scope.

II. TESTING METHODS TO ANALYZE THE USED LUBRICATING OIL

2.1. SPECTROMETRIC OIL ANALYSIS

2.1.1 Introduction

The spectrophotometer is a device used to measure the light intensity at different wavelengths. Light is passed through an oil sample; the light is diffracted into a spectrum which is detected by a sensor and interpreted into useful results. The result of a spectrophotometer is a graph plotted between light intensity and wavelength. It is a maintenance tool which is used to check the condition of the oil lubricated mechanical systems (Examples: Motors, Engines, Gear boxes, Hydraulic systems). The systems can be kept under surveillance without dismantling them. Abnormally worn compounds can be localized and replaced before a catastrophic failure occurs. The quantity and type of wear metals in a sample of lubricating oil is determined. The amplitude of graph can indicate something about the magnitude of the wear and the type of wear metals can reveal which component is wearing out. Data collected to generate this graph can typically be saved as a table of wavelengths. Spectrophotometer oil analysis is perhaps one of the more commonly used techniques for the determination of certain elements by either atomic emission or atomic absorption spectroscopy.

2.2 ROTARY PARTICLE DEPOSITOR

Rotary particle depositor is a low-cost method of separating the debris particles from the sample of engine oil by the use of Millipore filter. The concentration of wear particles is measured with an instrument called as Particle Quantifier or Debris Tester, which utilizes the eddy current principles to measure small quantities of ferrous particles. The interpretation of the information gathered, particularly that on characteristics such as shape and size, requires a degree of expertise that can be generated through the supplementary techniques such as Ferrography or Rotary particle depositor^[1].

2.2.1 Working

The RPD Rotary Ferrograph offers a rapid and simple method of debris separation and particle size analysis. A measured volume of lubricant sample is filled in the burette. The RPD machine is switched on, when the magnet and glass slide (substrate) assembly start to rotate at desired speed. This initiates lubricating oil sample on the glass slide by the means of nozzle fitted on burette in single drops. Keep the machine turn on till the lubricating oil is exhausted in the burette. Debris particles are deposited radially as three concentric rings by the combined effects of rotational, magnetic and gravitational forces.

2.3 FLASH POINT AND FIRE POINT

Flash point is the lowest temperature at which the oil lubricant liberates enough vapors that ignites oil for few moments

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when a tiny flame is brought near it. While fire point is the lowest temperature at which the vapor of the oil burns continuously for at least five seconds, when a tiny flame is brought near it. A good lubricant should have flash points at least above the temperature at which it is to be used. The flash and fire points are usually determined by using "Pensky-Marten's apparatus". This apparatus consists of:

2.3.1 Oil Cup

An oil cup is about 5 cm in diameter and 5.5 mm deep. The level to which oil is filled marked inside the cup. The cup is provided with the four opening of the standard size. Through one of these passes a thermometer and the second opening is used for introducing test flame.

2.3.2. Shutter

Shutter is the lever mechanism, provided at the top of the cup. By moving the shutter the lid opens and flame is dipped in to this opening, thereby burning the flame over the oil surface.

2.3.3 Flame exposure device

It is a tiny flame, connected to the shutter by a lever mechanism.

2.3.4 Air Bath

Oil cup is supported by its flange over an air bath which is heated by a heater.

2.3.5 Pilot Burner

As the test flame is introduced in the opening, it gets extinguished, but when the test flame is returned to its original position, it is automatically lighted by the pilot burner.

2.3.6 Working

Oil under examination is filled up to the mark in the oil cup and then heated by the heater. Stirrer is worked between tests at a rate of about 1 to 2 revolution per second. Heat is applied to rise the temperature of oil, test flame is introduced for a moment. The temperature, at which a distinct flash (a combination of weak sound and light) appears inside the cup, is recorded as the flash point. The heating is continued thereafter and then test flame is applied as before. When the oil ignites, it continues to burn for at least 5 seconds, the temperature reading is then recorded as the fire point of the oil.

2.4 VISCOSITY

Viscosity is the measure of resistance of a fluid which is being deformed by either shear stress or tensile stress. In other terms (and for fluids only), viscosity is thickness or internal friction. Thus, water is thin having a lower viscosity and honey is thick having a higher viscosity.

Viscosity of lubricating oil is determined with the help of an apparatus known as Viscometer. In a viscometer, a known volume of lubricant is allowed to flow from a given height through standard capillary tube under its own weight and the time of flow in second is recorded. The time in seconds is proportional to the true viscosity. The results are expressed in terms of time taken by oil to flow through particular instruments.

2.4.1 Procedure

Test of viscosity determination is very simple. First of all, oil is filled up to the mark in the oil cup, and then this cup is heated by the water bath. Insert thermometer in the oil cup and note the temperature raise. Now remove the valve rod from the jet opening and the oil is falling down in the beaker (50 ml in size) which is already placed just beneath of oil cup. The time required to fill the beaker is known as the viscosity of the respective oil.

2.5 LITMUS PAPER TEST

This test is very much simpler as compare to other tests. In this test litmus paper is required for the examination of oil. Some drops of lubricating oil are applied on it and then allow it for drying. After drying it gives a different color for different samples of lubricant. In this test paper color moves towards the dark black from the light brown.

2.6 SULPHUR TEST

Presence of considerable amount of Sulphur in the lubricating oil promotes corrosion. The corrosion test shows the amount of sulphur content.

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2.6.1 Procedure

Sulphur test is one of the important tests. For this 2 gm., weighted sample of lubricant are used (i.e. in this dissertation Sulphur test are used for 2 gm. oil samples). First of all, weight of a crucible is determined by the universal weighing machine. Net amount of sample is then mixed with the dilute HCl. This mixture is heated for 30 minutes and then allowed to cool for 30 minutes. This is then mixed with saturated solution of BaCl₂ (which works as an indicator). If Sulphur is present in the mixture, then the solution changes color otherwise it stays the same. If Sulphur is present, then an arrangement of conical flask and funnel made. Watt men filter paper is placed on the top the arrangement (i.e. funnel) and solution is applied to it. Liquid is filtered by filter paper and only sulphur is retained on it. This paper is allowed to dry and burnt in a crucible. The pre-determined weight of the crucible is then subtracted from the weight of the resultant sample hence the weight of Sulphur present in the sample is determined.

2.7 MOISTURE CONTENT TEST

For this test 5 gm. of each sample are taken. During this moisture content test, samples of engine oil are then heated up until the oil sample begins to liberate smoke. If at this time sample of oil gives a splatter of water it indicates the presence of moisture in the sample.

2.8 FILTER GRAM ANALYSIS

Filter gram analysis is the microscopic examination of wear particles taken from an oil sample or filter medium. A Filter gram can identify particles from 3 microns to over 1,000 microns. Positive confirmation is assured to differentiate between chemical leaching and mechanical wear.

2.8.1 Procedure

A filter gram analysis of an oil sample can be a very useful addition to the more traditional methods of condition monitoring. The sample to be examined is dissolved in a solvent (Di methyl Sulphur oxide) and filtered through a very fine membrane filter. Filter papers used in the examination are capable of measuring the particle of size more than 22 microns. The wear debris and other contaminants in the oil are captured on the membrane for examination under a high-resolution microscope. The filter gram report gives an analysis of the size and composition of all the particles found as well as the wear mechanism which generate the metallic particles. Debris recovered from filter media can also be analyzed by these techniques.

2.9 INFRARED TECHNOLOGY

Infrared thermography has been used as a condition monitoring tool for over a decade. The technology provides thermal images that could help the experts in detecting faults in electrical and mechanical systems. In spite of its capabilities, infrared thermography has not found its way into autonomous systems. The main reason for this is the high cost of the technology. A typical infrared camera could cost more than £40,000 or far more. A recent drive to reduce the cost of the technology has had only a limited effect. Most of the available infrared systems in the market are designed as portable systems for measuring and saving data. The infrared multipoint radiometer is an uncooled pyro electric system. The pyro electric detectors generate a charge on every pixel that is proportional to the change in the infrared radiation received as a result of change in temperature of the viewed objects. Imagers of this type require a constantly changing image signal, and thus the imager has a mechanical chopper to generate a continuous change in infrared radiation. The difference between the chopper and the open view infrared radiation produces a corresponding charge which is converted into a voltage and amplified to produce a thermal representation of the object.

2.10 WEAR DEBRIS ANALYSIS

Relationship between wear characteristics and wear particle features are shown in the following table. 2.10.1. The technique of Wear Debris Analysis is gaining popularity in the field of Condition Based Maintenance. WDA is a method of predicting the health of equipment in a non-intrusive way, by the study of wear particles. The continuous trending of wear rate monitors the performance of machine / machine components and provides early warning and diagnosis. Oil condition monitoring can sense danger earlier than vibration technique. This technique holds good for

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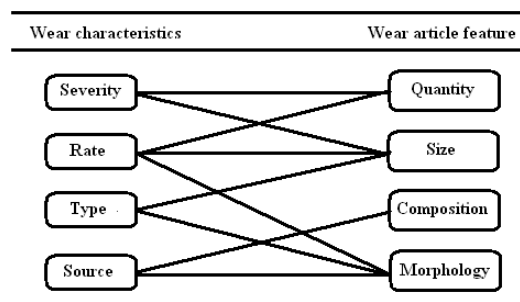
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both oil and grease samples.

Table 2.10.1: Relationship between wear characteristics and wear particle features



2.11 pH TEST

pH is the measure of hydrogen ion activity. It is used to express the intensity of acidic or alkaline condition of a solution. pH is the relative acidity or basicity of a substance. This value is important information to have in many situations as the pH level of a substance dictates its safety, chemical reactivity and effects on the environment. Everyone from chemical engineers to home gardeners can make use of the pH information for a specific substance. This value is so important that the ability to test the pH of a substance such as oil, has been around for many years and can easily be accomplished. pH of lubricating oil sample can be determined by electrometrically or calorimetrically.

2.11.1 Procedure

Following step shows the method of pH test:

1. Remove a universal indicator strip from its container.
2. Dip one end of the universal indicator strip into the oil for which you want to test the pH level.
3. Set the universal indicator on a dry surface for 60 seconds to allow the pH reading to take place.
4. Compare the changed color of the universal indicator paper to that of the pH chart that accompanied the paper's packaging.
5. Match the new color of the universal indicator paper to that of the chart to find an exact pH match.

2.12. PARTICLE COUNTER AND PARTICLE SHAPES CLASSIFIER:

Particle counter gives the different percentage of wear debris compositions and particle shape classifier helps to find out type of wear occurred like due to rubbing wear, cutting wear, rolling, fatigue wear, combined rolling and sliding, and severe sliding wear.

The LaserNet Fines (LNF) analysis process is illustrated in Fig. 2.12.1. A sample of fluid, either a bypass from the main flow for an on-line system or a bottle sample from a manually-sampled system, is illuminated with a laser diode and images of entrained objects are recorded on an electronic camera. LNF measures the size distribution of particles from 4 μm to above 100 μm , and provides classification based on shape features for objects larger than 20 μm . Analysis of particles in this size range is useful for the early detection of mechanical faults in diesel and turbine engines, turbochargers and gearboxes. This range of sizes is also relevant to particulate contamination levels in hydraulic and fuel systems. All particles bigger than 20 μm are sorted according to their typical shape into categories: (depending on the origin of their wear type) abrasive, sliding, fatigue, non-metallic and then are statistically evaluated. For individual particle types are stated quantities per 1 ml, average size, standard deviation and maximal diameter. The result is not only analysis of the quantity and size of the particles contained in the oil, but also analysis of abnormal abrasive wear particles and an overview of previous results related to the same equipment. This allows the gathering of data about oil condition, but above all also about wear mode and technical condition of the equipment, from which the oil sample was taken.

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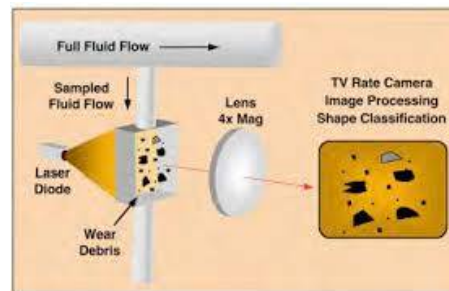


Figure: 2.12.1 The LaserNet Fines (LNF) analysis

2.13. ACID DIGESTION DIFFERENTIAL METHOD

In Acid Digestion Differential Method two measurements are made on each sample. In first measurement sample is introduced to plasma after diluting it with solvent by an appropriate ratio. In second measurement concentration of different metals is calculated. When these two measurements are compared, we get difference which is an indication of large particle fraction.

2.14. FERROGRAPHY

To overcome deficiencies of spectrometric oil analysis the Ferrography technique was developed in the 1970's. Ferrography technique helps to diagnose the composition of wear debris and source of wear debris. Source of materials also designated like aluminum due to piston worn, chromium-piston rings, valve seats, copper-rolling element bearing, lead-plain bearing, nickel-valve seats, and silver due to fretting of joints, silver plated bearing surface. In this method metal particles are separated from the fluid for microscopic examination and further analysis. In analytical Ferrography, strong magnetic field gradient is used to separate wear particles from the used oil sample. In this method size and concentration of different metals can be calculated which is helpful in determining rate of wear to predict future failure.

2.15. ROTATING DISK ELECTRODE

Optical emission spectroscopy (OES) is used to measure the ppm (parts per million) levels of wear, contaminants and additives in oil samples. In this method, oil is burned or sparked between a rotating carbon disc electrode and a carbon rod electrode. The sample is placed in a sample cap, the disc is partially immersed in the oil sample and the disc rotates as the burn proceeds. Burning light of different wavelength comes from plasma, an optical system is used to separate the discrete wavelengths. These separated wavelengths give information about the concentration of different metals in used oil.

III. CONCLUSION

Final conclusion on lubricating oil analysis from researcher work are as below

1. Used lubricating oil contains so many abnormal wear debris caused due to reciprocating motion, rotary motion or due to adhesive and abrasive wear, which results in the decrease of anti-wear properties of lubricating oil^[1].
2. Analytical Ferrography is among the most powerful diagnostic tools in oil analysis in tribology^[2].
3. Wear debris or particles analysis is an effective means to extract the relevant information about the physical aspects of used oil and the wear condition of the parts^[3].
4. The oil analysis techniques like infrared spectrometry, analytical Ferrography, particle counter and particle shapes classifier helps to evaluate depletion of lubricant additives and also to diagnose the composition of wear debris and source of wear debris^[4].
5. Oil analysis for large wear particles in used oil with acid digestion differential method, ferrography and rotating disk electrode methods^[5].
6. The method of oil analysis reduces the need for preventive maintenance^[6].

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7. Wear metal concentration obtained from the used lubricating oil provide vital information regarding the cause and level of the deterioration existed and progressed in operating mechanical components^[7].

IV. FUTURE SCOPE

The paper will help in providing the base for future studies that will be carried out for lubricating oil analysis and preventing the catastrophic failure. Highlights the varies methods of oil analysis techniques used to monitor the used oil for diagnosing engine health. And also, helps to choose the oil analysis method depending on which property of used oil has to be examined.

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