GETTING THE MOST OUT OF LUBE OIL ANALYSIS

The Basics

Common Oil Analysis Tests & Their Significance

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Overview

The practice of oil analysis has changed drastically from its original inception in the railroad industry. In today's exploding computer and information age, oil analysis has evolved into a mandatory tool in one's predictive maintenance (PdM) arsenal.

As a PdM tool, oil analysis is used to uncover, isolate and offer solutions for abnormal lubricant and machine conditions. These abnormalities can result in expensive, sometimes catastrophic damage causing lost production, extensive repair costs, and even operator accidents.

The goal of an effective oil analysis program is to increase the reliability and availability of machinery while minimizing maintenance costs associated with oil change outs, labor, repairs and downtime. Accomplishing this goal takes time, training and patience. However, the results are dramatic and the documented savings and cost avoidance are significant.

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Lubrication Properties

Lube oil analysis is used extensively to help companies maintain their equipment. In order to take full benefit from the test data from oil samples, it is important to understand the basic properties of a lubricant. Equally important is the understanding of how these properties affect the ability of the lubricant to function. Lastly, knowledge of the common test techniques and instrumentation used to analyze oil can aid in data interpretation and lead to more productive corrective action.

The primary functions of a lubricant are to lubricate, cool, clean, protect, seal and transmit power.

To effectively monitor how well a lubricant is working, the functions of the lubricant must be understood. The primary function of a lubricant is quite obviously to lubricate (that is, to reduce friction). By reducing friction, wear is reduced, as is the amount of energy required to perform the work.

In 1699, a physicist named Guillaume Amontons deduced that friction is the result of surface roughness. Since no solid surface is perfectly smooth, opposing friction surfaces have peaks called asperities that come in contact with one another. Ideally, a lubricant will physically separate these asperities with an oil film. This is called full fluid film lubrication.

When the proper lubricant is used, and the proper load is applied, the asperities are not in contact and in theory no wear will occur. When inadequate lubrication is present, or the load is increased, the oil film will not be thick enough to fully separate the asperities. Mixed lubrication, a cross between boundary and hydrodynamic lubrication, occurs when the oil film thickness is equal to the average asperity height. The largest asperities will come in contact, resulting in increased wear.

Many oils are fortified with anti-wear additives to combat wear under these circumstances. As load continues to increase, or lubrication degrades, boundary lubrication occurs and the oil film thickness cannot

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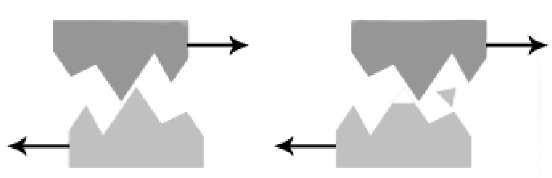
separate the friction surfaces. This can result in metal-to-metal contact. At this point, asperities are adhering to one another, causing severe machine wear. This can also manifest itself during periods of shock loading, startup or shutdown. Extreme pressure additives are used in oils that frequently encounter these types of situations.

Lubricants also control the temperature of the equipment. Oil absorbs heat generated at the friction surface and carries it away to be dispersed. Many systems incorporate heat exchangers or radiators to aid in removing heat from the system. Along with heat, lubricants transport dirt and other debris away from the friction surface.

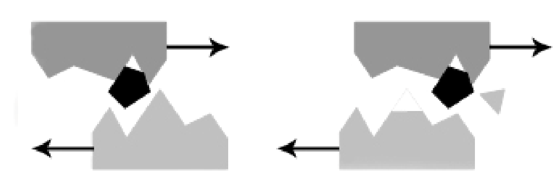
Particulate contamination leads to increased wear through abrasion and reduced oil flow. Some oil additive packages contain agents that break up contaminants and hold them in suspension to be filtered out. This prevents harmful deposits and varnish from forming within the equipment. Alkaline additives also protect the components by neutralizing acid and preventing corrosion.

Hydraulic oils have the added function of transmitting power. To function properly, hydraulic oil must be clean and free of contaminants. Many contaminants will cause oil to foam and entrain air or water. Entrained air causes the oil to compress under pressure, resulting in a loss of power. Particulate contaminants can cause the control valves to malfunction and restrict the oil flow.

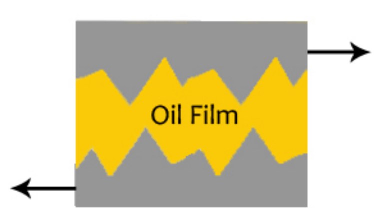
Two Body Abrasive Wear



Three Body Abrasive Wear



Full Fluid Film Lubrication



The Role of Oil Analysis

Selecting the proper lubricant, along with careful maintenance of that lubricant, is essential to ensure adequate protection to any machine. Proper lubrication is defined as a correct amount of the correct lubricant at the correct time.

Maintaining a lubricant means ensuring that it has the correct viscosity and the necessary additives for the application. Steps must be taken to keep the lubricant clean and serviceable. **Oil analysis is the most effective way to prolong the useful life of lubricants, while maintaining maximum protection of equipment.**

Oil analysis tests reveal information that can be broken down into three categories:

- **Lubricant condition:** the assessment of the lubricant condition reveals whether the system fluid is healthy and fit for further service, or is ready for a change.

- **Contaminants:** increased contaminants from the surrounding environment in the form of dirt, water and process contamination are the leading cause of machine degradation and failure. Increased contamination indicates that it is time to take action in order to save the oil and avoid unnecessary machine wear.

- **Machine wear:** an unhealthy machine generates wear particles at an exponential rate. The detection and analysis of these particles assist in making critical maintenance decisions. Machine failure due to worn out components can be avoided. It is important to remember that healthy and clean oil leads to the minimization of machine wear.

Lubricant condition is monitored with tests that quantify the physical properties of the oil to ensure that it is serviceable. Metals and debris associated with machine wear are measured to monitor equipment health. Some tests target specific contaminants that are commonly found in oils. It is imperative to select the proper blend of tests to monitor the machine’s lubricant condition, wear debris and contaminants in order to meet the goals of successful oil analysis.

Elemental Spectroscopy

Elemental spectroscopy is a test that monitors all three categories (lubricant condition, wear debris and contaminants). A spectrometer is used to measure the levels of specific chemical elements present in an oil.

Two types of spectrometers are commonly used. Arc emission spectrometers apply energy in the form of an electric arc to the sample. This excites the atoms into vapor form, creating a spectrum where light is generated. Individual light frequencies in the spectrum are measured and quantified to determine the presence and quantities of specific elements present. The other common type of spectrometer is the ICP (inductively coupled plasma) spectrometer. This operates on a similar principle, except that the energy is applied to the sample by a plasma flame rather than an electric arc.

Elemental Spectroscopy is generally used to provide qualitative and quantitative information about metals in oil samples.

There are typically 20 elements measured by spectroscopy and reported in parts per million (ppm). These measurements represent elements in solution. Spectroscopy is not able to measure solid particles larger then roughly 7 µm, which leaves this test blind to larger solid particles.

Typical levels of wear can vary greatly depending on the type of equipment being sampled. For example, a gearbox will normally have much higher levels of iron than a hydraulic system. Levels of wear can vary across different units of the same type depending on oil hours, operating conditions, loading levels or other conditions. For this reason, it is impossible to establish firm limits for any piece of equipment based solely on the equipment type. To take full advantage of monitoring wear; a trend should be established to provide an operational baseline of data. This will ensure detection of abnormal wear rates as they develop and allows for the fact that similar equipment may not wear at the same rate.

Monitoring the additive levels provides information to ensure that the proper lubricant is being used for the application and for topping off. Four types of lubricants are generally used in most industrial applications, and each has different additive levels. It is important to note that an oil's level of additives measured by spectroscopy is not necessarily an indication of the oil's quality.

- **Engine oils** will typically contain anti-wear additives composed of zinc and phosphorus. One should expect to see these elements present in approximately 1000 ppm (±200 ppm). A detergent package should also be present, composed of some configuration of barium, magnesium and calcium. These levels will vary depending on the oil.

- **Extreme pressure oils** are typically for gear applications. It is common to see significant amounts of phosphorus.

- **Anti-wear oils** include many bearing oils, some gear oils and hydraulic fluids. These oils contain both zinc and phosphorus from 200 to 600 ppm. There may be very low levels of detergent (magnesium or calcium) present also.

- **Rust and oxidation inhibiting oils** are the easiest to identify. They include turbine oils, compressor oil, and some bearing and hydraulic oils. These oils have no metallic additives that can be measured by spectroscopy, so there should be extremely low numbers for all additive metals.

It is not uncommon to see low levels (<20 ppm) of some additive metals where they are not expected. This is usually the result of residual contamination in the equipment or storage tanks.

Many oils are formulated for specific applications and alternative additives must be used.

There are oils that do not fit into these descriptions. Many oils are formulated for specific applications and alternative additives must be used. An example would be oils formulated for some stationary and electro-motive diesel engines. In many cases, operating conditions or emission concerns call for a less traditional additive package.

As with any type of testing, spectroscopy is subject to inherent variance. High water levels can cause interference in the spectrum, as can the matrix of some synthetic base stocks. In short, always double check with another sample before taking any invasive maintenance action. Never rely on just one piece of data when making a maintenance decision.

Viscosity

An oil's viscosity is considered its most important property. The most common technique for measuring an oil's viscosity is following ASTM D445 using a viscometer (ASTM, 2011). A small sample of the oil is drawn into a calibrated capillary tube in a constant temperature bath. Once the sample comes to temperature, it is allowed to flow down the tube a predetermined distance. The viscosity is the product of the flow time and tube calibration factor. The results are reported as the oil's kinematic viscosity in centistokes (cSt).

Industrial oils are identified by their International Standard for Organization viscosity grade (ISO VG). The ISO VG refers to the oil's kinematic viscosity at 40 °C (104 °F). An oil's weight commonly refers to its kinematic viscosity at 100 °C (212 °F). The weight of multi-grade oils is represented by the second number in the rating. A 10W30 would be 30-weight oil. The 10 after the W, which stands for "winter",refers to how the oil performs in cold weather conditions.

When an oil's viscosity increases, it is usually due to oxidation, degradation or contamination. This is the result of extended oil drain intervals, high operating temperatures, or the presence of water or another oxidation catalyst. Increased viscosity can also be the result of excessive contamination with solids such as soot or dirt, as well as topping off with a higher grade lube. Water contamination can also cause high viscosity.

A lubricant with the improper viscosity will lead to overheating, accelerated wear. This will result in the failure of the machine.

A decrease in the oil's viscosity is most commonly due to contamination with fuel or a solvent. An oil's viscosity also can be affected if the wrong oil is used for top off or replenishment.

If a lubricant does not have the proper viscosity, it cannot properly perform its functions. If the viscosity is not correct for the load, the oil film cannot be established at the friction point. Heat and contamination are not carried away at the proper rates, and the oil cannot adequately protect the machine.

Acid Number

Acid number is an indicator of oil health. It is useful in monitoring acid buildup in oils due to depletion of antioxidants. Oil oxidation causes acidic byproducts to form. High acid levels can indicate excessive oil oxidation or depletion of the oil additives and can lead to corrosion of the internal components. By monitoring the acid level, the oil can be changed before any damage occurs.

An oil analyst is looking for a sudden increase. When your oil is flagged for high acid levels, it indicates accelerated oil oxidation, and you should change the oil as soon as possible. If any of the remaining highly acidic oil is left, it will quickly deplete the antioxidants in the new oil.

Acid number is measured by titration using ASTM D664 or D974. Both methods involve diluting the oil sample and adding incremental amounts of an alkaline solution until a neutral endpoint is achieved.

The Acid number of a new oil will vary dependent upon the base oil additive package. An R&O oil will usually have a very low AN, around 0.03. An AW or EP oil will have a slightly higher value, typically around 0.5. Engine oils commonly have a higher AN, in the neighborhood of 1.5.

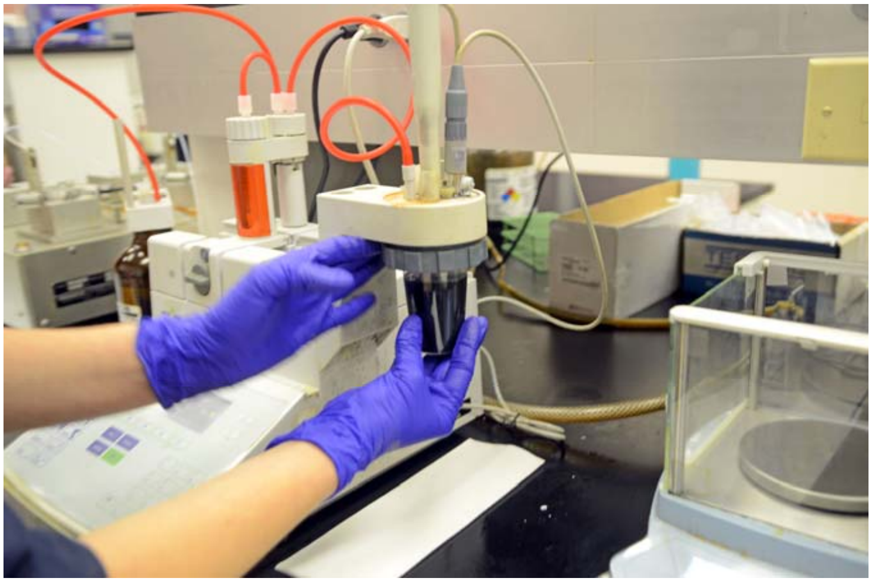
Acid number is measured by titration using ASTM D664 or ASTM D974 (ASTM, 2011; ASTM, 2008). Both test techniques involve diluting the oil sample and adding incremental amounts of an alkaline solution until a neutral endpoint is achieved.

Base Number

Base number testing is very similar to acid number testing except that the properties are reversed. The sample is titrated with an acidic solution to measure the oil's alkaline reserve. ASTM D2896 and ASTM D4739 are the most commonly used methods to measure the base number (ASTM, 2007; ASTM, 2008).

Many oils (especially motor oils) are fortified with alkaline additives to neutralize acids that are formed as a result of combustion. In diesel engine applications, acid is formed in the combustion chamber when moisture combines with sulfur under pressure. Measuring the base number will help ensure that a sufficient amount of additives have been added to the oil to help resist oxidation due to acid.

The base number of oil is highest when the oil is new and decreases with use. Once again, condemning limits are based on the application. As a rule, the base number should not drop below half of its original value. Base number values for new engine oils very greatly depending on the application.



Base number testing measures the reserve alkalinity in a lubricant. The amount of reserve alkalinity in a lubricant is critical for certain oils. Often an oil is fortified with alkaline additives to combat acid formation. The base number is at its highest as a new oil and decreases with service.

Water Contamination

Water contamination is detrimental to any lubricant. A simple crackle test is used to determine if water is present in oil. A small volume of the lubricant is dropped onto a hot plate and, if bubbles or crackles occur, water is present.

If a crackle test is positive, further testing is needed to quantify the amount of water by using Karl Fischer titration by ASTM D6304 (ASTM, 2007). A measured amount of oil is introduced into a titration chamber. This solution is titrated with Karl Fischer reagent to a specific endpoint. The amount of reagent used and the sample volume are calculated and converted to ppm or percent by mass.

Low levels of water (<0.5%) are typically the result of condensation. Higher levels can indicate a source of water ingress. Water can enter a system through seals, breathers, hatches and fill caps. Internal leaks from heat exchangers and water jackets are other potential sources.

When free water (non-emulsified) is present in oil, it poses a serious threat to the equipment. Water is a very poor lubricant and promotes rust and corrosion to the components. Dissolved water in oil (emulsified) will promote oil
oxidation and reduce the load handling ability of the oil. Water in any form will cause accelerated wear, increased friction, and high operating temperatures. If left unchecked, water will lead to premature machine failure. In most systems, water should not exceed 500 ppm.

Using the Karl Fischer titration method, a reagent is titrated into a measured amount of sample and reacts with the hydroxide molecules present in the moisture. This depolarizes an electrode and determines the titration endpoint. Results are reported as either percent water or ppm (1% = 10,000 ppm).

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Particle Count

Particulate contamination has negative effects on all types of equipment. Particle count testing is a way to monitor the level of solid contamination in the oil. Two types of automatic particle counters are used to test oil cleanliness: light blockage and pore blockage.

- **Light blockage:** The light blockage technique involves passing a sample through a small orifice that has a laser light source on one side and an optical sensor on the other side. Particles interrupting the light beam are counted, and size is determined by the degree of light blockage. Light blockage particle counting is not effective when oil is contaminated with water or when air is entrained in the oil. In these circumstances, water or air bubbles will be counted as particles causing erroneous results.

- **Pore blockage:** The pore blockage or flow decay technique passes the sample through a mesh filter. As a filter clogs, the flow of the sample is slowed. The amount of flow decay is calculated, and the particle count can then be extrapolated. Because water droplets and entrained air will not restrict the fluid flow, there is no interference from these contaminants.

High particle counts indicate dirty oil.

Results are reported as particles per milliliter in six size ranges: >4, >6, >14, >25, >50 and >100. ISO Cleanliness Codes are then assigned for particles in 4, 6 and 14 µm ranges (ISO 4406:1999). The result is reported by three numbers with a slash between them; the first number refers to particles in the >4 µm range, the second to particles in the >6 µm range and the third in the >14 µm range. The lower the numbers in the ISO Cleanliness Code, ISO 4406, the cleaner the fluid.

Particulate contamination is a measurement of the effectiveness of filtration and can indicate when excessive external contamination is occurring. Advanced machine wear will also cause increased particle counts. Generally, the lower size ranges are considered indicative of contamination and silt, while the larger size ranges point to wear problems.

Ferrous Wear Concentration

In some cases, a particle count is not an effective test because the sample is inherently dirty and filtering the oil may not be plausible. A particle count indicates that the sample is extremely dirty, but it does not give any indication of ferrous wear. In gearboxes, ferrous wear may be more important than overall particle count. In such an application, ferrous wear concentration is a good substitution for a particle count test.

A wear particle analyzer quantifies the amount of ferrous material present in a sample of fluid. A measured amount of sample is inserted into the analyzer and amount of ferrous material is determined by a change in magnetic flux. This change is then converted into ferrous concentration in parts per million. Using this method, there are no interferences with non-ferrous particles.

One advantage of a ferrous debris monitor is that it will measure ferrous wear debris in all types of oil, from gearbox lubricants through hydraulics. One of the other key benefits is that it will also measure ferrous wear debris found in grease.

A similar test to the ferrous debris monitor is DR (direct read) ferrography. DR ferrography collects positively charged particles on two light sources and measures the amount of blocked light to determine the level of ferrous contaminants present in an oil. Although these two tests provide the same information, they are not interchangeable.

The ferrous wear concentration gives a direct measure of the amount of ferrous wear metals present in a sample.

Analytical Ferrography

Analytical ferrography is used to separate solid contamination and wear debris from a lubricant for microscopic evaluation. As stated earlier, spectroscopy is not able to measure wear particles larger than 7 µm in size. While particle counting, ferrous wear concentration and DR ferrography are able to detect the presence of larger particles, they cannot qualify their composition or origin. Analytical ferrography is able to identify wear particles, their composition and their origin by visually analyzing them microscopically.

Analytical Ferrography is the best method for determining severity and type of wear present with no particle size or metallurgy limitations.

A diluted oil sample is allowed to flow over a specially treated slide which is positioned at an angle over a strong magnet. The ferrous (iron) particles are attracted to the magnet and deposited onto the slide in decreasing size as the oil flows down the substrate. Nonferrous particles are deposited randomly while ferrous particles line up in chains as a result of the magnetic flux. The result is a microscopic slide with the particles separated by size and composition.

Microscopic examination of the debris reveals information about the condition of the equipment. Observing the concentration, size, shape, composition and condition of the particles indicates where and how they were generated. Particles are categorized based on these characteristics, and conclusions can be drawn regarding the wear rate and health of the machine.

The composition of the particles can be identified by color. Heat treating the slide causes specific color changes to occur in various types of metals and alloys. The particle's composition indicates its source. The particle's shape reveals how it was generated. Abrasion, adhesion, fatigue, sliding and rolling contact wear modes each generate a characteristic particle type in terms of its shape and surface condition.

Solid contaminants can also be visually identified provided they are of a commonly found origin. Sand and dirt, fibers, oxidation products, rust and metal oxides are examples of contamination debris that can be identified.

Conclusion

While the results of these tests are a powerful maintenance tool, they are useless if not monitored and acted upon. A successful oil analysis program will be one where the test data and analysis are coupled with the maintenance department's knowledge and expertise to provide the most effective maintenance practices.

About TESTOIL

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TESTOIL is a full service oil testing laboratory owned by Insight Services. Since 1988 the laboratory has been providing fast and reliable oil analysis results across all industries throughout the Americas.

The firm's comprehensive range of oil analysis services assists reliability engineers with condition monitoring and identification of machine wear.

TESTOIL employs a sophisticated diagnostic technology that assists their Machine Condition Analysts in making equipment and lubrication condition assessments.

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