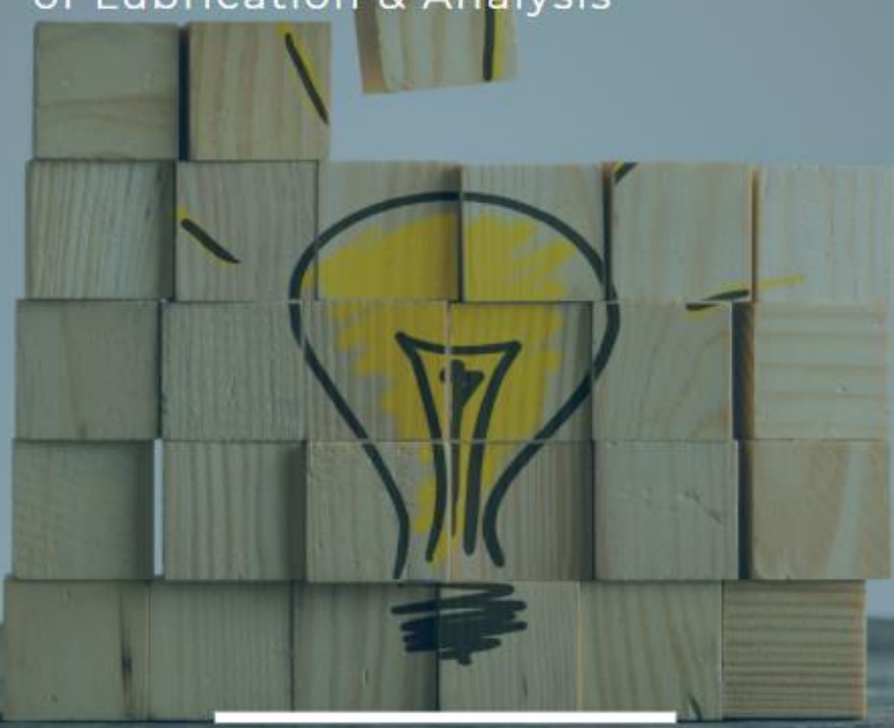
Building Blocks

A Guide to the Fundamentals of Lubrication & Analysis



TESTOIL

TABLE OF CONTENTS

ABOUT TESTOIL

TestOil has been in the oil analysis business since 1988.

We started out providing Analytical Ferrography services to power customers and in the early 90's expanded our services. We have focused on assisting large industrial facilities reduce their maintenance costs and avoid unexpected downtime through oil analysis program implementation.

Our customers rely on us to be their technical experts when it comes to diagnosing oil related issues in equipment such as turbines, hydraulics, gearboxes, pumps, compressors, and diesel generators.

Our state-of-the-art-laboratory has the capacity to process and analyze 4000 samples per day. We employ lean process management to drive excellence and ensure that we maintain our guarantee of providing same day turn around on all routine testing.

"Management, operations, engineering, and financial personnel should adopt the concept that: Maintenance Doesn't Cost, It Pays."

- AISE Steel Technology Magazine –

SECTION 1

AN OVERVIEW OF LUBRICATION & LUBRICANT ANALYSIS

The practice of lubricant analysis has changed drastically since its original inception in the railroad industry. Today’s exploding computer and information age has caused lubricant analysis to evolve 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, if left unchecked, usually result in expensive, sometimes catastrophic, damage. These damages can cause lost production, extensive repair costs and even operator accidents.

The goal of an effective lubricant 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.

Lubricant Properties

Lubricant analysis is used extensively to help companies maintain their equipment. In order to receive the full benefit of a lubricant's sample results, 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 as well as instrumentation used to analyze the lubricant can aid in data interpretation and lead to more productive corrective actions.

To effectively monitor how well a lubricant is working, the functions of the lubricant must be examined. The following graphic provides greater insight as to the correlation between a lubricant's function and by what method that function is tested.

Reduce Friction & Wear

- Elemental Spectroscopy
- Viscosity
- Particle Count
- Ferrous Wear Concentration
- Analytical Ferrography
- Foaming Tendency

Carry Away Heat

- N/A

Neutralize Acidic By-Prodcuts

- Acid Number
- Base Number
- FTIR
- RPVOT
- RULER

Protect Against Rust & Corrosion

- Elemental Spectroscopy
- Water Contamination
- Demulsibility

Prevent Formation & Deposition of Insoluble

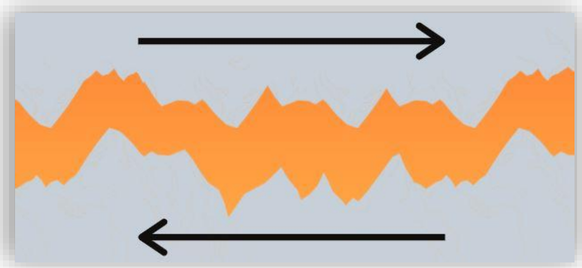
- MPC
- Ultra-Centrigue

Reduce Friction & Wear

The primary function of a lubricant is - quite obviously - to lubricate (i.e. to reduce friction.) By reducing friction, wear is reduced, as is the amount of energy required to perform the work.

Since no solid surface is perfectly smooth, opposing frictional surfaces have peaks that come in contact with one another called asperities. This contact between frictional surfaces determines the Lubrication Regime or the type of lubrication film that is created under specific operating conditions.

Hydrodynamic Lubrication Regime



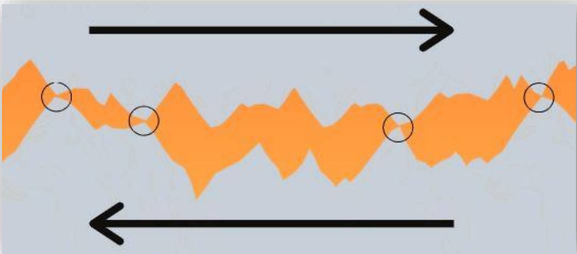
What's Happening?

- A Lubricant will completely separate asperities with an oil film
- Prevent wear from occurring

When Does This Occur?

- Occurs at high speeds

Mixed Lubrication Regime



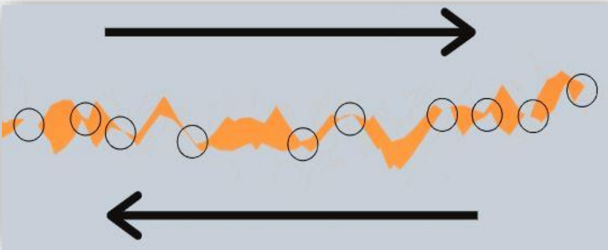
What's Happening?

- The majority of the load rests on the surface peaks, allowing for the largest asperities to occasionally come in contact
- The oil film thickness is measred in relation to the root mean square of the surface roughness and is anywhere from 1 to 4 times this value
- Ultimately results in increased wear

When Does This Occur?

- During the transition from low to high speed operations

Boundary Lubrication Regime



What's Happening?

- Load continues to increase, or lubrication degrades
- The oil film thickness cannot separate the surfaces undergoing friction
- Can result in physical, metal-to-metal contact
- Asperities are adhering to one another
- Severe wear to the component occurs

When Does This Occur?

- During periods of shock loading, start up, or shut down

Prevention

- Many oils are fortified with anti-wear additives to combat wear under these circumstances
- Extreme pressure additives are used in oils that frequently encounter these types of situations

Carry Away Heat

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 component surface.

Neutralize Acidic By-Products

Viscosity is the most important property of a lubricating oil. When the combination of viscosity and boundary lubrication is satisfactory, the oil will properly perform its lubrication function. A key factor to ensuring this top performance, is a lubricant's thermal stability. When a lubricant becomes too hot while in use, it can break down causing improper lubrication to occur.

Protection & Prevention

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 or to settle in the reservoir. This prevents harmful deposits and varnish from coating surfaces within the equipment. Alkaline additives also protect the components by neutralizing acid and preventing corrosion.

The Role of Lubricant Analysis

Lubricant analysis testing reveals information that can be broken down into three categories: Lubricant Condition, Contamination & Machine Wear.

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.*

Contamination

- *Increased contamination from the surrounding environment in the form of external, internal and built-in sources 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 importnat to remember that healthy and clean oil leads to the mininmization of machine wear.*

Lubricant condition is monitored with tests that quantify the physical properties of the lubricant to ensure that it is serviceable. Metals and debris associated with component wear are measured to monitor machine condition. Some tests target specific contaminants that are commonly found in lubricants. It is only the proper blend of tests that will allow goals to be reached.

Lubricant analysis is the most effective way to prolong the useful life of lubricants, while maintaining maximum protection of equipment.

SECTION 2

ELEMENTAL SPECTROSCOPY

Inductively coupled plasma (ICP) spectroscopy *(ASTM D5185)* is a test that monitors all three categories. A spectrometer is used to measure the levels of specific elements present in a lubricant. This is done by injecting a diluted sample into plasma where it is ionized where the intensity of the emitted colors are measured to determine the concentration of elements present.

There are 21 elements measured by spectroscopy and reported in parts per million (ppm). These measurements represent elements in solution.

A noteworthy limitation to this test is that the sample must completely ionize within a very small, measured area of the plasma. As such, only particulate within 0-5 microns is accurately measured, and particles larger than 10 microns are essentially not measured at all. Wear particles generated under normal conditions and airborne contaminants easily fall within this range, however severe wear and/or contamination may produce particles too large for detection and would require supplemental testing such as particle counting or analytical ferrography.

Typical levels of wear metal elements 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 metals can vary in different units of the same type depending on lubricant 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 in metals, a trend should be established to provide an operational baseline of data. This will ensure detection of abnormal wear rates as they develop.

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.

An oil's level of additives measured by spectroscopy is not necessarily an indication of the oil's quality.

Four types of lubricants are generally used in most industrial applications, and each contains different additive levels:

Extreme Pressure Oils

- *Typically used for gear applications*
- *Common for significant amounts of phosphorus to be present*

Anti-Wear Oils

- *Includes many bearing oils, hydraulic fluids, and some gear oils*
- *Contain both zinc and phosphorus from 200 to 600 ppm*
- *May be very low levels of detergent (magnesium or calcium) present*
- *Engine oils are a subset and typically contain antiwear additives composed of zinc and phosphorus*
- *Detergent package should also be present, composed of some configuration of barium, manesium and calcium - levels will vary depending on oil*

Rust & Oxidation Inhibiting Oils

- *Easiest to identify due to the undetectable additives present*
- *Include turbine oils, compressor oils, and some bearing and hydraulic oils*
- *Have no additives that can be measured by spectroscopy*
- *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 lubricants that do not fit into these descriptions. An example would be lubricants formulated for some stationary and electro-motive diesel engines. In many cases, operative conditions or emission concerns call for a less traditional additive package.

As with any type of testing, spectroscopy is subject to inherent variance. All tests discussed are subject to the need for a representative and uncontaminated sample, as well as a calibrated test instrument. 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.

SECTION 3

VISCOSITY

A lubricant’s viscosity is considered its most important property. The most common technique for measuring a lubricant’s viscosity is following *ASTM D445* using a viscometer. A predetermined volume of lubricant is introduced into the viscometer tube. Gravity causes the sample to flow through the tube. The amount of time the sample takes to flow through the calibrated portion of the tube is recorded. The time is multiplied by the tube's calibration factor to give a result in centistokes (cSt). ASTM method - D445.

Industrial lubricants are identified by their “International Organization for Standardization” viscosity grade (ISO VG). The ISO VG refers to the lubricant’s kinematic viscosity at 40˚C.

Multi-grade lubricants commonly use kinematic viscosity at 100 ˚C. The weight of multi-grade lubricants is represented by the second number in the rating. A 10W30 would be a 30-weight lubricant. As the “W” stands for “Winter,” the 10W refers to how the lubricant performs in cold weather conditions as well as the base oil viscosity, as it only behaves like 30W at higher temperatures.

<u>Increase in Lubricant's Viscosity</u>

- *due to oxidation or degradation resulting from extended oil drain intervals, high operating temperatures, or the presence of water or another oxidation catalyst*
- *result of excessive contamaination with solids such as soot or dirt, as well as topping off with a higher grade lube*

<u>Decrease in Lubricant's Viscosity</u>

- *due to contamination with fuel or a solvent*
- *can be due to wrong oil being used for topping off or replenishment*

A lubricant with the improper viscosity will lead to overheating, accelerated wear, and ultimately the failure of the component.

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 lubricant 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 component.

SECTION 4

ACID NUMBER

Acid number is an indicator of lubricant serviceability. It is useful in monitoring acid buildup in lubricants due to depletion of antioxidants. Lubricant oxidation causes acidic by-products to form.

High acid levels can indicate excessive lubricant oxidation or depletion of the lubricant additives and can lead to corrosion of the internal components.

By monitoring the acid level, the lubricant can be changed before any damage occurs.

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

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

The acid number of a new lubricant will vary based on the base lubricant additive package.

Oil type	Typical AN
R&O Oil	• Usually a very low AN • Roughly 0.03
AW or EP Oil	• Slightly higher value AN • Roughly 0.5
Engine Oil	• Commonly higher AN • Roughly 2-3

SECTION 5

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 lubricant's alkaline reserve. *ASTM D2896* and *ASTM D4739* are most commonly used to measure the base number.

Almost no lubricants (except motor oils) are formulated with a base number additive to neutralize acids that are formed due to lubricant oxidation. 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 the lubricant is able to protect the component from corrosion due to acid.

The base number of a lubricant is highest when the lubricant 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 25% of its original value. Base number values for new engine oils range from 4 to 30, depending on the application.

SECTION 6

WATER CONTAMINATION

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

If a crackle test is positive, further testing is needed in the form of the Karl Fischer titration by *ASTM D6304*. A sample of lubricant is introduced into a titration chamber in known volume. This solution is titrated with Karl Fischer reagent to a specific electrometric endpoint. The amount of reagent used, and sample volume are calculated and converted to ppm or percent by volume.

Minor Increase in Water

Typically result of condensation

Major Increase in Water

Indicates a source of water ingress via; seals, breathers, hatches and fill caps as well as possible internal leaks from heat exchangers and water jackets

When free water is present in a lubricant, 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 a lubricant will promote lubricant oxidation and reduce the load handling ability of the lubricant. Water in any form will cause accelerated wear, increased friction, and high operating temperatures. If left unchecked, water will lead to premature component failure. In most systems, water should not exceed 500 ppm.

SECTION 7

PARTICLE COUNT

Particle contamination has negative effects on all types of equipment. Particle counting is a way to monitor the level of solid contamination in a lubricant. Two types of automatic particle counters are used to test a lubricant's cleanliness: Optical Particle Counting and Pore Blockage.

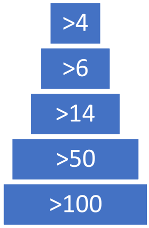
Optical Particle Counting

- This 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.
- Invovles careful sample and instrument preparation.
- Counting is not effective when a lubricant is very dark in color, contaminated with water or when air is entrained in the lubricant. In these circumsances, water or air bubbles will be counted as particles causing erroneous results.

Pore Blockage (Flow Decay)

- This technique passes the sample through a mesh filter. As the filter clogs, the flow of the sample is digitally recorded. The amount of flow decay is calculated, and the particle count can then be extrapolated.
- Since dark colored lubricants can be counted and water droplets & entrained air will not restrict the fluid flow, there is no interference.

High particle counts indicate a dirty lubricant. Results are reported as particles per milliliter in five size ranges:



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 Codes, the cleaner the fluid.

Particulate contamination is an indication 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 contamination and silt, while the larger size ranges point to wear problems.

SECTION 8

FERROUS WEAR CONCENTRATION

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

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 the amount of ferrous material is determined by change in magnetic flux. This change is then converted into ferrous concentration in parts per million. There are no interferences with non-ferrous particles using this method.

Advantages of a Ferrous Debris Monitor

- It will measure ferrous wear debris in all types of oil, from gearbox lubricants through hydraulics.
- It will also measure ferrous wear debris found in grease.

SECTION 9

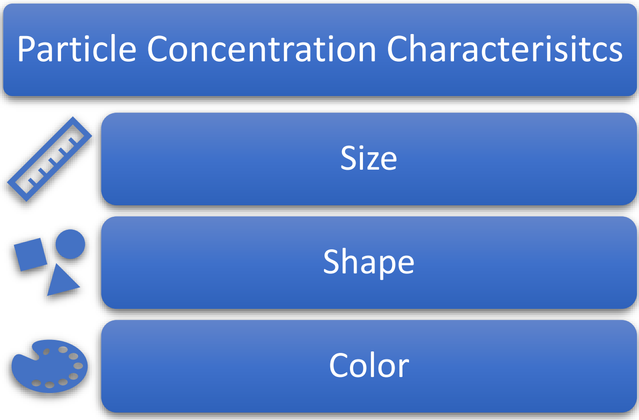
ANALYTICAL FERROGRAPHY

Analytical Ferrography is used to separate solid contamination and wear debris from a lubricant for microscopic evaluation. As stated earlier, spectroscopy testing has its limitation. While particle counting can detect the presence of larger particles, it cannot qualify their composition or origin. Analytical Ferrography can 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 lubricant sample is allowed to flow over a specially treated slide which is positioned at a given angle over a set of strong magnets. The ferrous (iron) particles are attracted to the magnet and are deposited onto the slide, in decreasing size, as the lubricant flows down the substrate. Nonferrous particles are deposited randomly while ferrous particles line up in chains due to 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. Testing the concentration size, shape, composition, and condition of the particles indicates where and how they were generated.



Particles are categorized based on these characteristics. Conclusions can then be drawn regarding the wear rate and health of the component that the sample was drawn from.

The composition of the particles can be identified by color by heat treating the slide. This 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.

Wear modes generate a characteristic particle type in terms of its shape and surface condition.

Wear Modes

- Rubbing Wear
- Rolling Contact
- Sliding Wear
- Rolling/Sliding Wear
- Cutting Wear

Solid contaminants can also be visually identified, provided they are of a commonly found origin.

Visual Contamination Debris

- Chunks
- Spheres
- Corrosion
- Dark Metallic Oxides
- Red Oxides
- Dust/Dirt
- Oxidation By-Products
- Other

SECTION 10

NOW WHAT?

While the results of these results 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.

Your Next Resource

The Right Path

- *Proper Sampling Guide*

Get The Picture

- *Report Interpretation Guide*

Sampling Best Practices

- *Webinar On Demand*

Extending Lubricant Life in Your Equipment Using Lubricant Analysis

- *Webinar On Demand*

TESTOIL
REMARKABLE IN EVERY WAY

www.TestOil.com