The Practical Guide to
Oil Analysis

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Preface

In writing the 4th edition of "The Practical Guide To Oil Analysis", it occurs to me that Insight Services has increased it's testing capacity significantly over the last couple of years. From our industry leading Filter Debris Analysis to our annual turbine testing, we can provide any number of testing solutions for your specific needs. The growth from our original roots has been exciting and I look forward to more innovations in the future.

We remain true to our initial goal with the book - helping you understand oil analysis. We have helped many companies develop and implement successful oil analysis programs. Our unrelenting drive to provide same day turnaround on all samples every time is the essence of the Insight Services' culture.

Michael Barrett

INSIGHT SERVICES

Overview

The practice of oil analysis has drastically changed 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 your reliability-centered maintenance program.

As a predictive maintenance 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 extensive, sometimes catastrophic damage causing lost production, extensive repair costs, and even operator accidents.

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

Why Analyze Used Lubricants

Three Aspects of Oil Analysis
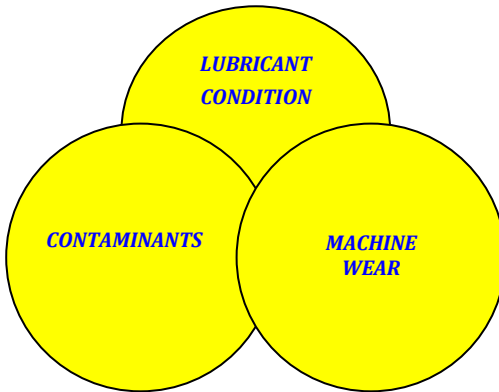
Lubricant Condition. The assessment of the lubricant condition reveals whether the system fluid is healthy and fit for further service, or is ready for a change.

Contaminants. Ingressed 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 alerts you 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. Remember, healthy and clean oil lead to the minimization of machine wear.

What Are Lubricants?

Industrial oils are specially designed fluids composed of a base oil and a compliment of additives.

The **Base Oil** performs the following functions:

- Form a fluid film between moving parts in order to reduce friction and wear.

- Carry away contaminants to the filter.

- Remove heat generated within the machine.

Additives are chemical compounds added to the base oil to significantly enhance the performance characteristics of the lubricating oil. Typical enhanced properties include:

- Oxidation Stability.

- Wear Protection.

- Corrosion Inhibition.

Functions of a Lubricant?

From cooling to cleaning to lubricating, the absolute key to keeping your equipment running.

LUBRICATE
By introducing a film between moving parts, opposing friction surfaces are separated and allowed to move freely without any interlocking of the asperities at the metal surface. By physically separating the moving parts, friction is greatly reduced. The result is less wear generated and less energy required to perform the work.

COOL
Lubricants absorb the heat generated at the friction surface and carry it away to a reservoir where it is allowed to cool before returning for service. Oil coolers and heat exchangers are sometimes used to more efficiently disperse heat. Lubricants are an excellent dissipator of heat.

CLEAN
Oil picks up solid contaminants and moves them away from the contact zone. The contaminants can then be removed by filtration or settling in the reservoir. Many oils have detergent characteristics to hold tiny dirt and soot particles in suspension at help prevent sludge and varnish in a system.

PROTECT
Lubricants coat component surfaces providing a barrier against moisture. The presence of moisture in the air causes oxidation,

eventually leading to corrosion. Rust occurs when steel surfaces are attacked by moisture. Corrosion occurs when a metal surface is attacked by acids, a byproduct of oxidation. Oils can be fortified with alkaline reserves to counter the corrosive contaminants.

SEAL

Many lubricants form a viscous seal to keep contaminants out of a component. Greases form physical barriers to protect against dirt and water ingress.

TRANSMIT POWER

Hydraulic systems use lubricants to protect sliding, contacting surfaces and as a source of fluid power. Fluid under pressure actuates moving parts.

How Do Lube Oils Fail?

Contamination , degradation , or the loss of specific properties provided by additives.

CONTAMINATION

- External Sources: Dirt, water, and process related liquids or materials.

- Internal Sources: Machine wear and degradation by-products

OIL DEGRADATION

- Oxidation: What is it? Atmospheric oxygen combines with hydrocarbon molecules. The hotter the oil and the greater exposure to air, the faster oxidation proceeds. The initial by-products of oxidation are sludges and varnishes. However, further oxidation converts these by-products into carboxylic acids. These acids aggressively attack and corrode many machine component surfaces.

ADDITIVE DEPLETION

- Additives are consumed or chemically changed while performing their function. The performance characteristics of the lubricant are altered and the enhanced properties are wiped out.

What Does Oil Analysis Measure?

Physical and chemical properties of the oil, contamination, and mechanical wear.

LUBRICATING OIL PROPERTIES. Uncover contamination or degradation by trending rates of change in selected lube properties.

- Fourier Transform Infrared (FT-IR)
    Degradation by-products (oxidation, nitration, sulfate).
    External contaminants (water, glycol, fuel, soot).

- Viscosity
    Physical property.
- Karl Fischer Water
    Contamination.
- Acid Number (AN)
    Degradation.
- Particle Counting
    Both contamination and wear debris.

MECHANICAL WEAR. Uncover machine related problems.

- ICP Spectroscopy
    Wear metals, contaminant metals, additive metals.
- Ferrous Wear Concentration
    Ferrous wear particles.
- Analytical Ferrography
    Type and severity of wear particles.

Wear Mechanisms

TYPE	CAUSE
Abrasive Wear	Hard particles between or embedded in adjacent moving surfaces.
Adhesive Wear	Metal to metal contact due to overheating or insufficient lubrication.
Fatigue Wear	Repeated stress on friction surface leading to microcracks and spalling.

| **Corrosive Wear** | Water or chemical contamination. |

| **Erosive Wear** | Particles and high fluid velocity. |

Viscosity

Measure of lubricant's resistance to flow at a specific temperature.

Operating Principle. Measured using a viscometer. The sample is introduced into a "U" shaped calibrated glass tube, submerged in a constant temperature bath. The oil is warmed to a desired temperature of 40°C or 100°C and allowed to flow via gravity down the tube and up the other side. The number of seconds the oil takes to flow through the calibrated region is measured. The viscosity in centistokes (cSt) is the flow time (seconds) multiplied by the tube constant.

Significance. Viscosity is measured at 40°C for industrial applications and 100°C for engine oil applications. Viscosity for industrial lubricants is classified using the ISOVG (International Standard Organization Viscosity Grade) system which is the average viscosity (cSt) at 40°C. Viscosity for engine oils is classified according to SAE (Society of Automotive Engineers). Viscosity is the most important physical property of oil. Viscosity determination provides a specific number to compare

to the recommended oil in service. An abnormal viscosity ($\pm$ 10%) is usually indicative of a problem.

VISCOSITY (centistokes) ASTM D 445					
Date	Reference	1/11/07	12/7/06	11/2/06	10/19/06
Lab Number	107391	168113	168112	168111	168110
40 cSt	219.3	221	220.9	221.3	220.7

⇑ An increase in viscosity may indicate:

- Increasing suspended solid material such as wear particles, contamination, or soot.
- Additions of a higher viscosity oil.
- Lubricant oxidation.

⇓ A decrease in viscosity may indicate:

- Contamination from water, fuels, or process fluid.
- Additions of a lower viscosity oil.
- Additive shear.
-

Advantages. Quickly detects the addition of a wrong oil. Quick and inexpensive to run. Best measurement of oil serviceability.

Application.   All industrial lubricants.

ICP Spectroscopy

Measures the concentration of wear metals, contaminant metals and additive metals in a lubricant.

Operating Principle. A diluted oil sample is atomized by inert gas (argon) to form an aerosol. This is magnetically induced to form a plasma at a 9000° C. The high temperature causes metal ions to take on energy and release new energy in the form of photons. A spectrum with different wavelengths is created for each element. The instrument quantifies the amount of energy emitted and determines the concentration in parts per million (ppm) of 20 elements present in the sample.

Significance. The Inductively Coupled Plasma (ICP) Spectrometer measures and quantifies the elements associated with wear, contamination, and additives. This information assists decision makers in determining the oil and machine condition. The following list outlines the specific elements detected and possible sources of the element.

Advantages. Very repeatable, proven technology.

Disadvantages. Can not detect particles greater than 7 microns in size. Level of additive elements not necessarily indicative of additive package depletion.

Application. All industrial lubricants.

SPECTROSCOPIC ANALYSIS (ppm) ASTM D 5185				
Date	Reference	1/11/07	12/7/06	11/2/06
Lab Number	107391	168113	168112	168111
Iron	0	277	142	55
Copper	0	10	6.1	4.3
Lead	0	4.7	0	0
Aluminum	0	0	0	0
Chromium	0	3	0	0
Nickel	0	0	0	0
Silicon	2	105	55	25
Boron	0	3.4	1.6	1.2
Phosphorous	47	56	57	48
Zinc	87	55	35	21

Elements

Elements		Possible Source
Iron	**(Fe)**	Shafts, Gears, Housings, Piston Rings, Cylinder Walls
Copper	**(Cu)**	Brass/Bronze Alloys, Bearings, Bushings, Thrust Washers
Lead	**(Pb)**	Bearings, Anti-Wear Gear
Tin	**(Sn)**	Bearing Alloys, Bearing Cages, Solder
Aluminum	**(Al)**	Pumps, Thrust Washers, Pistons
Chromium	**(Cr)**	Roller Bearings, Piston Rings, Cylinder Walls
Nickel	**(Ni)**	Pumps, Gear Platings, Valves
Titanium	**(Ti)**	Exotic Alloy
Silver	**(Ag)**	Some Bearings
Magnesium	**(Mg)**	Detergent Additive, Coolant Additive
Silicon	**(Si)**	Dirt, Defoamant Additive
Boron	**(B)**	Anti-corrosion in Coolants
Sodium	**(Na)**	Detergent Additive, Coolant Additive
Barium	**(Ba)**	Rust and Corrosion Inhibitors
Calcium	**(Ca)**	Detergent/Dispersant Additive
Phosphorus	**(P)**	Anti-wear Additive, EP Gear Additive
Potassium	**(K)**	Coolant Additive
Molybdenum	**(Mo)**	EP Additive
Zinc	**(Zn)**	Anti-wear Additive
Vanadium	**(V)**	Turbine Blades

Crackle Test

Quick screen to determine if a sample contains moisture.

Operating Principle. A drop of oil is placed on a hotplate that has been heated to approximately 600° F. The sample drop bubbles, spits, crackles or pops when moisture is present. When moisture is detected, a Karl Fischer water test is performed.

Significance. A crackle test is a good screening test to use to determine if a sample contains moisture.

Advantages. This is a very low cost test. It is a good way to determine the need for further moisture analysis.

Disadvantages. The crackle test can only detect moisture greater than .05% (500ppm).   A sample with entrained gas often results in false positive results.

Applications. All lubricants that are non-water based.

Karl Fischer Water

Quantifies the amount of water in the lubricant.

Operating principle. A reagent is titrated into a measured amount of sample and reacts with the OH molecules present in the moisture. This depolarizes an electrode and determines the

titration endpoint. Results are reported as either **% water** or **ppm** (1% =10,000ppm).

Significance. Water seriously damages the lubricating properties of oil and promotes component corrosion. Increased water concentrations indicate possible condensation, coolant leaks, or process leaks around the seals.

KARL FISCHER WATER (%)					
Date	Reference	1/11/07	12/7/06	11/2/06	10/19/06
Lab Number	107391	168113	168112	168111	168110
% Water	.001	.92	.81	2.604	.024

Advantages. Accurate to .001%. Quantifies both emulsified and free water.

Disadvantages. Sulfur , acetones and ketones can sometimes trigger erroneous readings.

Applications. All lubricants, especially effective in systems sensitive to water.

Forms of water in oil:
- Free water (emulsified or in droplets).
- Dissolved water.

Water contamination causes:
- Fluid breakdown, such as additive precipitation and oil oxidation.
- Reduced lubricating film thickness.
- Corrosion.
- Accelerated metal surface fatigue.

Sources of water contamination:
- Heat exchanger leaks.
- Seal leaks.
- Condensation of humid air.
- Inadequately sealed reservoir covers.

Demulsibility

Measures the ability of a lubricant to separate from water.

Operating Principle. Combine 40 ml of distilled water with 40 ml of oil in a graduated cylinder. Place in a constant temperature bath and stir for 5 minutes. The amount of oil separation is recorded at 5 minute intervals over a period of 60 minutes. Failure is considered an emulsion layer greater than 3ml at the end of the test
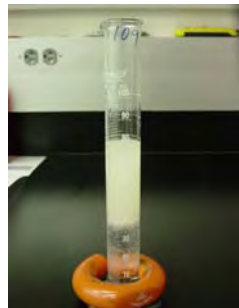
The results are reported as such: [40-40-0 (60)]

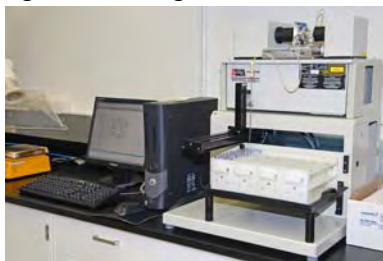| ml oil	ml water	ml emulsions	Minutes
40	40	0	60

After 60 minutes this sample passed. It contained 40 ml of oil, 40 ml of water and 0 emulsion. This sample separates water and therefore, has good demulsibility.

Significance. Lubricating oils used in circulating systems should separate readily from water that may enter the system as a result of condensation or other means. If the water separates easily, it will settle to the bottom of the reservoir where it can be periodically drained.

FT-IR Spectroscopy

Measures the chemical composition of a lubricant.

Operating Principle. Every compound has a unique infrared signature. Using a Fourier Transform Infrared (FT-IR) Spectrometer, these key signature points of a specific lubricant in the spectrum are monitored. These signatures are usually common contaminants and degradation by –products unique for a particular lubricant.

Significance. Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on

molecular species of interest, including additives, fluid breakdown products and external contamination. Infrared spectrum of used oil is compared to baseline spectrum (baseline spectrum chosen from one of five groups depending on oil type). The differences in IR spectrum are quantified. Levels of oxidation, nitration and sulfate by-products are reported along with soot, water, and glycol.

Oil Degradation by chemical change:

- **Oxidation.** At elevated temperatures, oil exposed to oxygen from the air will oxidize to form a variety of compounds. The majority of these are carbonyl containing compounds e.g. carboxylic acid.
- **Nitration.** Results from the reaction of oil components with nitrogen oxides.
- **Sulphate.** Various oxides of sulfur and water react together to form acid.   Their acid is neutralized by basic reserve and normally results in formation of metallic sulfates
- **Soot.** Measure of the level of partially burned fuel in oil. Relevant for diesel engines.
- **Glycol.** Coolant leak

Advantages.   Provides information on the overall degradation of an oil. Assists in optimizing oil change outs.

Disadvantages.   Imprecise quantification of water and glycol levels.

Applications.   All industrial lubricants.

RPVOT

Rotating Pressure Vessel Oxidation Test

Significance. Measures the resistance of an oil to oxidation when subjected to accelerated oxidation in a sealed chamber filled with pure oxygen under pressure and at elevated temperatures. This is influenced by the quantity and type of antioxidants, the presence of natural inhibitors in the base oil, and the resilience of the base oil to oxidation. As a lubricant absorbs oxygen, pressure in the sealed chamber drops. The results of this test are reported as the time (minutes) until the pressure drops to a predetermined level.

Rust Test

Rust preventing characteristics of oil in the presence of water.

Operating Principle. A portion of the oil is placed in a beaker along with water and a polished steel rod. The beaker is then immersed in a heated bath and is stirred for 4 hours. At the end of the 4 hours, the steel rod is inspected for the presence of rust / corrosion.

Significance. Evaluates the ability of the lubricant to prevent the corrosion of ferrous parts should water become mixed with the oil.

Application. Turbines or any other machine where there is a concern of corrosion with the presence of water.

Foam Test

Measures the foaming tendency of a lubricant.

Operating Principle. Air is forced through a diffuser within a portion of oil creating foam. After 5 minutes of blowing, the amount of foam is recorded. Then, the sample is observed for the clearing of generated foam. Then either time of full dissipation is recorded or amount of foam remaining after 10 minutes.
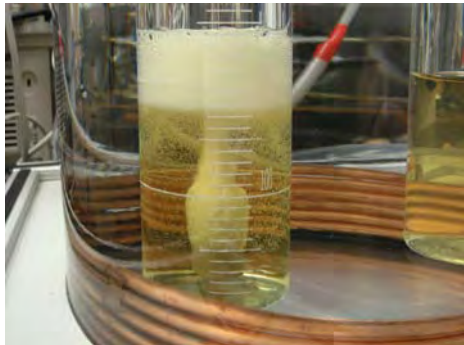
Significance. The tendency of lubricants to foam can cause serious issues in systems with high-speed operations. Not only can foam cause inadequate lubrication but also other problems such as overflowing reservoirs.

Base Number

Measures the reserve alkalinity in a lubricant.

Operating Principle. A weighed amount of sample in titration solvent is titrated with a hydrochloric acid solution to a definite end point.

Significance. 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 TBN is at its highest as a new oil and decreases with service.

BASE NUMBER (mg KOH / g)						
Date	Reference	1/11/07	12/7/06	11/2/06	10/19/06	
Lab Number	107391	168113	168112	168111	168110	
Base #	8.5	6.0	5.8	7.1	7.5	

Applications. Diesel engines.

Fuel Dilution

Measures amount of fuel (%) present in an engine oil.

Operating Principle. The instrument samples the headspace above a sample for fuel vapors. A pump inside of the test equipment draws the vapors across a sensor where absorbed hydrocarbons are measured in percent fuel present.

Significance. Fuel dilution in engine oils is measured by this process and returns a value in percent fuel dilution. Excessive fuel dilution can cause a drastic drop in viscosity which may lead to increased wear.

Application. Diesel and Gasoline Engines.

Acid Number

Measures the acidity of a lubricant.

Operating Principle. A weighed amount of sample in titration solvent is titrated with a potassium hydroxide solution to a definite end point.

Description.   Organic acids, a by-product of oil oxidation, degrade oil properties and lead to corrosion of the internal components. The AN is lowest as a virgin oil and can gradually increase with use. High acid levels are typically caused by oil oxidation.

ACID NUMBER (mg KOH / g)					
Date	Reference	1/11/07	12/7/06	11/2/06	10/19/06
Lab Number	107391	168113	168112	168111	168110
Acid #	1.6	1.95	1.98	1.67	1.7

Advantages. A sudden rise in acid number is an alarm for an oil change.

Applications. All lubricating systems where extended drain intervals are considered. Limited applications for combustion engines.

Particle Count

Measures the size and quantity of particles in a lubricant.

Operating Principle. Light Blockage Principle. A known volume of oil (5ml) is injected through a sampling cell. On one side of the cell is a beam of laser light and on the other side is a detector. As particles pass through the cell, they block the beam and cast shadows on the detector The drop in light intensity received by the detector is proportional to the size of particle blocking the light beam. Both the number and size of particles are measured.

Operating Principle. <u>Fluid Flow Decay Principle</u>. Oil is passed through a screen of known mesh size (10 micron) and the time taken to plug the screen is determined. The instrument then calculates the distribution in the other predetermined size ranges by extrapolation.

Significance. *Optical particle counters* use the light blockage method and are particularly effective in clean systems such as turbines and hydraulics. However, this method yields inaccurate results in the presence of water or air bubbles. *Pore blockage particle counters* are based on the fluid flow decay principle. Their data is not effected by air bubbles or water.

PARTICLE COUNT (per ml) ISO 4406:99					
Date	Reference	1/11/07	12/7/06	11/2/06	10/19/06
Lab Number	107391	168113	168112	168111	168110
ISO CODE	15/14/11	21/19/17	19/17/15	18/17/13	17/16/13
> 4	311	10156	2518	1456	899
> 6	114	2695	789	654	401
> 14	12	1256	198	78	52
> 50	0	25	5	2	1
> 100	0	12	2	0	0

Advantages. Excellent for "clean" systems (turbines, hydraulics etc.). Limits provided by equipment manufactures determine filter efficiency.

Disadvantages. Abnormal wear can be masked on systems with routinely high levels of particulate matter. Does not determine what TYPE of debris is in sample.

Application. Use whenever equipment manufacturer provides recommended lubricant cleanliness levels. Turbines, Boiler Feed Pumps, EHC Systems, Hydraulics, Servo Valves. Any system where oil cleanliness is directly related to longer lubricant life, decreased equipment wear or improved equipment performance.

Sources of Contamination

Built in contaminants. This is residual contamination remaining in a system during construction or assembly.

External ingression. This is contamination which enters the systems from outside. Possible sources include: during an oil fill, leaving breathers off, leaving covers off the reservoir, or faulty seals.

Internally generated. This is wear debris normally caused by the two sources above. If you can control built- in and ingressed contamination, wear debris will be generated at significantly lower levels.

Target Cleanliness

Pressure Range

Component	>2500	1500-2500	<1500
Servo Valve	14/12/10	15/13/11	16/14/12
Proportional Valve	15/13/11	16/14/12	17/15/12
Fixed Piston Pump	17/15/12	17/16/13	18/16/14
Vane Pump	17/16/13	18/16/14	19/17/14
Pressure Control Valve	17/16/13	18/16/14	19/17/14
Gear Pump	17/16/13	18/16/14	19/17/14
Roller Bearing System			16/14/12
Journal Bearings			18/16/14

Insight Cleanliness Code

The Insight cleanliness code references a three-digit code that represents the cumulative number of particles greater than 4, 6 and 14 microns in the fluid. The number of particles at each size range is cross-referenced to the following table to locate the ISO contamination code. The code is written as three numbers with a slash, " / " , between them. For example: 21/19/15. The first number represents the code number at 4 micron, the second number the code number at 6 micron, and the third number the code number at 14 micron.

Making Sense Out of ISO Particle Counts

INSIGHT SERVICES

MAKING SENSE OUT OF ISO PARTICLE COUNTS

ISO 4406:99
$R_4/R_6/R_{14}$

INSIGHT Particle Count

Size (micron)	Particles
>4	3471
>6	1198
>14	107
>25	8
>50	2
>100	0

There are 3471 particles greater than 4 micron. Where does it fit?

There are 1198 particles greater than 6 micron. Where does it fit?

There are 107 particles greater than 14 micron. Where does it fit?

= ISO 19/17/14

Number of Particles per ml		
More than	Up to	Range Number (R)
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5,000	10,000	20
2,500	5,000	19
1,300	2,500	18
640	1,300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8
0.64	1.3	7
0.32	0.64	6
0.16	0.32	5
0.08	0.16	4
0.04	0.08	3
0.02	0.04	2
0.01	0.01	1

WHAT DOES IT MEAN???

Using ISO 4406:99, a sample is assigned a cleanliness rating using the chart on the right. To arrive at the rating Insight performs a particle count to determine the number of particles greater than three size ranges (4,6,and 14 microns) in one milliliter of sample. The chart on the left depicts the actual particles of one of our particle count tests. This particle distribution translates to an ISO 4406:99 rating of 19/17/14.

Ferrous Wear Concentration

Measures the amount of ferrous wear in a lubricant.

Operating Principle.   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 change in magnetic

flux. This change is then converted into ferrous concentration in parts per million. Instead of using a light sensor to measure particles and report a unitless number, this instrument measures concentration and reports the results in parts per million. Using this method, there are no interferences with non-ferrous particles.

Significance.   This test gives a direct measure of the amount of ferrous wear metals present in a sample. Trending of ferrous concentration reveals changes in the wear mode of the system.

Advantages. Excellent trending device for "dirty" systems such as large splash lubricated gearboxes. No particle size limitation.

Disadvantages. Does not detect non-ferrous particles.

Application. Gearboxes, Anti-Friction bearings.

Analytical Ferrography

Allows analyst to visually examine wear particles present in a sample.

Operating Principle. To create a ferrogram, a sample of oil is passed over a glass slide. The slide rests on a magnetic plate that attracts ferrous wear particles in the oil onto the surface of the slide. The ferrous wear particles line up in rows with the largest particles forming rows at the top of the ferrogram. Non-ferrous particles are easily detected because they deposit randomly across the slide.

Significance. A trained analyst visually determines the type and severity of wear deposited onto the substrate by using a high magnification microscope. The particles are readily identified and classified according to size, shape, and metallurgy.

Advantages. Best method for determining severity and type of wear present. There are no particle size or metallurgy limitations. Wear can be documented by digital photography.

Disadvantages. Subjective results dependent upon the Analyst. The test is time consuming, labor intensive, and, therefore, expensive.

Application. Best used when other test methods indicate possible problems.

Classifying Wear

Rubbing Wear

Description. Ferrous particles, less than 30 microns in size. Some Sources: Rubbing wear is typically found in both reciprocating and non-reciprocating units.
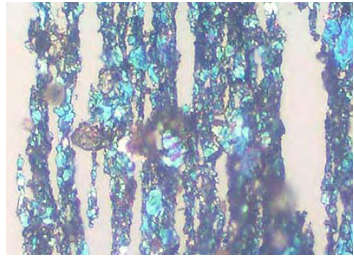
Comments. On a ferrogram the particles tend to align in chains. Normal ferrous wear can be categorized as low alloy, cast iron and high alloy steel.

Severe Wear

Description. Metallic particles greater than 30 microns. Fatigue or component overload that cause larger pieces of wear to detach creates severe wear.
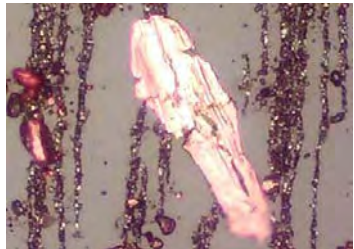
Comments. Severe wear is a definite sign of abnormal running conditions.

Sliding Wear

Description. Metallic particles, both normal and severe, with sliding striations along one or more surfaces. Sliding wear can be created when two parts of a machine scrape together.
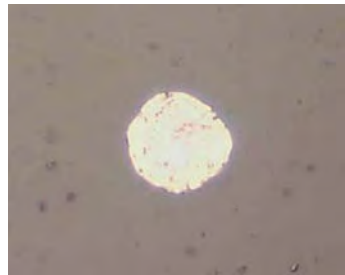
Comments. Sliding striations are often a good clue as to what part of a machine is causing wear.
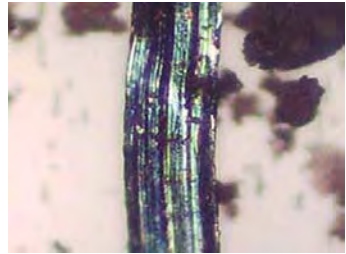
Laminar

Description. Thin, smooth particles which appear to have been rolled flat. Roller bearings, areas where high-pressure angled or lateral contact occurs.

Comments. Wear created by extraneous particle if the laminar has small holes or indents.

Cutting Wear

Description. Shaved metal particles that look like wood shavings from a lathe. Seen in sleeve bearings and shaft couples. Abrasives embedded in soft bearing or burrs on hardened metals create these wear particles.
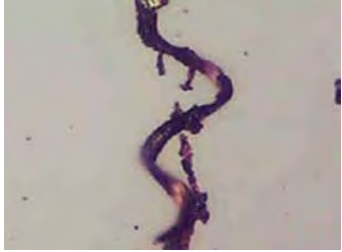

Comments. Worm drives have a tendency to create this type of particle. When seen it indicates abnormal wear.

Dark Metal Oxide Wear

Description. Grey to black chunks with a semi-metallic appearance and mottled edges. Some Sources: Breakdown of boundary film, excessive operating temperatures, lubricant oxidation.

Comments. The darker the color, the more severe the oxidation of the particle.
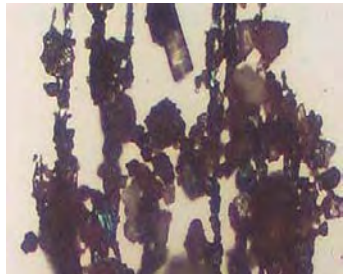
Sphere

Description. A relatively smooth spherical particle. Spheres are created in bearing fatigue cracks, typically roller bearings.


Comments. Spheres are often precursors of bearing spalls. A large increase in quantity is indicative of imminent spalling.

Non-Ferrous Metal Wear

Description. Any metallic particle that is not ferrous. Most common include aluminum, copper alloy, chrome, and babbitt. Non-ferrous wear can be created by the machines or as additive packages in the lubricant.
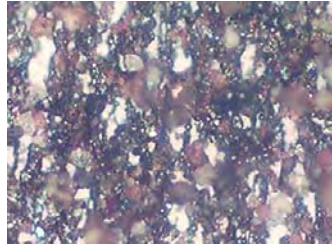

Comments. Non-ferrous metallic wear can be across the entire length of a ferrogram. These particles will not be aligned with the ferrous wear chains.
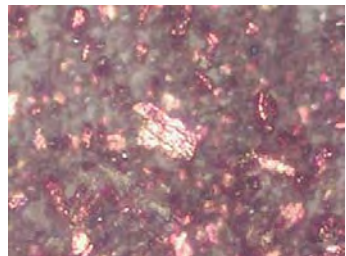
Contaminants

Description. Dirt, sand and other silica particulate. Contaminants can enter into a system by a variety of ways: poor seals, incorrectly installed breather, during oil change, etc.


Comments. Some can appear like crystals. Contaminants are easily identified by using only the transmitted light source on the microscope.

Fiber

Description. Fibers are thread like material made of asbestos, paper, glass or a synthetic material. Most common source is filter material. Could be from machine housing, cleaning rages, or air contaminants.
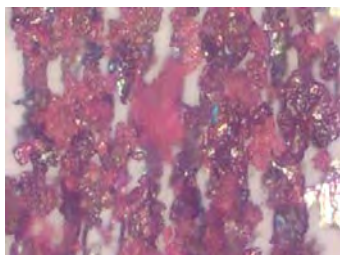
Comments. A small amount of fibrous material in oil is common.
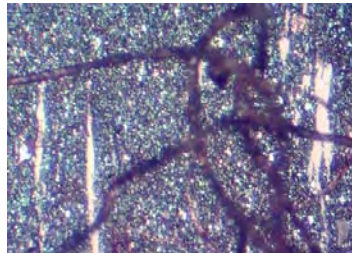
Red Oxide

Description. Iron oxides or rust. It appears as orange/red in color. Red oxides are produced when moisture enters into a system. Water does not have to be present when red oxides are seen, as they are often difficult to filter out of oil.

Comments. Red oxides are not necessarily magnetic like ferrous wear. Alpha hematite is paramagnetic and will be found on all regions of a ferrogram.

Varnishing Potential

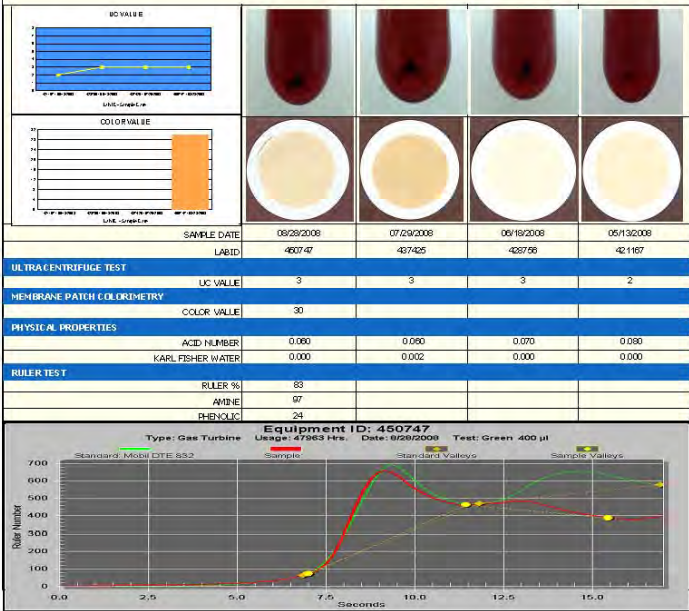### Detect the onset of varnishing problems in turbines and hydraulics.

Varnish is formed when degradation by-products come out of solution and form soft contaminants, which can agglomerate and form varnish deposits. Varnish is detrimental to the performance of rotating equipment, particularly gas turbines. Several condition monitoring tests have been developed which can be used to gauge the varnishing potential of a lubricant.

EXAMPLE VARNISHING POTENTIAL ANALYSIS REPORT

Ultra Centrifuge

Operating Principle. As an oil sample is spun at 17,000 rpm in the ultra centrifuge the soft contaminant oxidation by-products which have a higher molecular weight than the oil will be forced to the bottom of the centrifuge tube.

Significance. The amount of deposited contaminants can be visually compared to a scale to quantify the level of contaminants present in the oil.

Membrane Patch Colorimetry (MPC)

Operating Principle. Insoluble deposits are extracted from the sample using a membrane patch. The color of the patch is analyzed using a spectrophotometer. Results are reported as a deltaE value in the CIE LAB scale.

Significance. The delta E value can be trended and used to monitor oil condition with regard to varnish potential.

RULER

Operating Principle. Antioxidants are removed from the oil by
mixing sample with a solvent.
The dissolved antioxidants are
then measured using linear
sweep voltammetry.

Significance. By comparing
the levels of antioxidants in
the used oil sample to the
levels present in a virgin
reference sample of the same
lubricant the remaining useful life of the used oil can be
estimated.
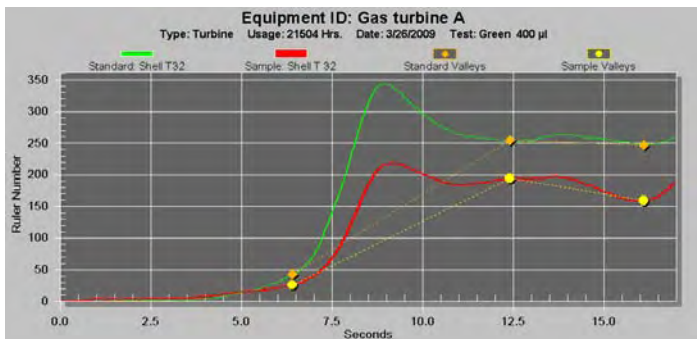
Filter Debris Analysis

Operating Principle. The FDA instrument is a self-contained unit which employs an automated method for filter washing to extract all debris from the filter with high repeatability and reproducibility. A used filter is placed in the system wash chamber and all debris is removed from the filter using a combination of fluid and pressurized air. The wash fluid carrying the filter debris passes through an on line sensor which quantifies and sizes the amount of ferrous debris. The fluid then runs through a filter patch where the sample of debris is captured for further metallurgical analysis by X-Ray Flourescence (XRF). XRF analysis provides the percentage elemental composition of the sample which can be correlated to the wear debris of interest.
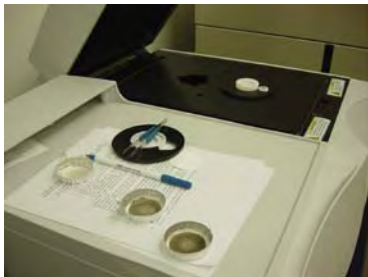
Significance. In traditional oil analysis, the only particles available for analysis are those circulating in the oil or immediately released in the oil prior to sampling. Given the fine filtration used in rotating equipment today to produce longer life cycles, 95% of the wear debris which could provide useful insight into machinery condition is caught in the filter and never end up in an oil sample. It typically is discarded with the filter. Increasingly, fine filtration is making conventional monitoring techniques less effective at providing reliable indication of machinery component wear. FDA captures this lost information and identifies the specific components that are wearing,

providing improved diagnostic and prognostic information about impending failures.

INSIGHT SERVICES
Tel: 261-251-2510, Fax: 216-251-2515

FILTER DEBRIS ANALYSIS

GASTOPS

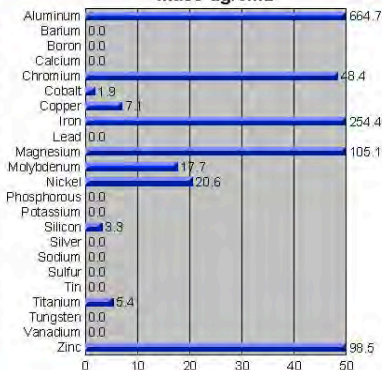| Lube Type: | MOBIL JET OIL II | Received: | | ATTN: Jack Boilerman |
Machine MFG:	OEM	Report:	14-Feb-08 4:46:17PM	GREAT LAKES GENERATION
Machine MOD:	Aero Deriv GT	Sample No:	19 - 1 - 1000 - 1	1643 Fastcatte Rd
Machine Type:	Aero/Aircraft Turbine	Analyst:		McMacken, IN 60543
Filter MFG:	OEM Unknown	Filter Loc:	Lower Filter	
Filtration:	10 mic	Row:	Canister	
Installed:		Removed:	02/05/2008	Hours:

Observations / Recommendations:
The current analysis detected an abnormal wear progression. Please inspect and repair immediately.   Several elements are significantly over their recommended limits. In addition, the non ferrous counts on the Metalscan exceed their limits. The primary elements detected are aluminum and iron. It is likely that the wear debris may be due to failure causing damage to the aluminum housing.

EDXRF Elements

	Limit	Rate	%	Mass
Aluminum	58.8	0.4	54.2	664.7
Barium	0.0	0.0	0.0	0.0
Boron	0.0	0.0	0.0	0.0
Calcium	0.0	0.0	0.0	0.0
Chromium	28.5	5.1	3.9	48.4
Cobalt	4.0	0.1	0.2	1.9
Copper	14.7	0.8	0.6	7.1
Iron	647.3	26.8	20.7	254.4
Lead	0.0	0.0	0.0	0.0
Magnesium	17.7	11.1	8.6	105.1
Molybdenum	76.6	1.8	1.4	17.7
Nickel	52.9	2.2	1.7	20.6
Phosphorous	0.0	0.0	0.0	0.0
Potassium	0.0	0.0	0.0	0.0
Silicon	19.8	0.3	0.3	3.3
Silver	30.4	0.0	0.0	0.0
Sodium	0.0	0.0	0.0	0.0
Sulfur	0.0	0.0	0.0	0.0
Tin	0.0	0.5	0.0	0.0
Titanium	44.5	1.4	0.4	5.4
Tungsten	6.4	0.0	0.0	0.0
Vanadium	4.3	0.0	0.0	0.0
Zinc	11.5	10.3	8.0	98.5

Mass ug/cm2

Aluminum 664.7
Barium 0.0
Boron 0.0
Calcium 0.0
Chromium 48.4
Cobalt 1.9
Copper 7.1
Iron 254.4
Lead 0.0
Magnesium 105.1
Molybdenum 17.7
Nickel 20.6
Phosphorous 0.0
Potassium 0.0
Silicon 3.3
Silver 0.0
Sodium 0.0
Sulfur 0.0
Tin 0.0
Titanium 5.4
Tungsten 0.0
Vanadium 0.0
Zinc 98.5

0   10   20   30   40   50

MetalSCAN Debris

Micropatch

	Size Range	100-199 um SML	200-499 um MED	>500 um LRG	Total
Ferrous Count		212	25	0	237
Ferrous Count Limit		270	135	21	405
	Size Range	400 - 549 um SML	550-849 um MED	>850 um LRG	
Non-Ferrous Count		12	8	1	21
Non-Ferrous Count Limit		9	4	0	13
Ferrous Mass (mg)					12.30
Ferrous Mass Limit (mg)					20.00

Thickness   1241.00 ug/cm2

GREAT LAKES GENERATION assumes sole responsibility for the application of and reliance upon results and recommendations reported by Insight Services, whose obligation is limited to good faith performance.

Page 1 of 1   Insight Services - 20338 Progress Drive - Cleveland, OH 44149   Lab No.399023

Alarm Levels

The alarm level is the difference in world class programs .

In assessing machine condition, it is essential not only to look at the machine's current and past data, but also compare that particular machine with the "family" that the machine is a member. Families can be made up of machine types, manufacturers, models and sump capacities depending on the level of information provided by the user. Statistics are calculated by looking into the database and extracting previous test results of "family" data. *Family alarming* produces tight limits which provide great value to the oil analysis user.

Another alarming method is to use *customer specific limits*. When a customer has previous knowledge of machine fault levels it is beneficial to provide these hard limits to the lab. They can be utilized at either the machine or customer level to trigger appropriate alarms.

If there is not enough information identifying a machine but there is historical information for the specific sampling point, alarms can be set by using linear regression.

Sampling Procedures

Goal: Obtain a sample in a manner that is easily repeatable and which effectively represents the actual condition of the oil in the machine. Good sampling ensures consistency and reliability of data and instills confidence in the decisions made with your reports.

When to Sample

While equipment is at full operating temperatures

During operation if possible

Directly after shut down

Where to Sample

Should be good representation of oil in system

Location/Method must be consistent

Never on a "dead leg"

Safely and readily accessible while equipment is running

Should lend itself to a "clean sample"

Sampling Methods

<u>Non-Pressurized Valves</u>. Install valves upstream of any filter in order to capture wear particles generated by the machine. Make sure the valve is clean and adequately flushed.

<u>Pressurized Valves</u>

Use a vacuum pump with appropriate tubing. Make sure to use new tubing for each sample in order to avoid cross contamination. Cut the tubing to the same length each time you sample. Try to avoid scraping the tubing along the sides or bottom of the tank or reservoir.

<u>Ball Valves</u>

The least desired method of sample acquisition. Make sure you drain plenty of oil before you collect your sample. The sludge, particles, and water that settle to the bottom of a tank or reservoir provide poor results.

GLOSSARY

AF = Analytical ferrography. Powerful diagnostic procedure to detect large wear particles, i.e. up to 100 microns. Provides a qualitative assessment of wear generation through microscopic examination of debris suspended in representative sample of used oil.

Abrasive particles = Crystalline particles or silica which have contaminated the oil and when accompanied by cutting wear particles cause abnormal wear.

Acid number = AN: mg of KOH required to neutralize basic buffer in oil using the procedure ASTM 974. A reduction indicates loss of basic reserve indicating possibility of corrosive wear in diesel engine.

Aluminum alloy = White particles which indicate wear of aluminum component such as a casing wall.

Babbitt = Particles observed during analytical ferrography which indicate wear of babbitted bearing.

Cast Iron = Ferrous wear particles observed during analytical ferrography which can originate from outside of case hardened gear tooth and is a common material used in machine housings.

Contaminants = Non-metallic particles observed during analytical ferrography which are being introduced into lube reservoir. If abrasive particles, increased cutting wear can be expected.

Copper alloy = Yellow particles indicating wear of copper alloy component such as an oil ring, bushing, etc.

Corrosive wear = Dark sub-micron particles observed microscopically during ferrographic analysis. Caused by acid attack of metals surfaces when oil is degraded.

cSt = Centistokes (units of viscosity) measured at either 40° C or 100° C.

Cutting wear = Long spiral or crescent shaped particles, resembling machining swarf. Can be due to abrasives or misalignment.

Dark Metallo = Oxidized ferrous particles which are very old or have been recently produced by conditions of inadequate lubrication.

Density = Mass of oil per unit volume.

Flash C = Flash point = the temperature at which the oil will produce sufficient volatile vapors to ignite when exposed to test flame. (ASTM D-92)

Fibers = Natural or synthetic observed by ferrographic analysis sometimes indicating contamination or filter deterioration.

Friction Polymers = Polymerization of the oil usually due to high stress. Not generally harmful, expect when it significantly affects viscosity or blocks fine filters.

FTIR = Fourier Transform Infrared Spectroscopy. A very effective test for providing levels of soot, sulfates, oxidation, nitrates, glycol, fuel, and water contaminants.

% Fuel = Calculated using an instrument called a Fuel Sniffer.

Glycol = An approximate percentage measurement of glycol contamination in oil. Glycol is found in engine coolant.

High Alloy Steel = Ferrous metal particle observed in analytical ferrography which is commonly found in shaft material.

ISO 4406:99 = Standard mainly use for hydraulic systems. The three number code uses an logarithmic scale to classify the cleanliness of the oil based on the number of particles greater than 4, 6 and 14 microns.

Infrared spectra = A graph of infrared energy absorbed at various frequencies in the additive region of the infrared spectrum. The current sample, the reference oil (R) and the three previous samples are shown.

Insolubles = Particles of carbon or agglomerates of carbon and other material. Indicates deposition or dispersant dropout in an engine. Not serious in compressor or gearbox unless there has been a rapid increase in these particles.

Lab No = Sequential number given to each sample received in laboratory.

Laminar Particles = Particles generated in rolling element bearings which have been flattened out by a rolling contact.

Low Alloy Steel = Ferrous particle observed during analytical ferrography which can originate from anti-friction bearings (52100 bearing steel) or inside of case hardened gear tooth.

Lubricant condition = Expert system conclusion based on whether certain limits were exceeded in the oil analysis results.

Machine condition = Expert system conclusion based on whether certain limits were exceeded in the oil analysis results.

Machine name = Name of machine which is unique to that unit. For example, NE gearbox on #4 crane.

Machine type = For example, Internal combustion engine, gas turbine, centrifugal compressor, etc.

Nitrate = An indicator of oil degradation in gasoline and natural gas engines.

Oxidation = A trend indicator of oil degradation.

Percent large = WPC results indicating the total weight in micrograms of large ferrous particles found in 1 ml of oil as a percentage of total weight of large and small particles.

Physical analysis = Includes common tests for physical and chemical properties. For example, viscosity, TAN, etc..

Product = The amount of contamination of the oil by degradation products or external source.

Received = Date and time sample was received.

Recommendations = Maintenance actions indicated.

Red Oxides = Ferrous oxide particles (red) observed by ferrography where a severe moisture problem is present.

Sample reference = General information on the current and past samples from the same machine. Indicates time on oil, time since overhaul, sample date, etc.

Sample date = The date that the oil is sampled as indicated on the sample bottle by customer.

Severe sliding = Large ferrous particles which are produced by sliding contacts. Trend is important to determine whether abnormal wear is taking place.

SP = Spectroscopy by atomic emission (ICP). The measurement of small (less than 7 microns) and dissolved metal particles in oil.

Spheres = Small (2-10 micron) ferrous spheres observed during analytical ferrography which can be indicative of abnormal rolling wear. Trend is important.

Sulfate = An indicator of oil degradation in diesel engines.

Time on oil = Service time on the oil. Either indicated by the customer on the sample bottle or estimated by us based on time elapsed since last sample and average operating hours per week.

Time since overhaul = Service time of the machine. Either indicated by the customer on the sample bottle or estimated by us based on time elapsed since last sample and average operating hours per week.

Type of machine = Reciprocating engine, gas turbine, centrifugal compressor, etc..

Viscosity = Measure of oil's resistance to flow at 40 C or 100 C. All tests are normally done at 40° C, except for engine oils.

Water Kf = Water measurement using Karl Fischer titration.

% Water = Water content expressed in percentage. (0.1% = 1000ppm)

White Non-Ferrous Metallic Particles = observed in Analytical Ferrography which do not respond to heat treatment. These

particles are usually aluminum but can also be tin, chrome, silver and other more exotic metals.

WPC = Wear Particle Concentration. A quantitative ferrous measurement of ferrous material in oil.

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