OIL ANALYSIS BASICS

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Table of Contents

1. Lubrication Fundamentals

1.1 The Functions of a Lubricant

Lubricants come in fluid, grease and solid forms depending upon the requirements of the application. Lubricants can deliver some or all of the following benefits:

- Friction and wear reduction - By separating moving surfaces with a load carrying fluid film, lubricants reduce friction. Friction generates heat and causes surface degradation in the form of wear (see Figure 1 -1). Both heat and wear reduce the useful life of mechanical components and the lubricant itself. The degree to which components are separated, if at all, depends upon several factors, including load, speed and viscosity. Typically, in sliding contacts, the lubricant film provides 2 to 20 microns of component separation. Where fluid film separation can't be achieved, solid or chemical lubricants reduce friction at the boundary (surface) contacts of components.

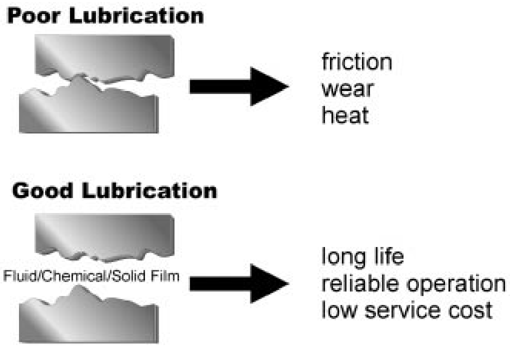


Figure 1-1

- Heat control - Flowing lubricants absorb heat at the point at which it is generated so that it may naturally dissipate, or be removed by a heat exchanger or other cooling system.

- Contamination control - Lubricants serve to seal the machine's components from the environment, stopping or slowing the ingress of contaminants like particles, water and chemicals. Likewise, fluid lubricants pick up contaminants and carry them to a tank or sump where they can settle by gravity, or to a filter or separator where they are removed.

- Prevent chemical attack - By coating component surfaces, lubricants provide protection against rust and corrosion.

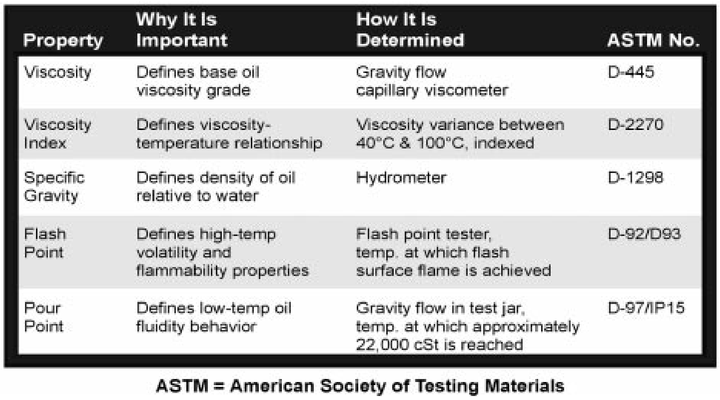
- Transfer of energy - In hydraulic systems, the fluid is the medium by which energy is transmitted to actuate cylinders, valves, motors, etc.

1. 2 Base-stock Considerations

Lubricants vary significantly from product to product. Figure 1-2 describes some of the tests commonly used to describe base oil properties. The properties of a lubricant's base-oil largely determine the operating performance of the resultant fluid lubricant or grease. Most base-oils are mineral oils, meaning they are produced from crude oil using a number of different refining processes. Usually, refining begins with fractional distillation whereby the molecules are sorted according to size and type by varying temperature and pressure (vacuum). Then, other refining processes might be applied including:

- Solvent extraction - The distilled oil is mixed with solvents in which undesirable aromatic molecules dissolve, enabling their separation from the oil's other molecules.

These Tests Help Describe Key Physical Properties of New Base Oils



Property	Why It Is Important	How It Is Determined	ASTM No.
Viscosity	Defines base oil viscosity grade	Gravity flow capillary viscometer	D-445
Viscosity Index	Defines viscosity-temperature relationship	Viscosity variance between 40°C & 100°C, indexed	D-2270
Specific Gravity	Defines density of oil relative to water	Hydrometer	D-1298
Flash Point	Defines high-temp volatility and flammability properties	Flash point tester, temp. at which flash surface flame is achieved	D-92/D93
Pour Point	Defines low-temp oil fluidity behavior	Gravity flow in test jar, temp. at which approximately 22,000 cSt is reached	D-97/IP15

ASTM = American Society of Testing Materials

Figure 1-2

- Hydrogen processing:
    - Mild hydrotreating - Low temperature/low pressure hydrotreating removes sulfur, oxygen and nitrogen compounds, but does not affect aromatics.
    - Severe hydrotreating - High temperature/high pressure hydrotreating saturates aromatic molecules to convert them into more stable naphthenes, and removes polar compounds.
- Acid refining - Unsaturated compounds are removed using sulfuric acid leaving an acid sludge that is then removed and neutralized.
- Clay refining - Using special clay materials, highly reactive unsaturated molecules are removed.
- Solvent or catalytic dewaxing - After solvent refining, waxes are removed from paraffinic oil using solvents or converted into shorter chain hydrocarbons using special catalysts.

Mineral-based lubricating oils are combinations of millions of different hydrocarbon molecules. Generally, lubricating oils are produced from paraffinic oil. Occasionally, naphthenic oils are used for certain specialty applications, especially where low temperature fluidity is important. Select properties of the two base-oils are compared in Figure 1-3. Aromatic oil is also presented for comparison purposes, but it is not generally recommended in the formulation of lubricating oils.

Property	ASTM Method	Paraffinic Oil	Naphthenic Oil	Aromatic Oil
Viscosity (cSt) @ 40°C.	D 445	40	40	36
Viscosity (cSt) @ 100°C.	D 445	6.2	5	4
Viscosity Index	D 2270	100	0	-185
Specific Gravity	D 287	0.8628	0.9194	.9826
Flash Point °C	D 92	229	174	160
Pour Point °C	D 97	-15	-30	-24
% Paraffinic	D 3238	66%	45%	23%
% Napthenic	D 3238	32%	41%	36%
% Aromatic	D 3238	2%	14%	41%

Figure 1-3 - Comparison of typical base-oil properties (Ref. No. 1)

Mineral vs. Synthetic Base Oils

A minority of the lubricants in service are formulated using synthetic base-oils instead of base oils refined from crude. There are many different types of synthetic oils with varying properties. Below are a few potential benefits associated with using a synthetic base oil:

- Increased oxidative life
- Improved lubricity
- Fire-resistance
- Better thermal resistance
- Extended drain intervals

These benefits must be compared to the possible limiting factors associated with the use of synthetic lubricants to determine feasibility. These factors might include:

- High purchase cost
- Seal or coating incompatibility
- Potential toxicity
- High disposal cost
- Possible incompatibility with mineral oil

1.3 Lubrication Fundamentals

Ideally, the machine's component surfaces are physically separated by a film of lubricant. In the absence of surface-to-surface contact, and assuming the oil is free of contamination (discussed later), the machine should operate with little friction and produce little wear. However, when surface-to-surface contact is likely, friction at the boundary must be reduced using other means. Below, the different primary lubrication regimes are summarized and discussed:

- Hydrodynamic lubrication - Called full-film lubrication, hydrodynamic lubrication is the separation of components by a "wedge" of oil that is produced hydrodynamically (see Figure 1-4). The formation of a hydrodynamic film depends upon the machine's surface geometry, speed, load, and the oil's viscosity. Speed and viscosity are inversely related to load in the formation of hydrodynamic lubrication. Increasing speed and/or viscosity, or decreasing load will decrease the time it takes to achieve hydrodynamic separation and increase the film's thickness. Likewise, component size and surface smoothness affect the ease with which the hydrodynamic film is established. Hydrodynamic lubrication is not achieved during start-up, and it is lost during shutdown. Sudden speed and/or load variations (shock-loads) impair hydro-

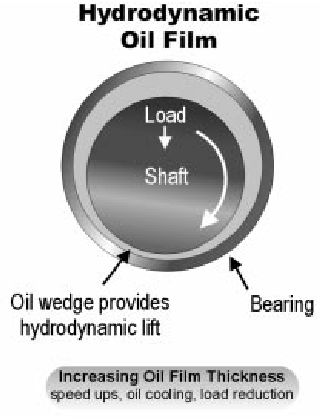
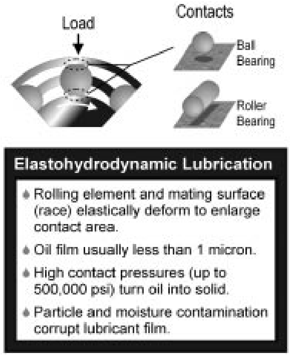


Figure 1-4

dynamic lubrication. Occasionally during start-up, an attempt to produce a hydrostatic film using pumps to "jack" the shaft up on the bearing are used to speed development of the hydrodynamic film and reduce start-up related wear.

• Elasto-hydrodynamic (EHD) lubrication - EHD lubrication is formed in rolling contacts where surfaces converge upon a point or a line, as in a rolling element bearing or the pitch line of two meshing gear teeth. Under point or line contact conditions, little surface area is available in the mating load zone. However, due to bearing material elasticity, during operation, bearing metals actually deform to produce the small area in which a hydrodynamic film is formed. Because the formation of the hydrodynamic film depends upon the deformation of the bearing materials, the lubrication regime is called elasto-hydrodynamic, or EHD lubrication (see Figure 1-5). The EHD oil film that separates component surfaces is very small, often less than one micrometer in thickness. Because a majority of the bearing's load is momentarily transferred across a very small area, pressure in this area is very high, as much as 500,000 psi. During the period of high transient pressure, the oil momentarily changes from a liquid to a solid. Once the pressure is released, the lubricant returns to a liquid state unharmed. The extreme local pressures at the rolling contact increases the importance of effective lubrication.



Elastohydrodynamic Lubrication

- Rolling element and mating surface (race) elastically deform to enlarge contact area.
- Oil film usually less than 1 micron.
- High contact pressures (up to 500,000 psi) turn oil into solid.
- Particle and moisture contamination corrupt lubricant film.

Figure 1-5

• Boundary lubrication - Where hydrodynamic or EHD lubrication can't be achieved, friction control depends upon other characteristics of the lubricant. This condition is called boundary lubrication. Boundary lubrication prevails under the following conditions:

- When an oil film thickness does not exceed the component's surface roughness.
- When equipment is subjected to frequent starts and stops, shock-load conditions, high static loads or slow speeds.
- Operational requirements dictate the use of low viscosity oil, compromising friction control of some system components.

Lubrication under boundary conditions may require the use of soft metals that generate less friction under contact or additives that produce a chemical reaction on the surface of the components producing low friction contact (discussed below), or solid lubricants like graphite or molybdenum disulfide to reduce friction.

1. 4 Additives and their Functions

Additives are chemicals introduced to the base oil to alter one or more performance properties. In general, it can be said that additives are used to:

- Enhance existing base oil properties
- Suppress undesirable base oil properties
- Impart new properties to base oils

Below is a review of common oil additives and their functions.

Antioxidants/oxidation inhibitors - Lubricating oil reacts with oxygen, especially at high temperatures, to form hydroperoxides, free radicals, ketones, aldehydes, and organic acids. The rate of this process, called oxidation, is dependent upon the following factors:

- Aeration - affects the amount of oxygen available to react with oil molecules
- Temperature - the rate of oxidation approximately doubles when the temperature is increased by 10° C
- Water - causes hydrolysis and promotes oxidation
- Metal catalysts - copper, lead, iron and other chemically active metals promote oxidation of the oil

Oxidative reactions change the oil's chemical and physical properties in the following ways:

- Increased viscosity
- Increased acidity
- Increased specific gravity
- Darkened color
- Varnished component surfaces
- Sludge accumulation

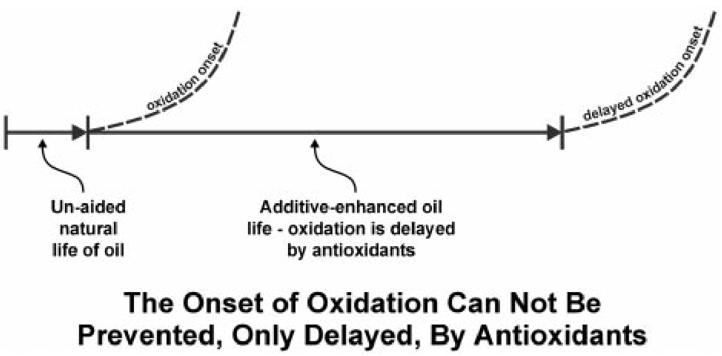


Figure 1-6

Anti-oxidant/oxidation inhibiting additives combat the oxidation process and prolong the life of the oil. These additives decompose reactive pro-oxidants (free radicals, hydroperoxides, etc.), producing stable byproducts. The additives sacrifice themselves to protect the oil and extend its useful life (see Figure 1-6). The following are common anti-oxidant/oxidation inhibiting additives:

- Hindered phenols
- Zinc dithiophospates (also provides anti-wear protection)
- Aromatic amines
- Alkyl sulfides

Rust Inhibitors - Water adversely affects both lubricants and machine surfaces. Rust results from water contamination and is a common form of corrosive wear that reduces the useful life of iron and steel machine components. To protect against rust, many oils are formulated with rust inhibitors. As Figure 1-7 depicts, rust inhibitors are polar molecules that are chemically attracted to steel or iron surfaces (metallophilic) and have an oil soluble (oleophilic) tail. The additive forms a barrier film to repel water from the iron or steel surfaces. By separating the water from the component surfaces the rusting process is inhibited. The following are typical rust inhibiting additives:

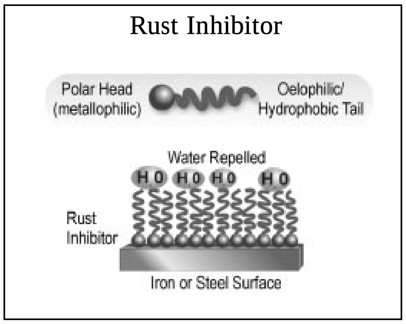

Rust Inhibitor

Figure 1-7

- Sulfonates
- Phosphates
- Organic acids, succinimides, esters and amines

Dispersants and Detergents - Dispersants are polar molecules that envelope sludge and soot particles to inhibit their agglomeration and deposition onto component surfaces especially in cooler zones of the engines (oil pan, rocker cover, etc.). By keeping the soot particles small and finely divided, they remain more effectively suspended and will not condense easily onto component surfaces (see Figure 1-8). Detergents help cleanse high-temperature surfaces (pistons, rings, valves, etc.) from deposits that form from combustion by-products. Additionally, they

Dispersants

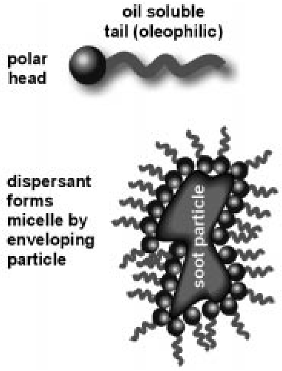


Figure 1-8

Detergents

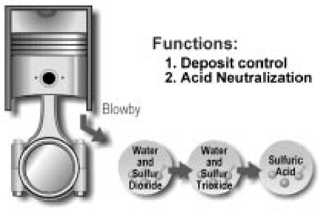


Figure 1-9

provide an over-base condition in engine oils to neutralize the acids that are generated from combustion and oil oxidation (see Figure 1-9). Common dispersant and detergent additive compounds include:

- Succinimides
- Calcium and barium sulfonates
- Phenates
- Polymeric detergents
- Amine compounds

Anti-wear and Extreme Pressure Additives - Anti-wear (AW) and extreme pressure (EP) additives protect lubricated components under the boundary conditions previously described. They are also known as antiscuff additives. Under high pressure, these chemically-active additives react with component surfaces to form soft, soap-like oxide films that offer enhanced lubricity at the boundary contact between surfaces (see Figure 1-10). AW and EP additives differ in the depth to which they react with component surfaces (see Figure 1-11). It is ideal to avoid boundary lubrication conditions. When it can't be avoid-

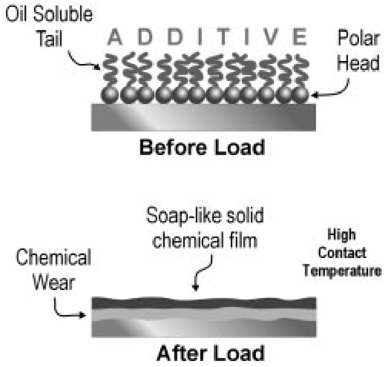


Figure 1-10 *Figure 1-11*

ed, it is best to choose the weakest (least chemically active) additive that will accomplish the task of friction control to avoid unnecessary surface degradation. Stronger additives should only be used as required. Common AW and EP additives include:

- Zinc dithiophosphate/dialkyl dithiophospahte (AW)
- Tri-cresyl phosphate (AW)
- Sulfur-phosphorous (EP)

References:
1. Society of Tribologists and Lubrication Engineers. *Starting from Scratch Tribology Basics*, Lubrication Engineering

2. Oil Analysis and Condition-Based Maintenance

While the benefits of detecting abnormal machine wear or an aging lubricant condition are important and frequently achieved, they should be regarded as low on the scale of importance compared to the more rewarding objective of failure avoidance (see Figure 2-1).

Whenever a proactive maintenance strategy is applied, three steps are necessary to insure that its benefits are achieved. Since proactive maintenance, by definition, involves continuous monitoring and controlling of machine failure root causes, the first step is to set a target, or standard, associated with each root cause. In oil analysis, root causes of greatest importance relate to fluid contamination (particles, moisture, heat, coolant, etc.) and additive degradation.

However, the process of defining precise and challenging targets (e.g., high cleanliness) is only the first step. Control of the fluid's conditions within these targets must

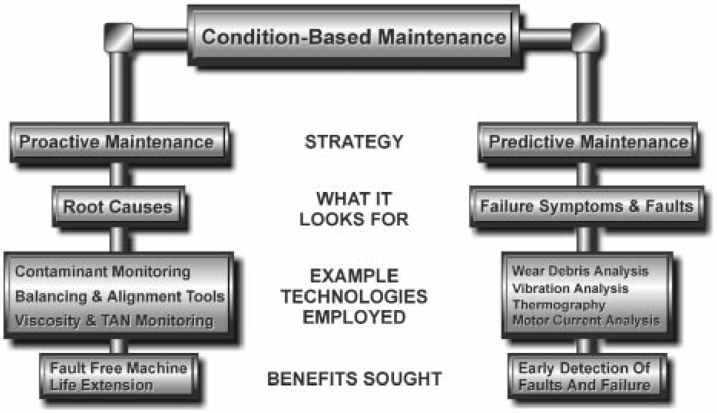


Figure 2-1

then be achieved and sustained. This is the second step toward proactive maintenance and often includes an audit of how fluids become contaminated and then systematically eliminating these entry points. Often upgraded filtration and the use of separators is required to meet proactive maintenance objectives.

The third step is the vital action element of providing the feedback loop of an oil analysis program. When exceptions occur (e.g., over target results) remedial actions can then be immediately commissioned. Using the proactive maintenance strategy, contamination control becomes a disciplined activity of monitoring and controlling high fluid cleanliness, not a crude activity of trending dirt levels.

When the life extension benefits of proactive maintenance are flanked by the early warning benefits of predictive maintenance, a comprehensive condition-based maintenance program results. While proactive maintenance stresses root-cause control, predictive maintenance targets the detection of incipient failure of both the fluid's properties and machine components like bearings and gears. It is this unique, early detection of machine faults and abnormal wear that is frequently referred to as the exclusive domain of oil analysis in the maintenance field.

3. Contamination Control

Contamination is the scourge of hydraulic and lubricated mechanical systems. It enters from the atmosphere or is generated from within to rob lubricants and components of precious life. Contamination, by definition, is anything in the oil that shouldn't be there. The four most common lubricant contaminants are discussed below.

3.1 Particle Contamination

Abrasive particles are responsible for much of the wear that leads to mechanical failure. The amount of damage inflicted by particles depends largely upon their size, shape, hardness and chemistry. Abrasive particles must be controlled in any system deemed critical to operation or expensive to repair.

Where particles enter - Many particles enter the oil at those points where the machine interfaces with its environment while others are generated from within. Here is a summary of particle ingression sources:

- Vents and breathers - Open vents provide contaminants with free passage to the oil. Likewise, breathers that are made of very coarse material often fail to effectively control the clearance-sized particles that cause damage to the system.

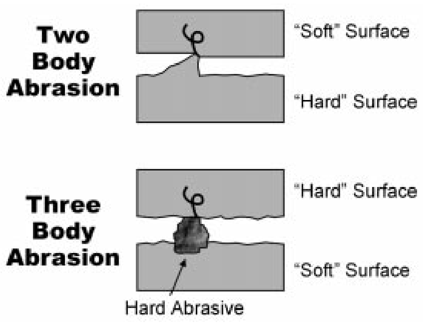
- Ineffective or damaged shaft seals and wiper seals (hydraulics) allow particles to freely enter and permit leakage.

- New oil - Contrary to popular belief that "fresh" oil is clean, new oil is often very contaminated. It may ship dirty from the supplier, become contaminated in storage or become contaminated during transport to the machine.

- Filters - Filters that are full, damaged or defective can release stored particles (desorption) or fail to effectively remove particles.

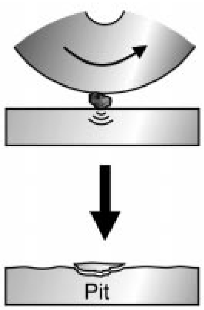
How particles affect the oil - Particles, especially catalytic metal particles like copper, iron and lead increase the rate at which oxidation occurs. Particles also strip the oil of its polar additives, including anti-wear additives, extreme pressure additives, rust inhibitors and dispersants. Also, numerous very small particles in stable suspension can cause the oil's viscosity to increase.

How particles affect the machine - Abrasive particles are responsible for much of the wear leading to premature failure of mechanical components. Under sliding conditions, clearance-sized particles enter the oil film between surfaces and cut away material much like a lathe cuts metal (see Figure 3-1). Under rolling contact conditions, particles transfer concentrated load between two surfaces in relative motion, resulting in surface fatigue, pitting, and spalling (see Figure 3-2). Particle-contaminated oil travel-



Abrasive Wear

Figure 3-1



Surface Fatigue

Figure 3-2

ing at high velocity can also cause erosive wear.

Controlling particle contamination - Ideally, the entrance of particles is restricted at those points where it is ingested. However, to achieve modern contamination control objectives, most machines require filtration. Numerous different filter media and separation mechanisms are available for removing particles. The performance of these devices is typically evaluated according to the following performance criteria:

- Filter stability - How stable is the filter's performance over time? Unstable filter performance equates to unreliable contamination control. Many factors influence filter stability, including temperature variation, cold-starts, pressure surges and mechanical vibration. The filter's size, design, and construction influences its stability.

- Filter capacity - This describes the amount of test contaminant a filter can remove, typically in grams.

- Filter efficiency - How effectively does a filter remove particles of a given size? This is important information in

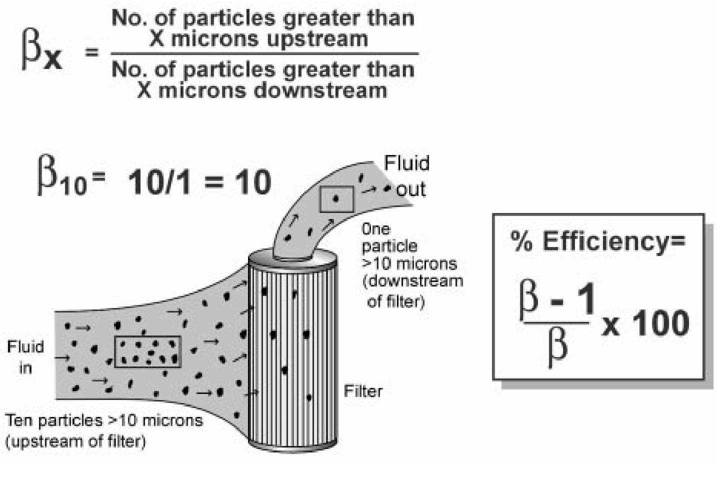


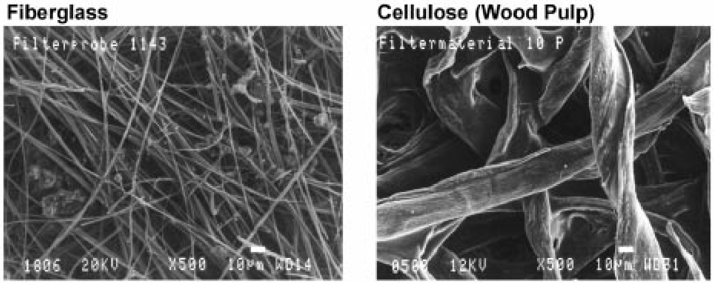
Figure 3-3

assessing a filter's ability to meet the machine's cleanliness requirements. It is also important to assess the total cost to filter oil. Several filter performance tests exist, but the most common is the Multipass-Test according to ISO 4572 (see Figure 3-3).

Particle separation options - The following techniques are among the available options for removing particles from oil:

- Cellulose fiber media filters - Available in cartridge or spin-on configurations, these filters are equipped with a paper-based (from wood pulp) pleated media. These filters are generally effective at removing larger particles, but often lack performance in the removal of silt-sized particles. Paper media is subject to damage caused by water and high temperature.

- Micro-fiberglass media filters - Also available in cartridge or spin-on configurations, the performance of micro-glass media filters is typically superior to cellulose fiber filters due to small fiber strand diameter, higher pore density, and smaller average pore size. These filters can remove most large particles and many smaller, silt-


Fiberglass

Cellulose (Wood Pulp)

Figure 3-4 - Microscopic comparison of cellulose and fiberglass filters media - Photos courtesy Internormen Filter sized particles from the oil. They offer superior thermal stability and are generally unaffected by the presence of water.

- Centrifugal separators - By spinning the oil, large suspended particles can be efficiently separated. These separators are generally effective at removing large, high-density particles from lower viscosity oil. Performance is degraded when particles are small, of lower-density, or when the oil's viscosity is high.

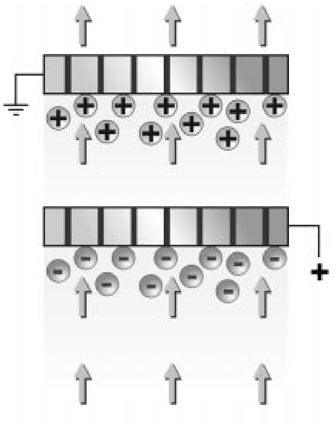


Figure 3-5

- Electrostatic separators - These devices capture particles by electrostatic precipitation. By creating a high-voltage potential cell (no current flow), charged particles are attracted to the separation plate with an opposite charge (see Figure 3-5). Electrostatic separators offer excellent performance in the removal of silt-sized particles and insoluble suspensions of oxides and carbon polymers that lead to varnish on component surfaces. Their performance depends upon the dielectric property of the oil and is, therefore, impaired by the presence of water.

3.2 Moisture contamination

Often called the scourge of hydraulic and lubricating machines, water contamination is the second most destructive contaminant. As depicted in Figure 3-6, water coexists with oil in the following states:

- Dissolved - Oil will dissolve a small amount of water into its chemistry. The volume of water the oil will dissolve depends upon its base-stock type, base-stock condition, additive package, contaminant load and temperature. New, high-grade, high-purity paraffinic base-oil, that has no additive or just an oxidation inhibitor, will dissolve very little water before reaching its saturation point. Conversely, oxidized, low-grade oil that is heavily loaded with polar additives and contaminants will dissolve a larger volume of water before reaching its saturation point. Of course, the saturation point of any lubri-

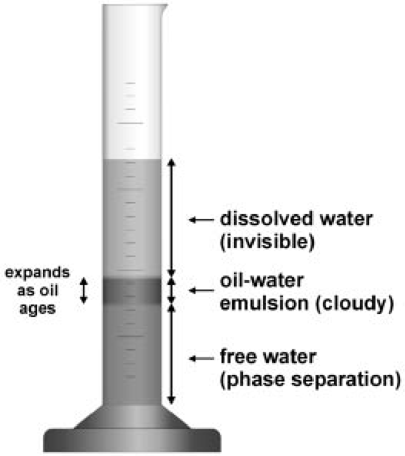


Figure 3-6

cant is relative to temperature. As temperature rises, the soluble volume rises. As temperature drops, the soluble volume also drops. If the temperature drops below the condensation point, some of the dissolved water becomes free water or emulsified.

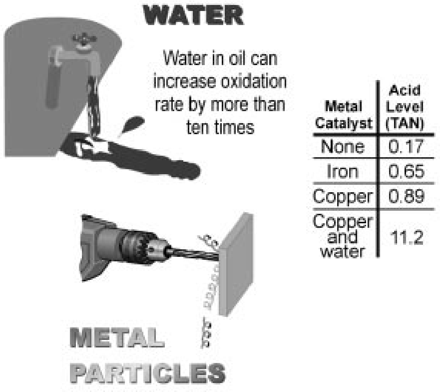
- Emulsified - When free (undissolved) water is subjected to shearing conditions present during pumping or caused by the churning of gear teeth or bearings, it is fragmented into small globules that can remain suspended in a stable state in the oil. Additives, oxides, and contaminants can encourage the stable emulsification of water in oil. Emulsified water produces hazy, cloudy or milky appearance depending upon the volume entrained.

- Free - Water is free when it separates from the oil due to inherent insolubility of the two substances and the differences in specific gravity. In mineral oil, free water will settle to tank and sump bottoms. However, certain synthetics have specific gravities above that of water making it buoyant.

Where water enters - Like particles, water enters at those places where the machine interfaces with its environment. Here is a summary of water ingression points:

- Atmosphere - Free water is often present in plant and fleet working environments. Rain,wash-down sprays, and cooler line leakage provide an opportunity for water to be ingested through seals, vents, reservoir hatches and with new oil.

- Condensation - Machines that operate with frequent starts and stops are subject to condensation ingression. When the temperature rises, the absolute volume of water the lubricant can dissolve (saturation point) rises. Conversely, the temperature drops, the saturation point drops and the oil might reach the dew point, or the point at which dissolved water is squeezed out of the oil. When the temperature rises again, the oil absorbs more water and the process continues. Water also condenses on the ceiling and walls of the headspace in tanks and sumps. The condensate can drip into the oil and puddle on the sump floor. In engines, cold temperature operation can condense water vapor from combustion. Finally, water can condense in oil from ineffective steam seals in certain machines.



Metal Catalyst	Acid Level (TAN)
None	0.17
Iron	0.65
Copper	0.89
Copper and water	11.2

Figure 3-7

- Coolant leakage - Coolers often leak due to chemical or erosive wear. When this happens, the cooler water leaks (and antifreeze where applicable) directly into the oil.

How water affects the oil - Water reacts with some additives to form precipitants and some chemically aggressive by-products. Water also acts as a catalyst to promote oxidation, especially in the presence of reactive metals like iron, copper and lead (see Figure 3-7). Where free water is accumulates in the reservoir, microorganisms can grow. The microbes feed on oil, decompose to form acids that promote oxidation and cause filter plugging.

How water affects the machine - Water that is in a free or emulsified form interferes with lubrication by weakening the strength of the lubricant film. The water-weakened film leaves the machine more susceptible to abrasive, adhesive and fatigue wear. Also, water rusts iron and steel surfaces and increases the corrosive potential of acids that attack bearing metals.

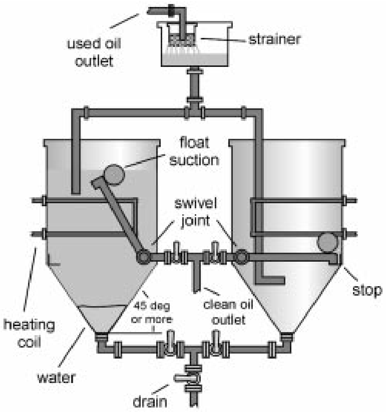


Figure 3-8 - Settling Tanks

Controlling water contamination - Once detected, the root cause for the ingress of water should be investigated. If the oil's physical and chemical properties are not

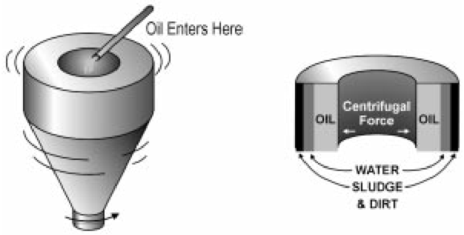
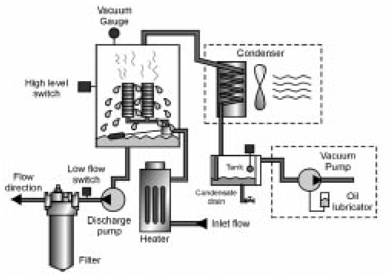


Figure 3-9 - Centrifugal Separators

damaged, the water can be removed and the oil kept in service. Removal methods include:

- Settling tanks - Although results vary depending upon the differences in specific gravity and the viscosity of the oil, free water can be removed from oil by providing a good settling location and environment and allowing sufficient time for the settling to occur (see Figure 3-8).



- Flows 2-20 gpm
- Water and dirt removal
- Expensive
- Wheel and skid mounted
- Vacuum 25-28" Hg, 150-160°F (water boils at 133°F at 25" Hg)
- Some risk of additive hydrolysis and volatilization

Ref: Parker Hannifin

Figure 3-10 - Vacuum Distillation

Occasionally, heaters are applied to encourage the separation. This method fails to remove dissolved or emulsified water.

- Centrifugal separators - The settling process can be accelerated when the forces of gravity are magnified using a centrifuge or vortex generator (see Figure 3-9). While more effective than gravity separation, centrifugal separation also fails to remove dissolved water and tightly held emulsions of water in oil.

- Vacuum distillation - Water can be effectively boiled out of the oil when the temperature reaches 100° C, but high temperature exposure causes thermal and oxidative stress on the oil (see Figure 3-10). Vacuum distillation devices dehydrate the oil without substantial damage to the lubricant by increasing the temperature modestly and

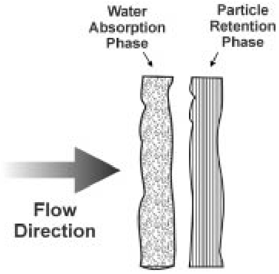


Figure 3-11 - Polymeric Filtration

drawing a vacuum to effectively reduce the boiling point of water.

- Polymeric filters - These filters look like conventional spin-on or cartridge type filters, but they utilize a filter media that is impregnated with a super absorbent polymer (see Figure 3-11). The polymer absorbs free and emulsified water and forms a gel that is locked tightly into the filter's media.

3.3 Fuel contamination

Fuel contamination occurs primarily in crankcase applications. Most engine oils accumulate some fuel dilution during operation. Extended oil drain, improper operation, or engine malfunction can lead to an unhealthy buildup of fuel in the lubricant.

Where it enters - Fuel enters the crankcase as blowby with combustion gases and from leakage. Blowby occurs due to incomplete or ineffective combustion caused by one or more of the following:

- Excessive idling
- Lugging
- Defective fuel injection spray pattern or dribbling
- Improper fuel/air ratio

Its effect on the oil - Fuel dilution substantially reduces the lubricant's performance in the following ways:

- Premature oxidation - Fuel molecules oxidize very easily. Their oxidation in the lubricant produces reactive byproducts that stress the lubricant's more stable hydrocarbons setting off a chain reaction of oxidative failure.
- Loss of viscosity - Fuel, being miscible with oil, causes viscosity thinning.
- Additive dilution - Fuel doesn't bring any additives to the crankcase. Therefore, the lubricant's additives are proportionally diluted.
- Sulfur build-up - Sulfur from some fuels, like diesel, increases the risk of corrosion.

Its effect on the machine - Fuel dilution adversely affects the machine in the following ways:

- Increased wear - Viscosity loss and anti-wear additive dilution couple to increase the rate at which mechanical wear occurs.
- Increased corrosion - Sulfuric acid and oxidation-induced organic acids pair up to corrode component surfaces.
- Fire and explosion risk - High levels of fuel dilution can lead to ignition of the mixture and engine explosion. Likewise, increasing lubricant levels (due to the addition of fuel) can lead to overflow out of the crankcase, creating a fire risk.

Controlling fuel dilution - Fuel dilution must be stopped at its source. Once contaminated with excessive fuel, the oil must be condemned.

3.4 Soot Contamination

Soot is a natural byproduct of combustion. Extended oil drains or poor combustion lead to abnormal soot accumulation that has harmful effects upon the lubricant and the machine. New EPA requirements to control atmospheric soot and nitrous-oxide (NOX) emissions using exhaust gas recirculation (EGR) will lead to increased soot loading in crankcase oils in the coming years.

Where it enters - Soot enters the lubricant as blowby with combustion gases (see Figure 3-12) and is caused by the following:

- Low compression - Produces poor combustion, increasing the rate at which soot is generated
- High fuel/air ratio - Caused by plugged or restricted air filter flow or incorrect mixture settings
- Cold air temperatures
- Lugging
- Excessive idling

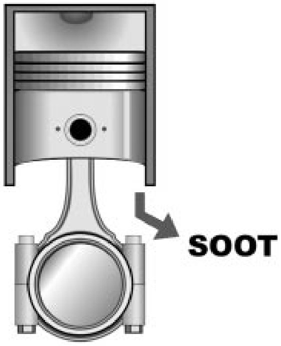


Figure 3-12

Its effect on the oil - Soot has the following effects on the oil:

- Dispersancy loss - By adsorbing dispersant additive molecules, dispersancy performance deteriorates rapidly when soot ingestion is high leading to premature oil failure.

- Anti-wear performance loss - Anti-wear additive molecules adsorb to soot surfaces rendering them unavailable to protect machine components.

- Increased viscosity - Soot suspended in the oil increases the oil's viscosity. This causes increased temperature and slows the flow of lubricant to machine components.

Its effect on the machine - Soot affects the machine in the following ways:

- Filter plugging
- Increased abrasive wear
- Deposit formation, sludge, and oil-way blockage

Controlling soot contamination - Soot must be controlled by dealing with the cause of ingestion through combustion and operation management. Once soot has contaminated the oil, little can be done to remove it. Some success in removing soot using low-flow, "slipstream" filters and centrifuges have been reported.

3.5 Glycol contamination

Glycol frequently contaminates crankcase lubricants and other systems that utilize a glycol and water mixture for cooling. Always present and flowing, glycol is a constant threat to leak into the lubricant, especially in crankcase applications.

Where it enters - Typically, glycol leaks into the crankcase for the following reasons:

- Defective seals
- Cavitation and erosion (mechanical and electro-kinetic)
- Corrosion
- Damaged cooler core

Its effect on the oil - Glycol has the following effects on the oil:

- Forms gels and emulsions
- Increases viscosity
- Increases oxidation
- Forms acids
- Forms "oil balls"

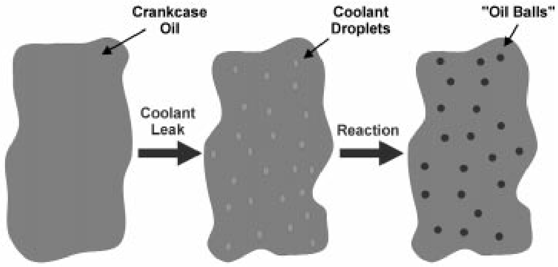


Figure 3-13

Its effect on the machine - Glycol has the following effects on the machine:

- Increased wear - This is caused by the generally poor lubricating quality of the oil, the formation of a glycol emulsion and starvation of lubricant to the components due to increased viscosity.

- Increased corrosion - Corrosion increases due the acid environment glycol creates in the lubricant.

- Filter failure - Glycol clogs filters prematurely.

Controlling glycol contamination - Glycol must be controlled at its ingestion point. It can't be effectively removed once the oil is contaminated except with an oil change. Under severe occurrences of glycol contamination, the crankcase or sump should be flushed before refilling with lubricant.

4. Oil Sampling Methods

Oil sampling is the most critical aspect of oil analysis. Failure to obtain a representative sample impairs all further oil analysis efforts. There are two primary goals in obtaining a representative oil sample:

- Maximize data density - Simply stated, samples should be taken in such a way that there is the most information per milliliter of oil possible. This information relates to such criteria as cleanliness and dryness of the oil, depletion of additives, and the presence of wear particles being generated by the machine.

- Minimize data disturbance - Samples should be extracted in such a way that the concentration of information is uniform, consistent and representative. It is important to make sure that the sample does not become contaminated during the sampling process. This can distort and disturb the data, making it difficult to distinguish what was originally in the oil from what has come into the oil during the sampling process.

To ensure good data density and minimum data disturbance in oil sampling, one should consider the following factors, each of which is discussed in detail later in the chapter:

- Sampling Location - Not all locations in the machine will produce the same data. Some are far richer in information than others. Some machines require multiple sampling locations to answer specific questions related to the machine's condition, usually on an exception basis.

- Sampling Procedure - The procedure by which a sample is drawn is critical to the success of oil analysis.

Sampling procedures should be documented and followed uniformly by all members of the oil analysis team. This ensures consistency in oil analysis data and helps to institutionalize oil analysis within the organization. It also provides a recipe for success to new members of the team.

- Sampling Device - The hardware used to extract the sample should not disturb sample quality. It should be easy to use, clean, rugged and cost-effective.

- Sample Bottle - The type of bottle and cleanliness of bottle both help assure that a representative sample is achieved.

It is always advised to spend the time and money to make sure machinery is properly fit with the sampling hardware to ensure these goals in oil sampling are achieved.

4.1 Sampling Locations on System Returns

There are several rules for properly locating oil sampling ports on circulating systems. These rules cannot always be precisely followed because of various constraints in the machine's design, application, and plant environment. However, the importance of proper oil sampling cannot be overstated as a priority in oil analysis. As closely as possible follow the several rules outlined below. These rules will be expanded and further discussed later in this section.

- Turbulence - The best sampling locations are highly turbulent. This means that the oil is not flowing in a straight line but is turning and rolling in the pipe. Sampling valves located at right angles to the flow path in long straight sections of pipe can result in "particle flyby". Basically, this leads to a substantial reduction of the particle concentration entering the sample bottle. This can be avoided by locating sampling valves at elbows and sharp bends in the flow line.

- Ingression Points - Where possible, locate sampling ports downstream of the components that wear and ingress particles and moisture. These return lines and drain lines heading back to tank offer the most representative levels of wear debris and contaminants. Once the fluid reaches the tank, the information becomes diluted.

- Filtration - Filters and separators are contaminant removers, therefore they can remove valuable data from the oil sample. Always locate sampling valves upstream of filters, separators, dehydrators, and settling tanks unless the performance of the filter is being specifically evaluated.

- Drain Lines - In drain lines where fluids are mixed with air, locate sampling valves where oil will travel and collect. On horizontal piping this will be on the underside of the pipe. Sometimes oil traps must be installed, like a goose neck, to concentrate the oil in the area of the sampling port.

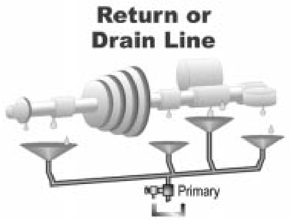


Figure 4-1

Look first at circulating systems where there are specific return lines or drain lines back to a reservoir. These systems include pressurized returns and drains such as those in hydraulic systems or forced circulating lubrication systems where there is a scavenger pump returning the oil back to the tank. There are also drain-line applications where the oil returns to the tank by the force of gravity. Sometimes these drains are vented like those commonly seen on steam turbines, paper machines, etc.

In the case of the circulating system, the ideal location for sampling is on the drain and return lines (see Figure 4-1). They allow you to catch a sample of the oil before it returns to the tank and always before the oil goes through a filter. If the oil is permitted to return to the tank, then the information in the sample becomes diluted, potentially by thousands of gallons of fluid in large lubricating and hydraulic systems. Return line sampling helps identify active debris generation while debris in the reservoir tends to accumulate over weeks and months and may not accurately represent the current condition of the machine.

Figure 4-2 is an example of a large lubrication system with oil being supplied to a set of bearings. The oil flows down from these bearings by gravity through a manifold or header, then back to tank. Here, a number of optional sampling locations are identified. Some locations are labeled with an "S" meaning they are secondary sampling locations.

The primary sampling location, labeled “P” is on the header of this drain line just before the oil is returned to the tank. By sampling at this location many potential problems can be detected. For example, if the bearings are experiencing abnormal wear, or if there are high levels of moisture, particles, process debris or chemicals being pulled into the oil from seals or vents, you will get an indication of this from the drain-line sampling port. Likewise,

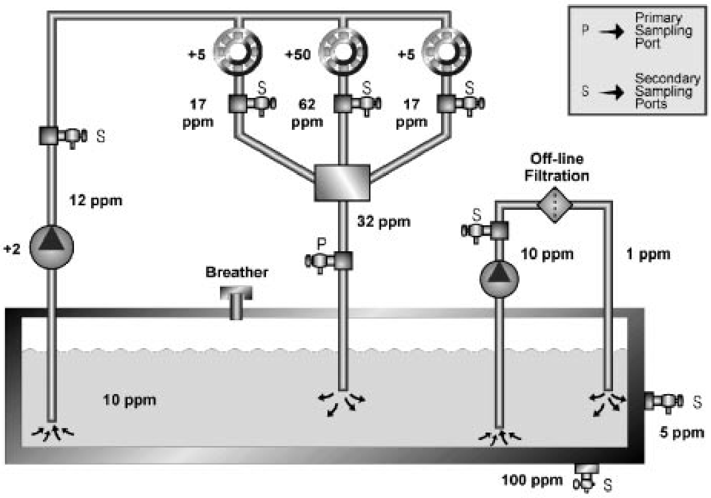


Figure 4-2

you can verify that the oil meets the required levels of cleanliness and dryness. It also verifies that the viscosity and all other physical properties of the oil are within the target range. This is considered the primary sampling location because it is representative of the oil that is being delivered to the bearings and also picks up any debris that the bearings might be adding to the oil.

When an abnormal machine condition is detected from the primary sampling point, the next step is usually to sample from secondary points to isolate the problem. In this case, on Figure 4-2, there is 32 ppm represented at the primary sampling point (for this example, assume that this number represents the amount of iron in the oil). This high reading leads you to use the secondary sampling points to identify the source of the increased iron concentration. In this example 17 ppm is being generated in each of the outside bearings while the center bearing is producing 62 ppm. The supply fluid of this system shows just 12 ppm. It is obvious in this example that the middle bearing is producing the wear debris. Diagnostic efforts can now be focused upon that component.

In this example, had we relied entirely upon oil sampled from the tank, we would have observed only 10 ppm because of dilution by the large volume of oil, particle settling and the presence of the off-line filter that removes much of wear debris from the oil.

Likewise, if we were to sample the bottom of the tank we would see a very high concentration of sludge and water and, in this case, there is a 100 ppm of iron. This, of course, is historic information and probably has nothing to do with the current condition of the bearings.

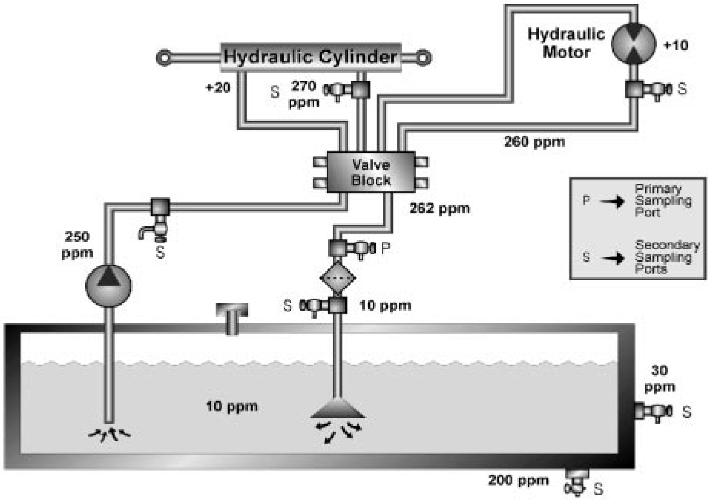


Figure 4-3

In summary, the drain-line provides the primary sampling point. If there is an abnormal reading or an overlimit alarm, samples should be taken from the individual bearing drains. A sample on the supply fluid should also be obtained. By comparing these samples, a good estimation of what the problem is and from where it is being generated can be determined.

Figure 4-3 illustrates a hydraulic system with fluid that is pressurized on all the lines. Again the primary sampling location is the return line. But, in this case, because there is a return line filter, the primary sample should be taken just upstream of this filter. If the filter is doing its job, it is a data remover. If a sample is taken on the downstream side of the filter, the filter can capture critical information about the condition of the machine before it has a chance to reach the sample bottle. If the filter itself is a problem, and is in bypass, or has collapsed, or is defective, the sample upstream of the filter will ultimately be contaminated just like the sample on the downstream side.

In this case, the sampling port on the return line upstream of the filter is showing 262 ppm of wear metal or contaminant. If a sample is taken at both of the secondary locations it is seen that there is 260 ppm coming downstream of the hydraulic motor and 270 ppm coming downstream of the cylinder. This suggests that the material entering the fluid is shared by both of these two actuators. By following the flow upstream and sampling downstream of the pump, it is clear that the 250 ppm is coming from the pump. This means that there is either a problem with the pump, or that dirty oil is being supplied to the pump from the tank. A sample drawn from the tank reveals the low reading of 10 ppm confirming that the pump is the problem. With the problem localized, diagnostic and corrective actions can now be focused entirely upon the hydraulic pump.

4.2 Live Zone Sampling From Circulating Systems

When a sample is taken from a line in a circulating system it is referred to as a live zone sample. There are things that can be done during the sampling process that improve the quality and effectiveness of the live zone sample. The following is a summary of do's and don'ts.

Do:

1. Sample from the system's turbulent zones where the fluid is moving and the oil is well mixed.
2. Sample downstream of the equipment after it has completed its primary functions such as lubricating a bearing or a gear or has passed through a hydraulic pump or actuator.
3. Sample systems during typical working conditions, on the run, and under normal applications. Try not to sample after an oil change, filter change or at some time when the fluid wouldn't represent typical conditions.
4. Where required, employ secondary sampling locations to localize problems.

Don't:

1. Sample from dead pipe legs, hose ends, and standing pipes where the fluid isn't moving or circulating.
2. Sample after filters or separators.

3. Sample when the machine is cold and hasn't been operating or has been idling.
4. Sample from laminar flow zones (lack of fluid turbulence). The best way to insure the fluids are turbulent and mixed during the sampling process is to sample from elbows instead of straight lengths of pipe (see Figure 4-4).

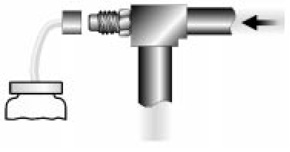


Figure 4-4

4.3 Sampling from Pressurized Lines

When samples need to be taken from pressurized feed lines leading to bearings, gears, compressors, pistons, etc. the sampling method is somewhat simplified. Figure 4-5 shows four different configurations.

- Portable High-Pressure Tap Sampling - The upper most configuration on Figure 4-5 is a high pressure zone where a ball valve or needle valve is installed and the outlet is fitted with a piece of stainless steel helical tubing. The purpose of the tubing is to reduce the pressure of the fluid to a safe level before it enters the sampling bottle.

- Minimess Tap Sampling - This alternative requires that a minimess valve be installed, preferably on an elbow. The sampling bottle has a tube fitted with a probe protruding from its cap. The probe attaches to the minimess port allowing the oil to flow into the bottle. There is a vent hole on the cap of the sample bottle so that when the fluid enters the bottle the air can expel or exhaust

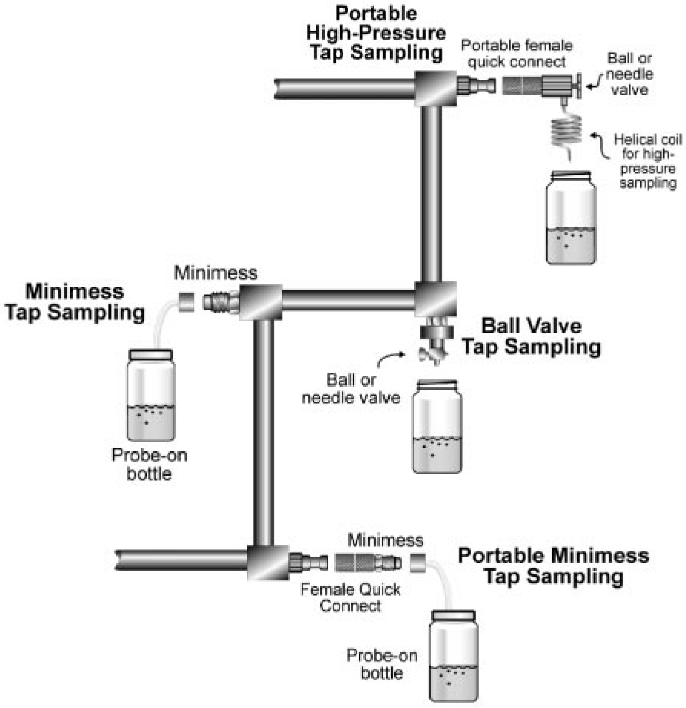


Figure 4-5

from the vent hole. This particular sampling method requires lower pressures (less than 500 psi) for safety.

- Ball Valve Tap Sampling - This configuration requires the installation of a ball valve on an elbow. When sampling, the valve should be opened and adequately flushed. Extra flushing is required if the exit extension from the valve is uncapped. Once flushed, the sampling bottle's cap is removed and a sample is collected from the flow stream before closing the valve. Care should be taken when removing the bottle cap to avoid the entry of contamination. This technique is not suitable for high pressure applications.

- Portable Minimess Tap Sampling - This option requires installing a minimess onto the female half of a standard quick-connect coupling. This assembly is portable. The male half of a quick-connect is permanently fitted to the pressure line of the machine at the desired sampling location. To sample, the portable female half of the quick-connect is snapped onto the male piece affixed to the machine. To sample, the bottle's probe tip is pressed onto the minimess valve to induce fluid flow into the bottle. In many cases these male quick-connect couplings are preexisting on the equipment. A helical coil, previously described, on high pressure lines should always be used.

Figure 4-6 - Minimess Sampling Valve

Figure 4-6 shows a minimess valve installed on hydraulic machinery. This valve is properly equipped with a dust cover so that the internal opening of the sampling port is protected from debris. The cap, when fitted with an o-ring also serves as a secondary seal in the unlikely event the minimess valve should fail.

4.4 Sampling From Low Pressure Circulating Lines

Occasionally a drain line, feed line, or return line is not sufficiently pressurized to take a sample. In such cases

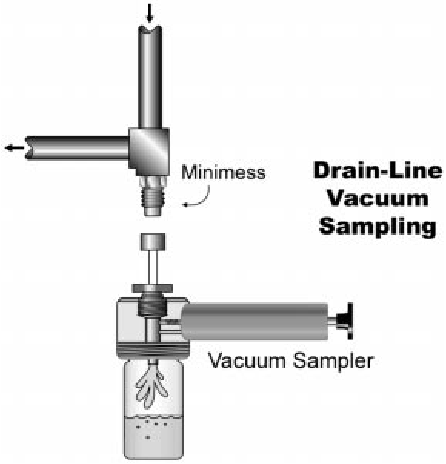


Figure 4-7

sampling requires assistance from a vacuum pump equipped with a special adapter allowing it to attach momentarily to a valve, such as a minimess valve, commonly used in sampling. A minimess valve has a mechanical check that is actuated by a probe. With the adapter threaded onto the minimess valve, fluid can be drawn by vacuum into the bottle (see Figure 4-7).

4.5 Sampling Wet-Sumps

Frequently, there are applications where a drain line or a return line can't be accessed or no such line exists.

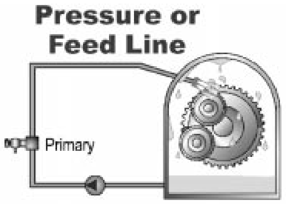


Figure 4-8

Basically these are wet sump applications where the sump within the casing serves as the reservoir. Examples of wet sump systems include:

- Diesel engines
- Circulating gearboxes
- Circulating compressors

In these applications, because there is no return line, fluid must be sampled from the pressurized supply line leading to the gearing and the bearings (see Figure 4-8). The sample should be collected before the filter, if one exists.

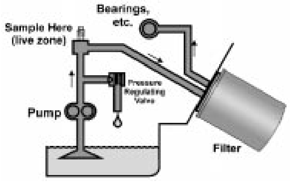


Figure 4-9

The best place to sample engine crankcase oil is just before the filter (see Figure 4-9). Install the sampling valve between the pump and filter. This sample location is highly preferred over sampling from a drain port or using a vacuum pump and tube inserted down the dipstick port.

Another example of a wet sump involving circulation

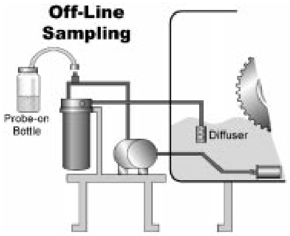


Figure 4-10

is shown in Figure 4-10 where there is a side loop that is often referred to as a kidney loop filter. This off-line circulating system provides an ideal location to install a sampling valve between the pump and filter. A ball valve or a minimess valve can be used so that the fluid under pressure flows easily into the sample bottle without disturbing the operating system or filtration system.

4.6 Sampling Non-Circulating Systems

There are numerous examples where no forced circulation is provided and a sample must be taken from a system's sump or casing. This often must be done with "in-service" equipment on the run. Ring or collar bath-lubricated bearings and splash lubricated gearboxes are common examples of these systems. All of these situations increase the challenge of obtaining a representative sample.

The most basic method for sampling such sumps is to remove the drain plug from the bottom of the sump allowing an amount of fluid to flow into the sample bottle. For many reasons this is not an ideal sampling method or location. Most important is the fact that bottom sediment, debris and particles (including water) enter the bottle in concentrations that are not representative of what is experienced near or around where the oil lubricates the machine. The drain plug sampling method should be avoided if at all possible.

Drain port sampling can be greatly improved by using a short length of tubing, extending inward and up into the active moving zone of the sump (see Figure 4-11). This ball valve and tube assembly can, in many cases, be threaded into the drain port and can be easily removed to facili-

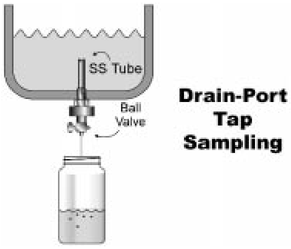


Figure 4-11

tate draining of the oil.

A third option is called drain port vacuum sampling. With this method a minimess valve is installed as previously described, but instead of fluid passing into a sample bottle by gravity, it is assisted by a vacuum sampler (see Figure 4-12). This is particularly helpful where the oil is viscous and difficult to sample through a narrow tube. During the sampling process the connector on the end of the plastic tube of the vacuum pump is threaded onto the minimess valve. Vacuum is produced by the pump pulling oil downward from the case into the sample bottle.

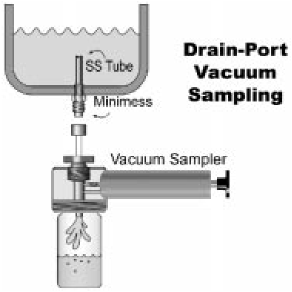


Figure 4-12

Still another method for sampling a gearbox or bearing housing is to use a portable oil circulating system such as a filter cart. In this case the filter cart is attached to the

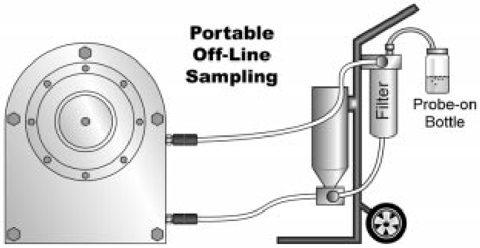


Figure 4-13

sump (see Figure 4-13). Here the cart circulates the fluid off the bottom of the sump and back into the sump. In order to keep from cleaning the oil before sampling, the filters must be by-passed using a directional valve. Allow the fluid to become homogenous by circulating the fluid for about 5 to 15 minutes, depending on the size of the unit, the amount of fluid in the unit, and the flow rate of the filter cart. Once sufficient mixing has occurred, a sample can be taken from the sampling valve (installed between the pump and the filter). With the sample drawn, the filters can be engaged to clean the fluid.

4.7 Drop-tube Vacuum Sampling

One of the most common methods for sampling a bath or splash-lubricated wet sump is to use the drop-tube vacuum sample method. A tube is inserted through a fill port or dip stick port and lowered into the sump cavity--usually about midway into the oil level (see Figure 4-14). This sampling method has a number of drawbacks and should be avoided if other sampling methods, as previously described, can be used instead. Below is a summary of the risks and problems associated with drop-tube vacuum sampling:

- Tube Location - A tube that is directed into the fill or dipstick port is extremely difficult to control. The tube's

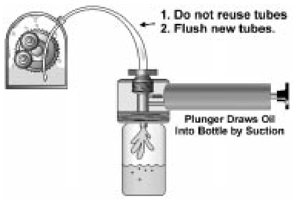


Figure 4-14 - Drop-Tube Vacuum Sampling

final resting place is hard to predict, resulting in samples being taken from different locations each time. There is always a risk of the tube actually going all the way to the bottom of the sump where debris and sediment is picked up.

• Drop Tube Contamination - There is considerable concern that the tube will scoop up debris from the sides of the casing as it is being inserted. Also, the tube itself may be contaminated due to poor cleanliness control when it was produced or while it was stored.

• Large Flush Volume - The drop-tube method substantially increases the volume of fluid that must be flushed in order to obtain a representative sample. For some small sump systems this practically results in an oil change. Likewise, if the removed volume of fluid is not replaced, the machine might be restarted with inadequate lubricant volume.

• Particle Fallout - For most systems, a shutdown is required to deploy the drop-tube method. This means that production must be disturbed for the sake of oil sampling, or sampling frequency must suffer because of production priorities. Neither situation is ideal. Likewise, particles begin to settle and stratify according to size and density immediately upon shutdown, compromising the quality of oil analysis.

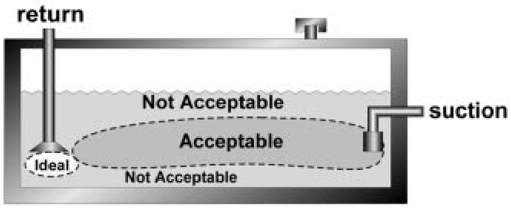


Figure 4-15

- Machine Intrusion - The drop-tube method is intrusive. The machine must be entered to draw a sample. This intrusion introduces the risk of contamination, and there is always the concern that the machine might not be properly restored to run-ready condition before start-up.

Whenever drop-tube sampling is used it should be considered a sampling method of last resort. However, there are situations where no other practical method of sampling is available.

In the case where drop tube vacuum sampling must be used on circulating systems, the best location to get the sample is between the return line and the suction line (Figure 4-15). This is known as the short circuit. Even in

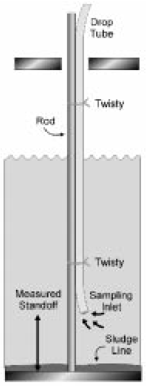


Figure 4-16

cases where there is baffling in the tank, the sample needs to be taken from the most direct flow zone between this return line and suction line. And, ideally this will be as close to the return port as possible. If there is baffling, it should be on the return side of the baffle.

In order to insure that the plastic tube is lowered to the same place each time, it can be fitted with a weight, attached to the end of the tube, where a specific length of tube is lowered into the tank. An easier way is to attach the tube to a metal or plastic rod using wire or twist-ties (Figure 4-16). Then, measure a stand-off on the bottom of the rod so that the rod is lowered to the tank floor and the end of the tube is a fixed distance above. This "measured stand off" is to be consistently used each time a sample is taken.

4.8 Sampling Bottles & Hardware

An important factor in obtaining a representative sample is to make sure the sampling hardware is completely flushed prior to obtaining the sample. This is usually accomplished using a spare bottle to catch the purged fluid. It is important to flush 5-10 times the dead space volume before obtaining the sample. All hardware that the oil comes into contact with is considered dead space and must be flushed, including:

- System dead-legs
- Sampling ports, valves and adapters
- Probe on sampling devices
- Adapters for using vacuum sample extraction pumps
- Plastic tubing used for vacuum pumps (this tubing should not be reused to avoid cross contamination between oils)

There is an assortment of sampling bottles that are commonly used in oil analysis. An appropriate bottle needs to be selected for the application and the test that is planned. Consider the following features when selecting sample bottles:

- Size - There are a number of different sizes of sample bottles that are available. They vary from 50 ml (or about two ounces of fluid) to a more common 100 to 120 ml bottle. The larger bottle is preferred when tests such as particle count and viscosity analysis are required. Where a considerable number of different tests are required a 200 ml bottle (or two 100 ml bottles) may be required. Coordinate with the laboratory to select the bottle size that will provide a sufficient volume to conduct all the required tests and leave some extra for storage in case a re-run is necessary. Another consideration in selecting the bottle size is that the entire volume of the bottle should not be filled with fluid during the sampling process. Only a portion of the sample bottle should be filled. The unfilled portion, called the ullage, is needed to allow proper fluid agitation by the laboratory to restore even distribution of suspended particles and water in the sample. Below is a general guideline for filling bottles:
    - Low Viscosity (ISO VG 32 or less) - Fill to about 3/4 of the total volume
    - Medium Viscosity (ISO VG 32 to ISO VG 100) - Fill to about 2/3 of the total volume.
    - High Viscosity (over ISO VG 100) - Fill to about 1/2 of the total volume.
- Material - Bottles are available in several materials. Below is a review of the most common bottle materials:

    - Plastic polyethylene - One of the most common bottle materials, this is an opaque material similar to a plastic milk jug. This type of sampling bottle presents a drawback because the oil can't be visually examined after the sample is obtained. Important properties of the oil can be immediately learned from a visual inspection such as sediment, darkness, brightness, clarity and color.
    - PET plastic - This is a completely clear, glass-like, material and it is available in standard sizes. This plastic is found to be compatible with most types of lubricating oils and hydraulic fluids, including synthetics.
    - Glass bottles - These bottles tend to be more expensive, are heavier, and there is the risk of breakage during the sampling process. One advantage with glass bottles is that they can be cleaned and used over and over. The cleanliness of glass bottles often exceeds that of plastic bottles.
- Cleanliness - One of the most important considerations in selecting a sample bottle is to make sure it is sufficiently clean. The bottle's required cleanliness level should be determined in advance. The bottle supplier should provide, with each bottle order (or upon request), a certificate of cleanliness that is based upon random testing of the bottles per ISO 3722. The report should identify the mean and standard deviation for the lot from which the shipped bottles were taken. Bottles can be classified according to their contribution to the particle count into the following cleanliness categories:
    - Clean - Fewer than 100 particles greater than 10 microns per ml of fluid.

- Super Clean - Fewer than 10 particles greater than 10 microns per ml of fluid.
- Ultra Clean - Less than 1 particle greater than 10 microns per ml of fluid.

4.9 Important Tips for Effective Oil Sampling

To achieve "bull's eye" oil analysis data, where oil sampling and analysis produces the most representative and trendable information, follow these basic sampling tactics:

1) Machines should be running in application during sampling. That means sampling when machines are at normal operating temperatures, loads, pressures and speeds on a typical day. If that is achieved, the data will be typical as well, which is exactly what is desired.

2) Always sample upstream of filters and downstream of machine components such as bearings, gears, pistons, cams, etc. This will ensure the data is rich in information. It also ensures that no data (such as particles) is being removed by filters or separators.

3) Create specific written procedures for each system sampled. This ensures that each sample is extracted in a consistent manner. Written procedures also help new team members quickly learn the program.

4) Ensure that sampling valves and sampling devices are thoroughly flushed prior to taking the sample. Vacuum samplers and probe-on samplers should be flushed too, and if there are any questions about the cleanliness of the bottle itself it should also be flushed.

5) Make sure that samples are taken at proper frequencies and that the frequency is sufficient to identify common

and important problems (more on this below). Where possible, especially with crankcase and drivetrain samples, record the hours on the oil. This can be a meter reading or some other record identifying the amount of time that the oil has been in the machine. If there has been any makeup fluid added or any change to the oil such as the addition of additives, a partial drain, or anything similar, communicate this information to the lab.

Sources of Garbage Data

- Systems are sampled under cold conditions (not running as usual)
- Drain port sampling or drop tube vacuum sampling methods
- Variable sampling methods and locations
- Contaminated sampling hardware
- Insufficient dead space flushing
- Sampling just after an oil change
- Cross contamination of fluids between two samples
- Sending the sample to the lab long after the sample was taken

6) Forward samples immediately to the oil analysis lab after sampling. The properties of the oil in the bottle and the oil in the machine begin to drift apart the moment after the sample is drawn. Quickly analyzing the sample ensures the highest quality and timely decisions.

4.10 Oil Sampling Frequency

The objective of oil analysis, like condition monitoring in general, is to find bad news. The objective of proactive maintenance is to manage bad news away. The machine and oil will generally give off silent alarms when problems first occur. In time, as the severity increases, these alarms are no longer silent and even the most rudimentary condition monitoring methods can reveal the problem. Of course, at this point, a great deal of damage has probably occurred. And, it is likely too late to arrest the problem on the run; the machine may have to be torn down and repaired.

Machine Type	Hours
Diesel engines - off highway	150
Transmission, differentials, final drives	300
Hydraulics - mobile equipment	200
Gas turbines - industrial	500
Steam turbines	500
Air/gas compressors	500
Chillers	500
Gear boxes - high speed/duty	300
Gear boxes - low speed/duty	1000
Bearings - journal and rolling element	500
Aviation reciprocating engines	25-50
Aviation gas turbines	100
Aviation gear boxes	100-200
Aviation hydraulics	100-200

Table 1 - Commonly Recommended Oil Sampling Frequencies

One of the extraordinary benefits of oil analysis is its incredible sensitivity to these silent alarms and the detection of incipient failures and faults. The methods of doing this successfully are discussed in later chapters. However, it is a very basic principle that you can't hear an alarm unless you are listening for it – restated, you can't catch a fish unless your hook is in the water. Unlike other machine condition monitoring techniques that employ monthly testing, many oil analysis programs are based upon annual or semi-annual sampling. This sampling infrequency compromises the powerful proactive and predictive capabilities of oil analysis.

Scheduled sampling intervals are common in oil analysis. The frequency may be keyed to drain intervals or operating hours. Table 1 gives commonly recommended intervals based on operating hours for different machine classes. Proper selection of sampling frequency must be adjusted to consider the following machine and application-specific criteria:

- Penalty of Failure - Safety, downtime costs, repair costs, and general business interruption costs should be considered.

- Fluid Environment Severity - Operation and fluid environment conditions influence the frequency and rate of failure progress. These include pressures, loads, temperature, speed, contaminant ingression rate, and system duty cycle severity.

- Machine Age - For most machines the chances of failure are greatest during break-in and after major repairs and overhauls. Likewise, the risk increases as a machine approaches the end of its expected life. Increase sampling frequency during these periods.

- Oil Age - Infant oils and old oils are the highest risk. Infant oils are those that have just been changed and are less than 10% into expected life. Occasionally, the wrong oil is put in the machine during a change, or the new oil's condition is unsatisfactory for service. Old age oils can show trends that suggest additive depletion, the onset of oxidation, or high levels of contamination. Adjust sampling frequency accordingly.

4.11 Registering Equipment For Oil Analysis

For those samples sent to outside oil analysis laboratories, the necessary machine registration information needs to be completed and submitted to the laboratory. The registration should include machine description, machine history, environment and application information plus lubricant description and specifications. Below is a list and discussion of registration information to include:

- Machine Identification Name or Number - This could be an asset number, a serial number or a name. If the component to be sampled has more than one sample point, an additional identifier must be used to distinguish it from other sample locations.

- Unit Type - This identifies the component that is being sampled. Unit type is the most misidentified part of many equipment lists, and it is the most critical item of information from the standpoint of interpretation. The more information provided, the more specific the analyst can be in interpreting the data. For example, "compressor" is not a valid unit type, inboard compressor roller bearing oil is (assuming more than one oil system or sampling point exists). Hydraulic press brake is not a valid unit type, high-pressure vane pump hydraulics is. Many labs have tables of standards based on specific detailed unit types. If the identification is not specific enough, it may mean that the sample will go through a "generic" table of standards. Therefore, it is usually worth the effort to try to obtain specific information on the unit to be sampled.

• Manufacturer and Model of Machine or Component - If the component is a centrifugal pump for instance, the make and model of the pump is needed. If it is a hydraulic system the make and model of the hydraulic pump is needed. This information is helpful in identifying the metallurgy, and the ranges of wear metals that can be expected under normal conditions.

• Fluid Manufacturer, Fluid Type (name) and Grade (ISO or SAE for instance) - A complete identification of the fluid is nearly as important as the component information. Many labs use tables of standards against which used oil physical and chemical properties are compared. If an oil type is not properly identified it will be compared to the wrong standard leading to erroneous conclusions.

• Operating and Environmental Conditions - Collateral information about the application and the environment in which the machine must operate is beneficial to the analyst during evaluation of the oil analysis data.

4.12 Sample Bottle Labels and Identification

The use of sample bottle labels is more than simply an identification system. The label and/or accompanying documentation identifies key information about the sample, the machine, and the required tests including any special instructions. While a great deal of information is supplied during registration on machine and component histories, changes are always occurring, many of which affect the oil analysis results. Below is a list of common information that needs to be supplied with the oil sample:

- Machine I.D.
- Sample point
- Date sampled
- Hot or cold running conditions
- Hour meter (or approximate level of machine usage since the last sample taken)
- Last fluid change
- Last addition of makeup fluid and amount
- Last major service, repair, or overhaul
- Last filter change
- Reported machine/fluid abnormalities by operator or technician
- Requested test bundle including any required special or exception tests

Many software packages provide for automatic printing of bottle labels. While this is very convenient, the importance of supplying information related to current conditions is equally valuable to maximizing the benefits of oil analysis. Some of the items in the above list relate to current operating information. Often this is communicated on a standard form that accompanies the sample bottle and is placed in the mailer or package along with the sample bottle. As the samples are logged into the computer by the lab, the information on the form is an input as well. Then, the analyst has a complete picture of current condition of the machine to consider in the evaluation of the oil analysis data.

5. Oil Testing and Analysis

Oil analysis is a broad field comprised of hundreds of individual tests that provide meaningful benefit by assessing one or more properties of a lubricant or machine. Many of the tests provide information about new oils where the fluid's chemical, physical or lubricating properties are evaluated for the purposes of quality control, product development and product performance classification.

Used oil analysis, our focus, differs substantially from new oil analysis. The objective of used oil analysis is to evaluate the condition of oils that are in service and to evaluate the condition of the machine being lubricated. In machine condition monitoring applications the lubricant serves merely as the carrier of the information that is generated by the machine in the form of contamination or wear debris.

In used oil analysis, a small number of tests are performed regularly to support important machine and lubricant decisions. This chapter provides an overview of these common oil analysis tests. This material will serve as the foundation for Chapter 6 where evaluative processes and information management techniques are discussed.

5. 1 Reasons for Performing Oil Analysis

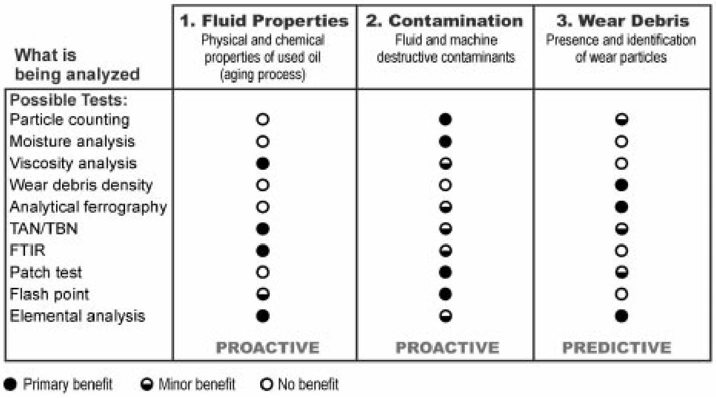
Essentially, oil analysis is performed to improve the quality of machine and lubrication maintenance decisions. There are three important categories of oil analysis:

- Fluid properties analysis - This category of oil analysis deals with the assessment of the chemical, physical and additive properties of the oil.

- Contamination analysis - Contaminants are foreign matter that enter the system from the environment or are generated internally. Contamination compromises machine reliability and promotes lubricant failure. Oil analysis ensures that goal-driven targets for contamination control are maintained.

- Wear debris analysis - When components wear, they generate debris. Monitoring and analyzing the generated debris enables technologists to detect and evaluate abnormal conditions so that effective maintenance decisions can be made and implemented.

Typical used oil analysis tests and their benefit to the three categories of oil analysis are tabulated in Figure 5-1.



What is being analyzed	**1. Fluid Properties** Physical and chemical properties of used oil (aging process)	**2. Contamination** Fluid and machine destructive contaminants	**3. Wear Debris** Presence and identification of wear particles
Possible Tests:			
Particle counting	○	●	◒
Moisture analysis	○	●	○
Viscosity analysis	●	◒	○
Wear debris density	○	○	●
Analytical ferrography	○	◒	●
TAN/TBN	●	◒	◒
FTIR	●	◒	○
Patch test	○	●	◒
Flash point	◒	●	○
Elemental analysis	●	◒	●
	PROACTIVE	PROACTIVE	PREDICTIVE

● Primary benefit ◒ Minor benefit ○ No benefit

Figure 5-1

5.2 Review of Common Used Oil Analysis Tests

5.2.1 Particle Count -The particle count method gives the number of particles in specified size ranges per fluid volume (usually per ml or 100 ml). Also, particle concentration and distribution data may be expressed in terms of ISO 4406 Cleanliness Codes (see Figure 5-2) and by other less frequently used codification systems like NAS 1638 and SAE 749 (disavowed). Particles can be counted manually with optical microscopy techniques, or automatically using optical or pore-blockage type particle counters. Regardless of the method selected, it is recommended that

ISO 4406 Cleanliness Code

Number of particles per mL		Range Number (R)
More than	Up to and including	
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	0.02	1

Figure 5-2

the same method be used consistently to ensure that results are comparable. Below is a list of possible causes for non-conforming particle count readings:

- Sampling error - Poor control over sampling procedures will result in false positive or false negative particle count readings depending upon the nature of the sampling process failure. It is always advised to re-sample and retest when a high or low particle count is observed to eliminate sampling error from the list of possible causes.

- Instrument error - A particle counter is subject to calibration related errors as is any instrument. The calibration of the instrument should be regularly verified.

- Testing procedure error - Samples must be aggressively shaken with a paint shaker before testing commences to evenly distribute the particles in the oil. Likewise, when using an optical particle counter, entrained air and suspended water must be completely removed prior to testing.

- Dirt ingestion - Dirt entering the system through seals, breathers and new oil will lead to an increased particle count. Diagnose according to the flow chart in Figure 5-3.

- Filter failure - When a filter is full and in bypass, or fails in some way, the particle count will increase. Diagnose

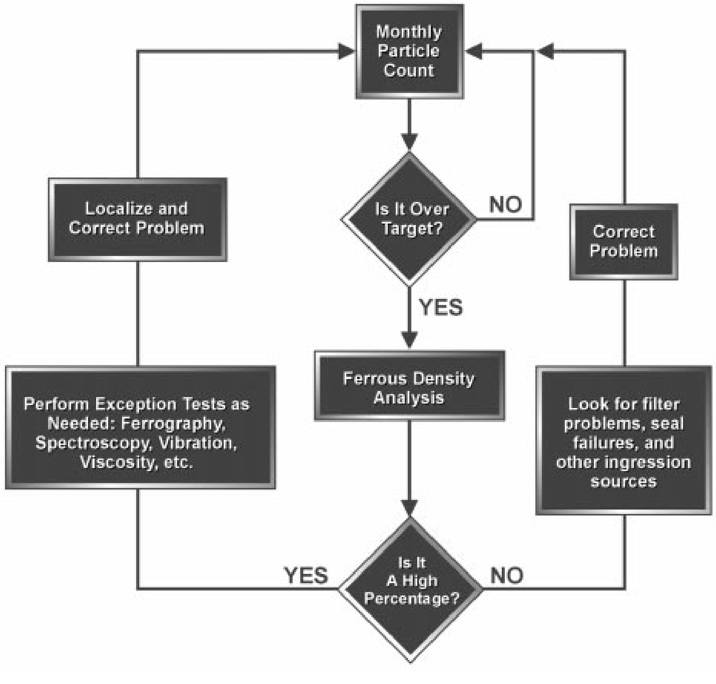


Figure 5-3

according to the flow chart in Figure 5-3.

- Generated wear - When machine components are abraded or fatigued, wear particles are released into the oil causing an increase in particle count. Diagnose according to the flow chart in Figure 5-3.

Applicable Standards: ISO 11171, ISO 4406, ISO 11500

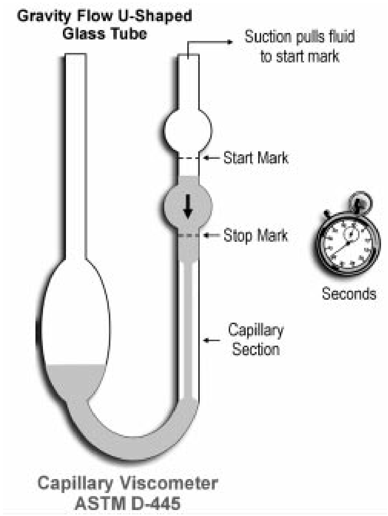
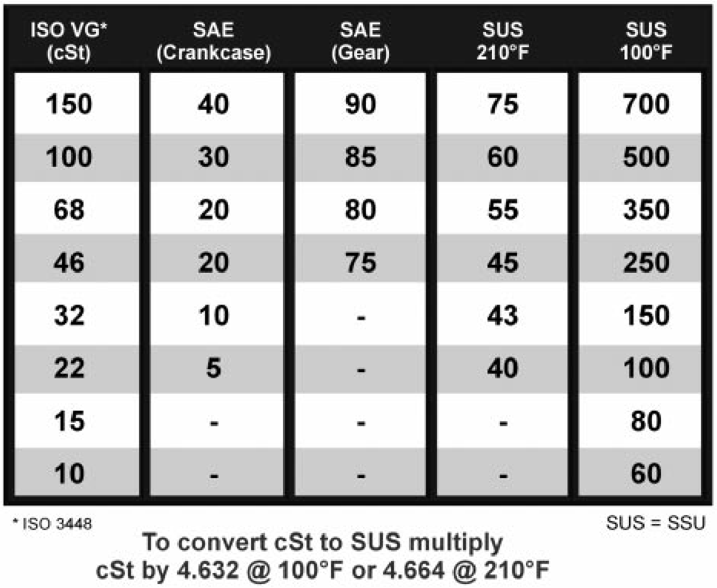


Figure 5-4

5.2.2 Viscosity - Kinematic viscosity is a measure of a fluid's resistance to flow under gravitational forces. It is determined by measuring the time, in seconds, required for a fixed volume of fluid to flow a known distance under gravity through the capillary of a calibrated viscometer under a reproducible driving head of pressure at a closely controlled temperature (see Figure 5-4). This value can be converted to the units of centistokes (cSt) or Saybolt Universal Seconds (SUS) as shown in Figure 5-5.



ISO VG* (cSt)	SAE (Crankcase)	SAE (Gear)	SUS 210°F	SUS 100°F
150	40	90	75	700
100	30	85	60	500
68	20	80	55	350
46	20	75	45	250
32	10	-	43	150
22	5	-	40	100
15	-	-	-	80
10	-	-	-	60

* ISO 3448

SUS = SSU

To convert cSt to SUS multiply cSt by 4.632 @ 100°F or 4.664 @ 210°F

Figure 5-5

Viscosity reporting is only valid when the temperature at which the test was conducted is reported, e.g., 32 cSt @ 40° C.

Viscosity affects equipment operation, friction losses and the oil film thickness in bearings. Its measurement and trending is, therefore, critical to used oil analysis. Even modest changes in viscosity may adversely influence the lubricant's performance and stability, possibly causing metal-to-metal contact and wear. Change in a lubricant’s viscosity is also a common symptom of a host of other problems.

The rate of viscosity change from oil degradation depends upon the presence of thermal and oxidative stressing agents that are in the system. A change in viscosity may also result from the following:

- Excessive amounts of contamination such as water, fuel, glycol, solvents, and/or very small particles

- Severe chemical degradation, usually due to oxidation
- Volatilization of the light ends of the base stock
- Topping up with the incorrect viscosity grade
- Severe mechanical shearing of the oil

Investigate the source of the changes in viscosity by analyzing under- or over-limit viscosity according to the flow model described in Figure 5-6. As required, refer the following tests as collateral information to determine the root cause for the problem:

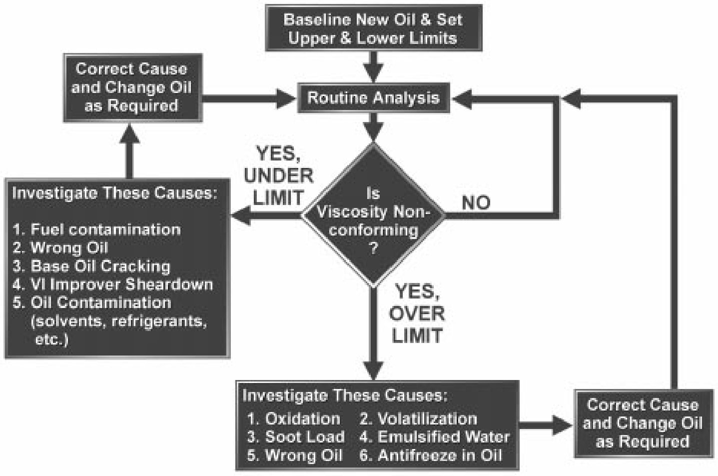


Figure 5-6

- Water content
- Flash point
- Elemental spectroscopy (for contaminants like glycol and reactive metals)
- Oxidation stability

- Neutralization number for chemical degradation
- Infrared spectroscopy and other tests for volatilization, chemical contamination and/or mechanical shearing

Applicable Standards: ASTM D445

5.2.3 Neutralization Number - Total Acid Number (TAN) - Applied to industrial (non-crankcase) oils, the total acid number (TAN) number is a measure of the total acid concentration of the oil. The TAN test result is expressed as the volume (milligrams) of potassium hydroxide (KOH) required to neutralize all the acidic components in one gram of sample oil. The reported unit is mg KOH/gm of oil. TAN can be quantified by either colorimetric or potentiometric titration methods although for dark colored oils the latter method should be used.

Some of the oil's additives, i.e., anti-rust and anti-wear additives can produce a rather high initial TAN value. Over time this value can decrease slightly as additives deplete. As the oil ages and oxidizes, small amounts of acidic by-products are formed in the oil causing the TAN to increase. The degree to which TAN has increased over and above the new oil's baseline TAN is an indication of the extent to which the oil has degraded. A high TAN typically indicates the oil's useful life has expired and it needs to be changed. TAN above 4.0 is highly corrosive, attacking bearing materials and other metal surfaces. This risk is increased in the presence of water contamination which strengthens the corrosive potential of acids.

A slow increase in TAN over a long period of use is considered normal. Rapid change in TAN may be caused by one or more of the following:

- Severe oxidation of oil

- Depletion of some additives (anti-wear, EP and rust-preventing)
- Large make-up of the incorrect oil such as anti-wear hydraulic oils or gear oils that have high baseline TAN values

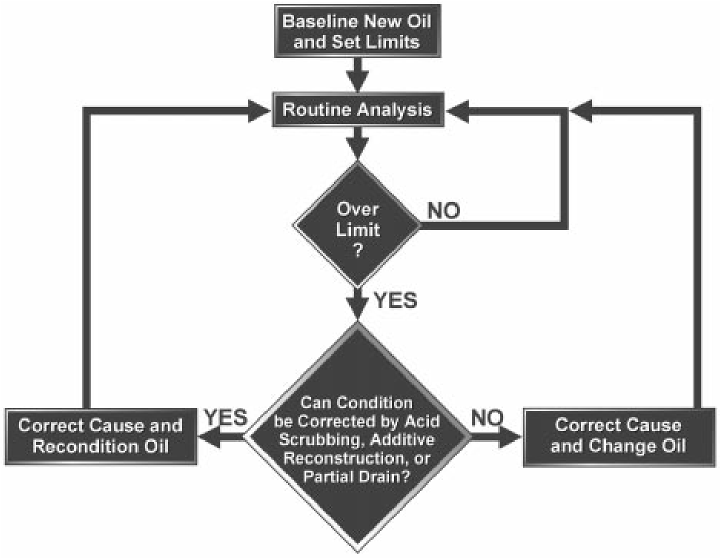


Figure 5-7

Diagnose TAN numbers according to the flow model on Figure 5-7. Employ the following collateral test as required to determine the problem's root cause:

- Elemental spectroscopy
- FTIR spectroscopy
- Moisture detection or quantification
- Viscosity
- RBOT

Applicable Standards: ASTM D664, ASTM D974

5.2.4 Neutralization Number - Total Base Number (TBN) - Applied primarily to crankcase applications, TBN measures the reserve alkalinity of an oil. Engine oils are equipped with additives that provide reserve alkalinity to neutralize the acids that are generated during combustion. Once this reserve is depleted, the oil can become highly corrosive. Like the TAN test, the TBN test is performed by colorimetric or potentiometric titration (usually potentiometric due to the darkness of engine oil). But in the case of TBN the alkaline oil is neutralized with hydrochloric (preferred for used oil analysis) or perchloric acid. Results are reported in mg KOH/gram of oil, same as the TAN test which can be confusing. The result is actually a derived value that represents the volume KOH that is required to neutralize the volume of TBN reagent acid required to neutralize the alkaline sample on which TBN is desired. In this way, the units are synchronized,

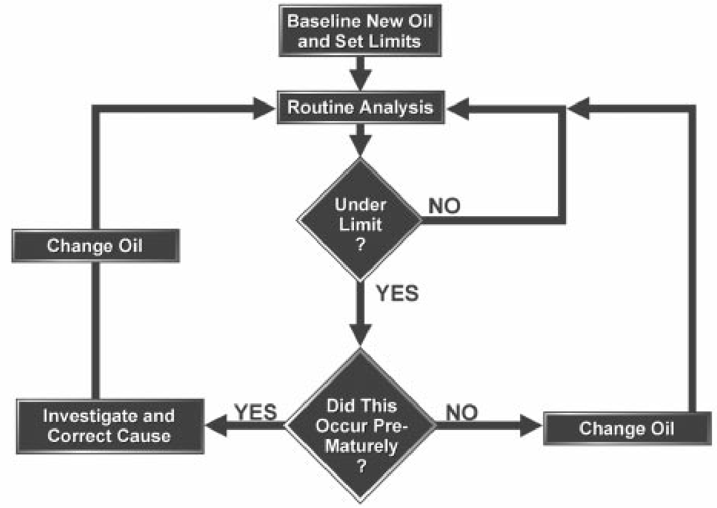


Figure 5-8

i.e., one unit of TBN neutralizes one unit of TAN.

TBN numbers trend steadily downward as the oil's reserve alkalinity is depleted by combustion and oxidative acids. Rapid change in TBN may be caused by one or more of the following:

- Burning high sulfur fuel
- Abnormal fuel dilution
- Poor combustion
- Excessive blowby
- Soot contamination
- Severe oxidation
- Overextended drain interval
- Wrong oil addition
- Glycol dilution

Interpret TBN numbers according to the flow model on Figure 5-8. If TBN numbers change rapidly, determine the root cause and enact corrective actions.

Applicable Standards: ASTM D974, ASTM D2896, ASTM D4739

5.2.5 Fourier Transform Infrared (FTIR) Spectroscopy - FTIR is a method that provides a rapid means to monitor multiple oil parameters simultaneously. To conduct a test, a fixed thickness of oil is applied to the FTIR instrument's test cell through which infrared energy is passed. Numerous oil properties, additives and contaminants absorb infrared energy at a particular infrared frequency. A Fast Fourier Transform (FFT) is applied to create a frequency spectrum of attenuated (absorbed and reflected) infrared energy, or transmitted infrared energy (preferred method). The spectrum of the used oil is compared to the baseline of an identical new oil for analysis of contaminants such as soot, water, glycol, fuel, chemical solvents, anti-wear and oxidation inhibiting additives, and lubricant degradation caused by oxidation, nitration and sulphation.

Infrared spectroscopy is unique in that it assesses the constituent components of the oil sample at the molecular level. This information is very useful when the existence of compounds such as additives and oxidation byproducts is of interest.

Contamination by water, soot, glycol, incorrect make-up oils and chemical solvents can all be monitored using FTIR. The analyst or instrument software looks for a spectral peak at specific absorption frequencies called wavenumbers (see Figure 5-9). Soot produces a broadband spectrum shift so a wavenumber where no other significant activity occurs is selected for soot measurement.

Parameter	Wavenumber (cm^{-1})
Oxidation	Mineral Oil - 1750
	Organic Ester - 3540
	Phosphate Ester - 815
Sulfation	1150
Nitration	1630
Soot	2000
Water	Mineral Oil - 3400
	Organic Ester - 3625
Glycol	880, 3400, 1040 and 1080
Fuel	Diesel - 800
	Gasoline - 750
	Jet Fuel - 795 - 815
Phenol Inhibitors	3650
ZDDP Anti-wear/Anti-oxidant	980

Figure 5 - 9

Lubricant health can also be monitored using FTIR. Oil degradation caused by oxidation, sulphation and nitration all result in wavenumber-specific known absorption corresponding to these components. A decrease in absorption at spectral bands relating to certain additives can also be observed.

For a number of reasons, many labs do not consider FTIR results to be sufficiently conclusive by themselves. However, when combined with many other routine tests, FTIR can offer valuable supporting information relating to fluid properties and contamination.

Applicable Standards: Equipment supplier specific

5.2.6 Ferrous Density - An increase in the population of large (> 5 microns) ferrous particles usually suggests the presence of an abnormal wear condition and should serve as a warning of impending failure. Several methods are available for determining the concentration of ferrous debris. The severity of the wearing event is generally proportional to the increase in generation rate of large particles. The ferrous density measurement units reported vary by equipment supplier.

An increase in the generation of ferrous particles can be brought about by a number of factors, including:

- Load changes caused by increased production
- Eccentric loads caused by imbalance or misalignment
- Insufficient lubrication caused by wrong lubricant, low reservoir/sump volume, additive depletion or lubricant degradation
- Contamination by particles, water, air, coolant, fuel, solvents, etc.
- Component fatigue and wear

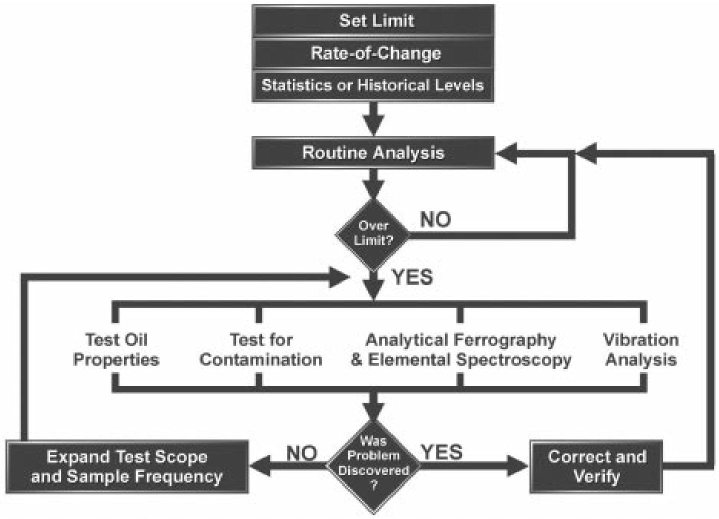


Figure 5-10

When abnormal wear is detected, apply the following diagnostic process (refer to the flow model in Figure 5-10):

- Localize the source of the debris with secondary port sampling
- Assess the rate at which wear is being generated to determine severity
- Analyze the debris with analytical ferrography and elemental spectroscopy to determine the nature and severity of the problem
- Employ oil analysis, vibration analysis and other collateral information to determine the root cause

Applicable Standards: Equipment supplier specific

5.2.7 Analytical Ferrography - An exception diagnostic test, analytical ferrography involves the analysis of debris deposited onto a ferrogram slide or filtergram membrane.

Analysis of particle morphology (shape), color, size, reflectivity, color, surface appearance, edge detail, angularity, elemental content and relative concentration provides the analyst with clues about the nature, severity and root cause of a wearing problem. Below is a brief summary of the microscopic wear debris analysis method:

- Particles are deposited onto a glass substrate (ferrogram) or a filter membrane disc (filtergram).
- An instrument called a ferrogram maker aligns the ferrous particles (and other magnetic metals) along magnetic gradients on the glass substrate. Other particles tend to settle gravitationally (random) on the slide. The analyst uses magnetism to differentiate the debris (primarily ferrous versus non-ferrous).
- Treatment with heat and/or chemicals further helps to establish the metallurgy of the particles in the sample.
- Particles are evaluated with respect to light effects. Organic materials and oxides transmit light while metallic particles reflect it.
- The size and shape of the particles are evaluated to assess what mechanisms caused their formation.

The wear analyst typically reports upon the presence of numerous wear particles, friction polymers, dirt and sand, fibers and other solid contaminants on a 1 to 10 or 1 to 100 scale to reveal severity. Descriptive text and photomicrographs usually accompany the enumerated values to clarify conclusions and recommend corrective actions.

An increase in the generation of wear particles can be brought about by a number of factors including:

- Increased loads due to production speed-ups or increases
- Eccentric loads caused by imbalance or misalignment

- Insufficient lubrication caused by wrong lubricant, low reservoir/sump volume, additive depletion or lubricant degradation
- Contamination by particles, water, air, coolant, fuels, solvents, etc.
- Component fatigue and wear

Analytical ferrography, when combined with tests for oil degradation, contamination, vibration analysis, thermography, etc., usually represents the terminal point in the oil analysis evaluation of an abnormal wearing event prior to failure. It is important to determine the root cause of the problem so it can be eliminated, avoiding recurrence of the symptom. As described in the flow model in Figure 5-11 the analyst attempts to answer the following questions when performing analytical ferrography:

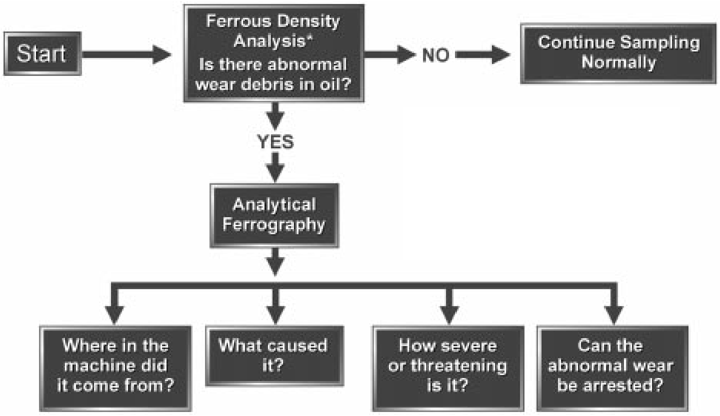


Figure 5-11

- Where in the machine did the wear originate?
- What caused it?
- How severe or threatening is it?

- Can the abnormal wear be arrested?

Applicable Standards: Equipment supplier specific

5.2.8 Rotating Bomb Oxidation Test (RBOT) - This test method utilizes an oxygen-pressured bomb (vessel) to evaluate the oxidation stability of the sample oil at high temperatures in the presence of water and a copper catalyst coil. The bomb is charged with oxygen to a pressure of 620 kPa (90 psi), placed in a constant-temperature oil bath at 150°C, and rotated axially at 100 rpm at an angle of 30°. The number of minutes required to reach a specific drop in gauge pressure for a used oil is compared to the reference number of minutes required for a new oil. A significant change between the new and used oil relates to a change in an oil's oxidation stability and remaining useful life (RUL).

Oil degradation begins with the formation of chemically unstable compounds from the hydrocarbons and these compounds are then easily oxidized thereby initiating the chain reaction. The final products are resins and sludge which accumulate in the bearing passages, coolers, strainers, valves (causing sticking) and the oil reservoir. It can also cause valve sticking. In addition, oxidation may increase the oil's viscosity and form complex organic acids which can increase the neutralization number (TAN).

A slow decrease in the oxidation stability over a long period of service is considered to be normal; however, it should not be allowed to progress too far. The rate of oil oxidation can increase rapidly in the presence of the following conditions:

- Decreased capability of the oil to resist oxidation due to anti-oxidant additive depletion or removal

- Increased oil or metal temperatures
- Contaminants such as metal particles and nascent metal surfaces act as oxidation promoters
- Increased air content of the oil operating at low levels
- Increased presence of water
- Increase in oil pressure

Diagnose RBOT data according to the flow model in Figure 5-12. If the oxidative life is normal no additional testing or action is required. If the RUL is abnormal (short), consider the following corrective actions:

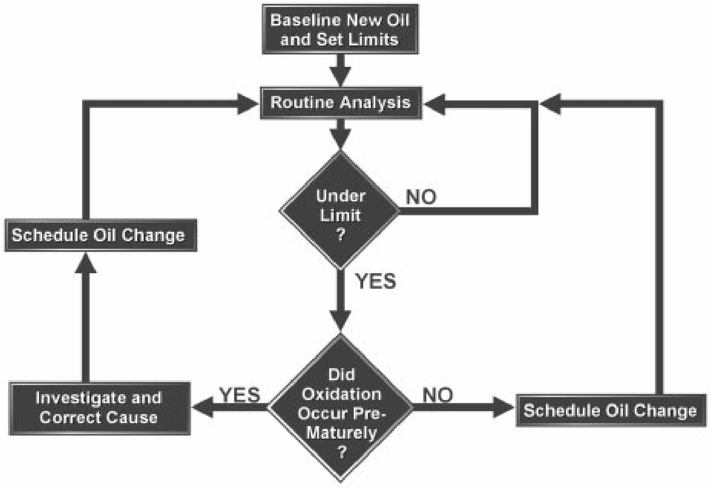


Figure 5-12

- Reduce oxidative stress (heat, air, water and reactive metals)
- Upgrade base-oil quality
- Upgrade the oil's anti-oxidant additive package

- Change the oil

Always investigate stressing conditions if RUL decays in an exceedingly short space of time.

Applicable Standards: ASTM D 2272

5.2.9 Water Content by Karl Fischer - The Karl Fischer test is usually performed after the sample is screened with the hot-plate "crackle test" or FTIR. Karl Fischer reports water content as concentration in percentage or parts per million (ppm) of the "total" water (free and dissolved) in the oil sample. In the test, the oil is titrated with a standard iodine containing Fischer reagent to an electrometric end point. The accuracy of the test is affected by the presence of sulfur containing additives such as anti-wear agents, rust-inhibitors and EP anti-scuffing agents.

Water rusts iron and steel surfaces, accelerates corrosion, depletes and degrades additives, promotes base-oil oxidation, and reduces lubricant effectiveness. Large amounts of water form persistent emulsions that join with insoluble oxidation products to form a sludge and may significantly impair machine reliability. In addition, free water may cause the formation of hard brittle deposits on bearing surfaces and promote bacteria growth.

Look for the following causes of increased water content:

- Topping-up with water-contaminated fluid
- Ineffective operation of a vapor extraction system
- Leaking oil coolers
- Excessive leakage from turbine gland steam seals
- Washdown sprays and leaky hatches
- Condensation in the reservoir

Diagnose the aberrant condition according to the flow model in Figure 5-13 and identify and eliminate the source of the water ingress.

- If high water content is caused by accidental contamination (with new oil) review the existing make-up procedure to avoid similar problems in the future.

- Ensure that there are no air leaks bypassing the reservoir's cover seals and that the vapor extraction fans are operating properly. With regard to the fans, too low a vacuum can cause a build up of humidity whereas too high a vacuum can pull in more gland steam or cause oil carryover.

- Check the oil coolers for leaks. To detect cooler leaks, the cooling water discharge at the coolers should also be checked for traces of the oil. Also, the inventory control, i.e., make-up, should be reviewed to determine if the oil use has been higher than normal. If the leak can't be detected, charge the system with pressure in isolated seg-

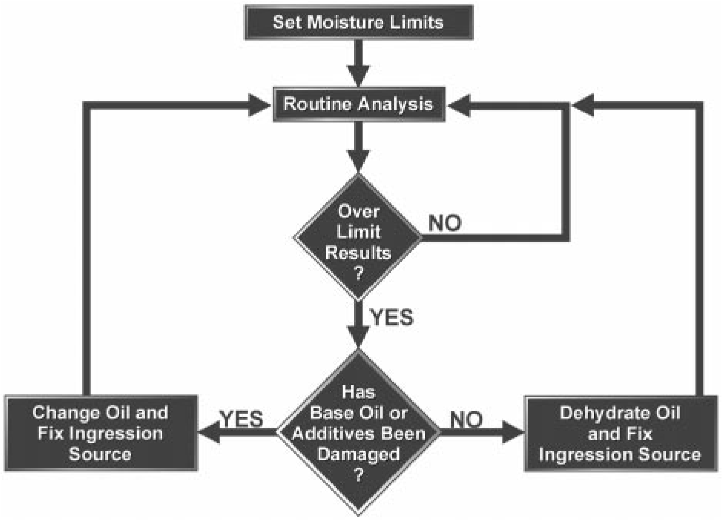


Figure 5-13

ments and look for a pressure drop to indicate the leaking area.

- If the turbine gland steam seals are suspected as the source of the water ingress, check the gland inlet and outlet pressure and regulate as required where gland conditions permit. In addition, consider inspecting the glands during the next outage.

Applicable Standards: ASTM D1744, ASTM D4928

5.2.10 Elemental Spectroscopy - Elemental spectroscopy quantifies the presence of dissolved and some undissolved inorganic materials by element in the oil. Most elemental spectrometers used today for oil analysis are the atomic emission type. These instruments work by exposing the sample to extreme temperatures generated by an arcing electrode or by an argon plasma torch. The extreme heat vaporizes the atoms causing them to emit energy in the form of light. Each atomic element emits light at a specific frequency. The spectrometer quantifies the amount of light generated at each frequency and calculates the concentration of each element (iron, lead, tin, etc.) in parts per million (ppm) or parts per billion (ppb).

Most elemental spectrometers report the concentration of 15 or more elements. The elements reported can provide an indication of increased generation of wear, ingress of contamination or depletion of certain additive elements.

Atomic emission spectroscopy is particle-size limited. Dissolved metals and suspended particles up to approximately two microns are detected with high accuracy. The accuracy diminishes as particle size increases up to five microns. Elemental concentrations can be greatly understated for particles larger than five microns.

Element	Wear	Contamination	Additive
Iron (Fe)	X	X	
Copper (Cu)	X	X	X
Chromium (Cr)	X		
Tin (Sn)	X		
Aluminum (Al)	X	X	
Lead (Pb)	X		
Silicon (Si)		X	X
Sodium (Na)		X	X
Boron (B)		X	X
Calcium (Ca)		X	X
Magnesium (Mg)		X	X
Zinc (Zn)	X		X
Phosphorous (P)		X	X
Molybdenum (Mo)			X
Potassium (K)		X	

Figure 5 - 14

Increasing or decreasing elemental concentration can signal a change in the generation of wear debris, the ingress of contaminants and the addition or depletion of additives. The table in Figure 5-14 generally categorizes the common elements observed with oil analysis as wear, contamination or additives.

Consider the following discussion when diagnosing non-conforming elemental data.

- An increase in the concentration of such elements as iron, copper, chromium, tin, aluminum and lead suggest that abnormal wear is occurring. Further steps should include analysis of the debris with complementary testing to determine its severity, nature, origin and root cause (see Figure 5-15).

- Increasing concentration of silicon, sodium, boron, calcium and magnesium can signal the ingress of contamination. A lock-step increase in silicon and aluminum typically suggests dirt ingress, although silicon is also the primary element found in anti-foaming additives (silicone) which can cause confusing results. Increasing levels of sodium and boron may signal the ingestion of glycol-based coolant (see Figure 5-16). Calcium and magne-

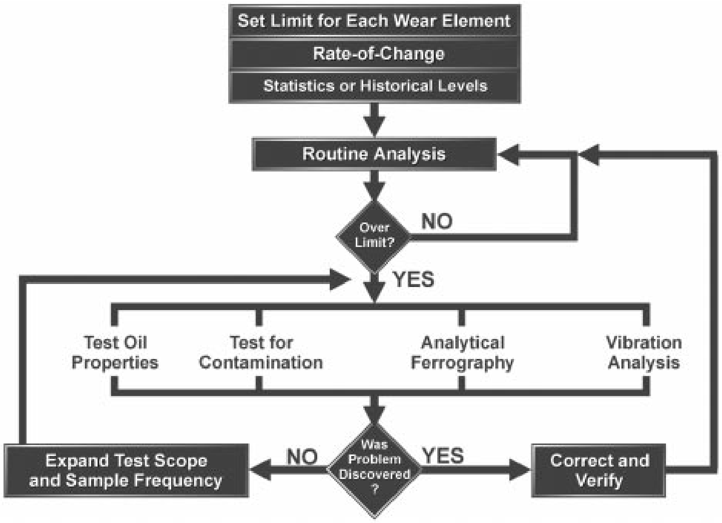


Figure 5-15

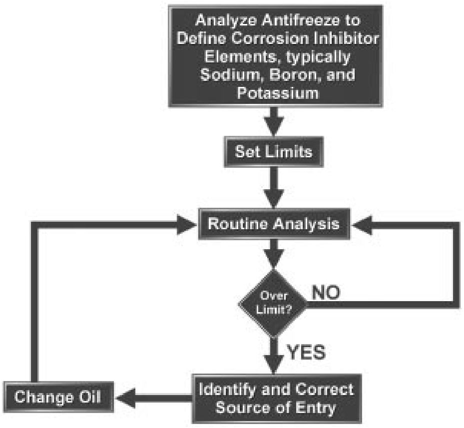


Figure 5-16

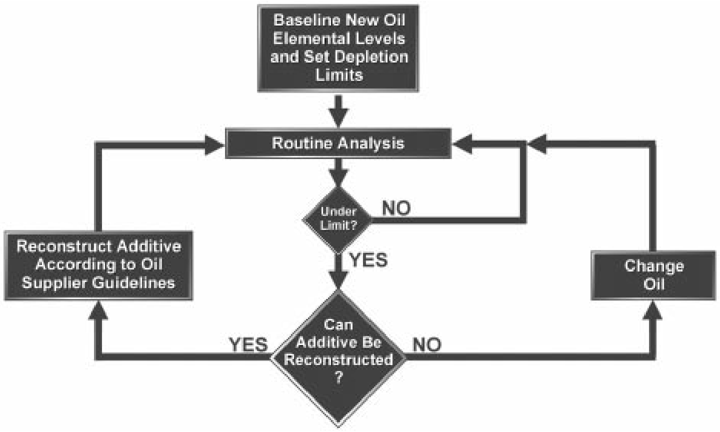


Figure 5-17

sium are often present when hard water is ingested due to spray downs or cooling system leaks, but they are also common elements found in engine oil additives.

- Numerous elements are used in a multitude of additives. For instance, zinc and phosphorous are common in anti-wear additives; sulfur, phosphorous and molybdenum are common components of extreme pressure additives; and calcium and magnesium are frequently components of engine oil alkalinity improvers. Knowledge of the new oil baseline is critical to trending additive depletion with elemental spectroscopy (see Figure 5-17).

Applicable Standards: ASTM D4951

5.2.11 Flash Point Test - The flash point identifies the presence of volatile molecules from fuel and other flammable contaminants. The test is conducted by placing the oil in a cup positioned under an open flame (applied periodically). The oil in the open cup is slowly heated and its temperature measured. The temperature at which the fluid emits sufficient vapors mixed with air to produce a flash

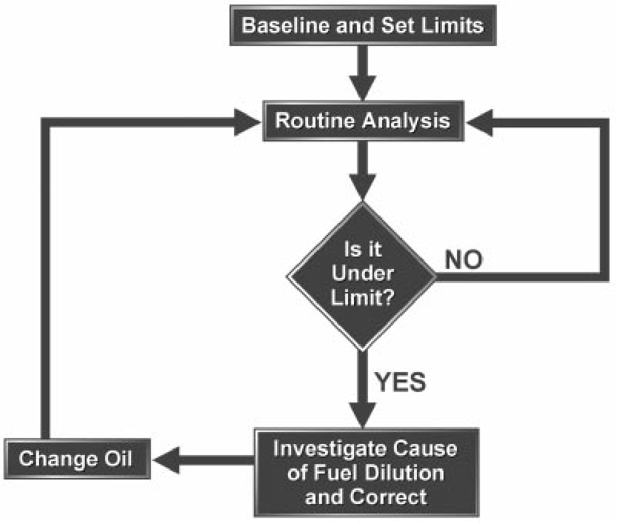


Figure 5-18

on the surface of the oil is the endpoint for the test. Many laboratories simply test up to a specified temperature and report pass/fail information.

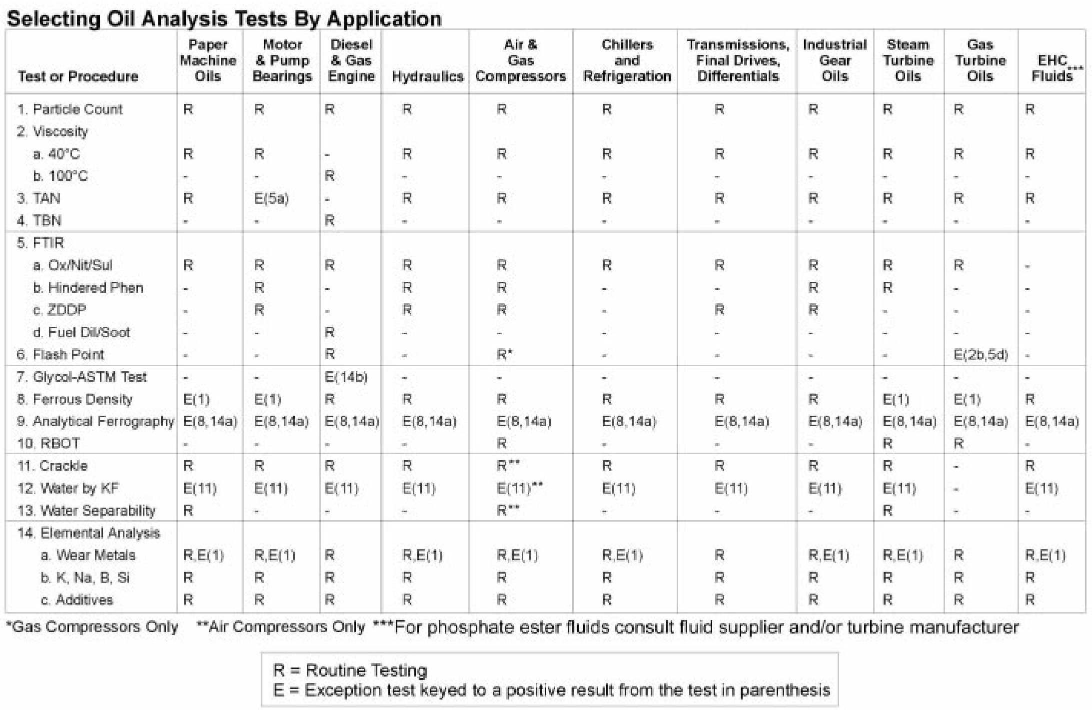
This test is important for engine oils as it measures the amount of fuel dilution in the oil. Fuel or chemical dilution severely impairs the lubricant's effectiveness and can cause fire or explosion hazard.

Refer to Figure 5-18 in evaluating fuel dilution data.

Applicable Standards - ASTM D92, ASTM D93

5.3 Selecting the Test Slate

It is important that the oil analysis test slate include those tests that provide meaningful information for a specific piece of equipment. Some tests are routine in nature while others are exceptional tests, triggered by the abnormal level of a routine test. Figure 5-19 describes the appropriate routine and exception test slate for typical machine types.



Selecting Oil Analysis Tests By Application

Test or Procedure	Paper Machine Oils	Motor & Pump Bearings	Diesel & Gas Engine	Hydraulics	Air & Gas Compressors	Chillers and Refrigeration	Transmissions, Final Drives, Differentials	Industrial Gear Oils	Steam Turbine Oils	Gas Turbine Oils	EHC Fluids***
1. Particle Count	R	R	R	R	R	R	R	R	R	R	R
2. Viscosity											
a. 40°C	R	R	-	R	R	R	R	R	R	R	R
b. 100°C	-	-	R	-	-	-	-	-	-	-	-
3. TAN	R	E(5a)	-	R	R	R	R	R	R	R	R
4. TBN	-	-	R	-	-	-	-	-	-	-	-
5. FTIR											
a. Ox/Nit/Sul	R	R	R	R	R	R	R	R	R	R	-
b. Hindered Phen	-	R	-	R	R	-	-	R	R	-	-
c. ZDDP	-	R	-	R	R	-	R	R	-	-	-
d. Fuel Dil/Soot	-	-	R	-	-	-	-	-	-	-	-
6. Flash Point	-	-	R	-	R*	-	-	-	-	E(2b,5d)	-
7. Glycol-ASTM Test	-	-	E(14b)	-	-	-	-	-	-	-	-
8. Ferrous Density	E(1)	E(1)	R	R	R	R	R	R	E(1)	E(1)	R
9. Analytical Ferrography	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)	E(8,14a)
10. RBOT	-	-	-	-	R	-	-	-	R	R	-
11. Crackle	R	R	R	R	R**	R	R	R	R	-	R
12. Water by KF	E(11)	E(11)	E(11)	E(11)	E(11)**	E(11)	E(11)	E(11)	E(11)	-	E(11)
13. Water Separability	R	-	-	-	R**	-	-	-	R	-	-
14. Elemental Analysis											
a. Wear Metals	R,E(1)	R,E(1)	R	R,E(1)	R,E(1)	R,E(1)	R	R,E(1)	R,E(1)	R	R,E(1)
b. K, Na, B, Si	R	R	R	R	R	R	R	R	R	R	R
c. Additives	R	R	R	R	R	R	R	R	R	R	R

*Gas Compressors Only **Air Compressors Only ***For phosphate ester fluids consult fluid supplier and/or turbine manufacturer

R = Routine Testing
E = Exception test keyed to a positive result from the test in parenthesis

Figure 5-19

Targets, Limits, Diagnostics, and Data Management

6.1 Setting Limits and Targets

Historically, users of oil analysis have relied almost exclusively upon the commercial oil analysis laboratory or oil supplier to identify when a machine is in alarm. Realizing the limitations of this approach, world class organizations are taking charge of their own alarm setting to ensure that their specific objectives are met. The recent advent of sophisticated oil analysis software has put this objective within reach of most anyone who desires it.

The primary purpose for alarms, or limits, is to filter (funnel) data so that the technologist spends his time managing and correcting exceptional situations instead of perusing the data trying to find the exceptions. The alarm serves as a "trip-wire" to tell the analyst that a threshold has been passed and that action is required.

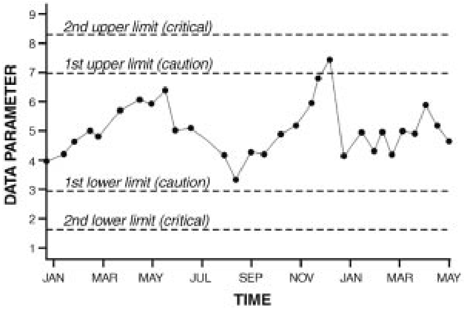


Figure 6-1

Some data parameters have only upper limits such as particle counts or wear debris levels. A few data parameters employ lower limits like TBN, additive elements, flash point, and FTIR (additive). Other data parameters like viscosity and FTIR use both upper and lower limits. These might relate to important chemical and physical properties of the lubricant such its viscosity (see Figure 6-1).

Alarming techniques vary to fulfill the requirements of different oil analysis objectives.

Proactive Alarms - Proactive alarms alert the user of abnormal conditions associated with controlling the root causes of machine and lubricant degradation. They are keyed to the proactive maintenance philosophy of setting targets and managing lubricant conditions within those targets. A strategic premise of proactive alarms is that they should be set to levels that will generate improvement over past performance, or ensure maintenance of levels at which performance has previously been optimized relative to organizational objectives. Within the proactive domain, we utilize the following types of alarms and limits.

- Goal-based Targets - Targets apply to the control of parameters like contamination to achieve machine life extension (see Figure 6-2). For example, a hydraulic machine running at ISO 18/15 cleanliness will experience a three-times life extension if the fluid is cleaned to to an ISO 15/12. Setting the limit at ISO 15/12 is a goal-based activity. Conversely, if the same hydraulic machine is running at ISO 15/12 and control is lost allowing the contamination level to reach ISO 18/15, we can expect a three times increase in wear during that period. The desire to return the system to an ISO 15/12 is driven by a specific objective, and is, therefore, a goal-based limit. This type of limit is usually applied to particle count, moisture level, glycol level, fuel dilution, TAN and other common root cause conditions.

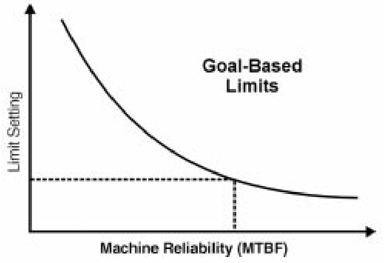


Figure 6-2

- Aging Limits - Another type of proactive limit or alarm relates to the progressive aging of a lubricant or hydraulic fluid (see Figure 6-3). From the moment a fluid is placed in service, its chemical and physical properties transition away from the ideal (i.e., those of the new formulated oil). Some properties transition very slowly, while others transition very dynamically. Limits keyed to the symptoms of lubricant deterioration are referred to as aging limits. Aging limits can be effectively applied to such parameters as TAN/TBN, viscosity, RBOT, elemental spectroscopy for additives, FTIR (oxidation, nitration, sulphation and additives) and dielectric constant. Figure 6-4 shows some example limits for both goal-based and aging parameters.

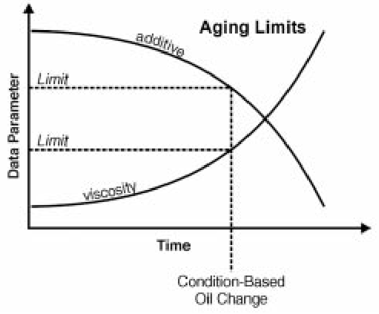


Figure 6-3

Goal-Based Limits (upper)			Aging Limits		
	Caution	Critical		Caution	Critical
Cleanliness	14/11	16/13	Viscosity	+5%	+10%
Dryness	200	600	RBOT	-30%	-60%
TAN	0.2	0.4	FTIR-Ox	0.3	1.0
Fuel	1.5%	5%	Zinc	-15%	-30%
Glycol	200 ppm	400 ppm	Calcium	-10%	-20%
Soot	2%	5%	TBN	-50%	-75%

Figure 6-4

Predictive Alarms - Predictive alarms signal the presence of abnormal machine conditions or the onset of wear and failure. They are aligned with the goals of predictive maintenance, i.e., the early detection of machine failure symptoms as opposed to failure root causes (proactive maintenance). In oil analysis, a properly set predictive alarm has many advantages over other predictive maintenance technologies, and as such, represents an excellent complement to vibration analysis, thermography, etc. Within the predictive domain, we utilize the following oil analysis alarming techniques.

- Rate-of-Change Based Alarms - Rate of change alarms are typically set to measure properties that are being progressively introduced into the oil, such as wear debris. The add rate (change) can be calculated per unit of time, hours, cycles, etc. For example, a 100 ppm increase in iron over a period of 100 operating hours could be stat-

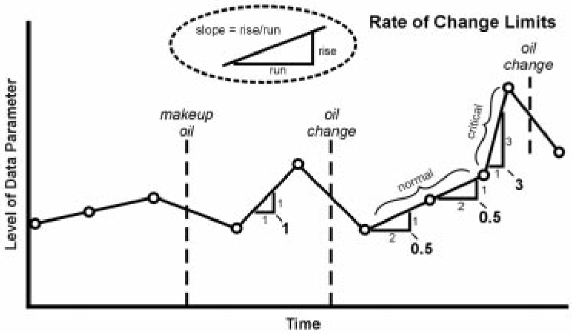
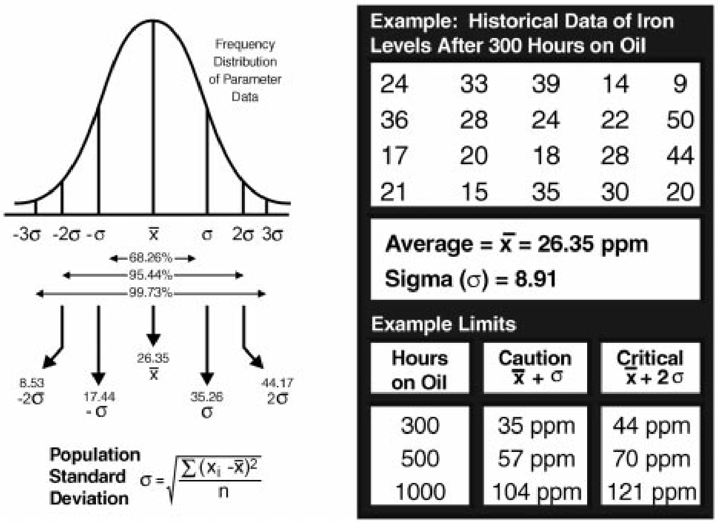


Figure 6-5

ed as one ppm per hour of operation. When the parameter is plotted against time, the rate-of-change (add rate) equals the current slope of the curve (see Figure 6-5). Unlike level limits, rate-of-change limits ignore the absolute value of the data parameter, emphasizing instead the speed at which the level is changing. Rate-of-change limits are effectively applied to particle counting (unfiltered systems), elemental wear metals, ferrous density, TAN and RBOT. It can also be effectively applied to monitor abnormal degradation of additives with elemental and FTIR spectroscopy.

- Statistical Alarms - For many years, statistical alarms have been used effectively in oil analysis. The practice requires the availability of a sufficient quantity of machine and application specific historical data from which to draw meaningful conclusions. The statistical alarming approach is simple (see Figure 6-6). A popula-



Population Standard Deviation $\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}}$

Example: Historical Data of Iron Levels After 300 Hours on Oil

24	33	39	14	9
36	28	24	22	50
17	20	18	28	44
21	15	35	30	20

Average = $\bar{x}$ = 26.35 ppm

Sigma (σ) = 8.91

Example Limits

Hours on Oil	Caution $\bar{x} + \sigma$	Critical $\bar{x} + 2\sigma$
300	35 ppm	44 ppm
500	57 ppm	70 ppm
1000	104 ppm	121 ppm

Figure 6-6

tion mean and associated standard deviation are generated from the available data. The data from a sample is compared to the mean of the population. If the value falls within one standard deviation of the mean, it is considered normal. If it falls outside of one standard deviation from the mean, but within two standard deviations, it is considered a caution. If the result exceeds two standard deviations, the value is considered in critical alarm

	Goal-Based	Age-Based	Change-Rate-Based	Statistics-Based
1. Particle Count	U	-	P	U
2. Viscosity				
a. 40° C.	U,L	U,L	-	-
b. 100° C.	U,L	U,L	-	-
3. TAN	L	U	P,N	U,L
4. FTIR				
a. Ox/Nit/Sul	-	U	P	U
b. Phenol	-	L	N	L
c. ZDDP	-	L	N	L
d. Fuel Dil/Soot	-	U	P	U
e. Water	U	-	P	P
5. Ferrous Density	-	-	P	U
6. Analytical Ferrography	-	-	-	-
7. RBOT	-	L	N	L
8. Water by Crackle	U	-	-	-
9. Water by KF	U	-	P	U
10. Water Separability	-	L	-	-
11. Elemental Analysis				
a. Wear Metals	-	-	P	U
b. Contaminants	U	-	P	U
c. Additives	-	L	N,P	L,U

Legend:
U = Upper Limit
L = Lower Limit
P = Positive Slope
N = Negative Slope
Note: Where alarms are bi-polar, the first shown is the most important.

Figure 6-7

as it is higher, or lower as the case may be, than 95% of the population. Should the value exceed three standard deviations, it is a critical situation indeed, as the value exceeds the 99th percentile of the population.

Figure 6-7 generally tabulates the applicability of different targeting and alarming techniques for specific oil analysis tests. It also identifies whether the target or alarm is upper, lower, or both.

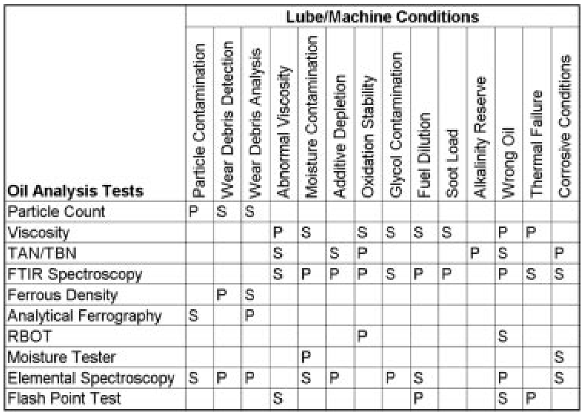
Statistical alarming methods are commonly applied to ferrous density, elemental metals and other predictive oil analysis measurements. While very useful in analysis, statistical data can result in false positives and negatives due to poor stratification of the data with respect to machine type, application and operating environment.

6.2 Interpreting and Applying Oil Analysis Results

Interpreting oil analysis data requires an understanding of the specific oil analysis tests, as described in chapter 5, and an understanding about how these tests interrelate when oil and machine conditions change. Reference the table in Figure 6-8 during the discussion of the primary and secondary oil analysis indications for typical abnormal conditions.

It is important to note that this section serves only as an introduction to evaluative diagnostics for oil analysis. Many generalizations are made that don't hold true under all conditions. A more detailed investigation of oil analysis diagnostics will be addressed in a later volume of this series.

6.2.1 Particle Contamination - An alarm on particle contamination signals an increase in suspended particles due to such occurences as the failure of a filter, ingestion of



	Lube/Machine Conditions													
Oil Analysis Tests	Particle Contamination	Wear Debris Detection	Wear Debris Analysis	Abnormal Viscosity	Moisture Contamination	Additive Depletion	Oxidation Stability	Glycol Contamination	Fuel Dilution	Soot Load	Alkalinity Reserve	Wrong Oil	Thermal Failure	Corrosive Conditions
Particle Count	P	S	S											
Viscosity				P	S		S	S	S	S		P	P	
TAN/TBN				S		S	P				P	S		P
FTIR Spectroscopy				S	P	P	P	S	P	P		P	S	S
Ferrous Density		P	S											
Analytical Ferrography	S		P											
RBOT							P					S		
Moisture Tester					P									S
Elemental Spectroscopy	S	P	P		S	P		P	S			P		S
Flash Point Test				S					P			S	P	

P = Primary Indicator
S = Secondary Indicator

Figure 6-8

contaminants from the environment through seals, vents, new oil, or an increase in the generation of wear debris.

Primary Tests:

- Particle Count - A particle counter provides the clearest indication of solid particle contaminants. Trend ISO codes or particle count against the predetermined target cleanliness level.

Secondary Tests:

- Elemental Spectroscopy - Often, when particle count increases, the elemental levels of the particles present increase. For dirt contaminated oil, silicon and aluminum increase as they are the primary constituents of the earth's crust. Likewise, wear metal elements may increase depending upon the metallurgy of the failing components if the machine is experiencing abnormal wear. Note, however, elemental spectroscopy produces frequent false negatives because the particles are often too large to be effectively measured by the instrument.

- Analytical Ferrography - While expensive and time consuming, depositing particles onto a slide or filter membrane disc and viewing them under a microscope will reveal an increase in particle count. Quantification of the particulate is limited with this technique.

Field Methods:

- Patch Analysis
    - Comparative Method - Involves the current patch to standards by color and density
    - Field Microscopy Method - Involves inspection of the particles with a field microscope (similar to analytical ferrography)

6.2.2 Wear Debris Detection - When machines are operating abnormally due to misalignment, imbalance, lubrication failure, contamination, corrosive conditions, etc., the machine sends messages into the oil in the form of wear debris. Oil analysis provides very early warning of this occurrence and increases the planning time and the number of options with which to correct the problem.

Primary Tests:

- Ferrous Density - Measuring an increase in the production of ferrous debris is a good indication of an abnormal situation because so many machine components are made from steel or iron. These tests are biased against non-magnetic wear debris generated from brass, bronze, aluminum, lead, tin and stainless steel surfaces.

- Elemental Spectroscopy - A rise in the level of elemental metals is an indication of the presence of an abnormal condition. And, by comparing results to component metallurgy records, the abnormal condition can often be qualified. Conventional elemental spectroscopy is particle size limited and frequently produces false negative readings for wear debris until the particles are ground or corroded into very small pieces or dissolved.

Secondary Test:

- Particle Count - Any wear that is generated will result in an increase in particle count. Particle count, however, provides no differentiation between ingested debris such as dirt, and generated wear particles.

Field Method:

- Magnetic Patch Method - Involves using a magnet to selectively prepare a patch.

6.2.3 Wear Debris Analysis - When an abnormal wearing condition is encountered, it must be analyzed to provide an indication of the nature, severity and root cause of the problem. This requires an investigation of the wear particles themselves along with a review of collateral information such as vibration analysis, operational information, lubrication analysis, etc.

Primary Tests:

- Analytical Ferrography - This microscopic technique provides an abundance of information about the wear debris and the wearing event. By evaluating particle size, dimension, shape and appearance, the analyst can often determine what wear mechanism generated the debris. By manipulating the particles with light, heat and chemicals, the metallurgy of the particles can often be defined.

- Elemental Spectroscopy - When component metallurgy is known, elemental spectroscopy proves invaluable for localizing wearing components. Because of the technique's particle size limitations, expensive particle digestion is often required to ensure accuracy.

Secondary Tests:

- Ferrous Density - Trending an increase in the rate at which ferrous particles are generated provides important information about the severity of a failure event. Also, some ferrous density testers provide large and small ferrous particle differentiation. A rising "percent large particles" reading suggests increased severity. These devices are biased toward magnetic particles.

- Particle Count - The rate at which particle count increases is indicative of the severity of the problem. Also, most particle counters sort the particles by size range. Increasing generation of large particles suggests high urgency. Particle counters lack the ability to differentiate particles by type (dirt or wear).

Field Method:

- Field Microscopy - Same as analytical ferrography but using a lower powered field microscope.

6.2.4 Abnormal Viscosity - Viscosity can increase for a number of reasons. Oxidation, thermal failure, water/glycol contamination, soot loading and wrong oil are the most common reasons. Fuel or solvent dilution, VI improver (additive) shear-down, base oil shear-down and base oil cracking all reduce the viscosity.

Primary Tests:

- Viscosity - Viscosity is the "catch all" test for a number of abnormal lubricant or contaminant conditions. This test often serves as a trigger for additional analysis.

Secondary Tests:

- TAN - If the increase in viscosity is associated with oxidative failure, the total acid number (TAN) will typically increase. TAN sometimes increases or decreases when the wrong oil has been added to the sump because of the influence of the additive package on the TAN.

- FTIR Spectroscopy - When viscosity changes because of thermal failure, oxidation, fuel/chemical dilution or glycol contamination, the FTIR spectrum tends to change in certain bands. If the wrong or mixed oil is being used, the spectrum will change as well.

- Flash Point Test - When the oil has been contaminated with fuel or solvents, the flash point will drop.

Field Methods:

- Numerous field viscometers are available ranging in type, cost, accuracy and simplicity.

6.2.5 Moisture Contamination - Moisture in all its forms brings nothing but trouble to the lubricant and machine. It rusts iron and steel surfaces, promotes corrosion on other metal surfaces and over time can destroy the lubricant. Moisture can enter the oil from many places. The task of chasing the source down can be very complicated but still important to overall control.

Primary Tests:

- Moisture Tester - Water can be screened to about 500 ppm with the crackle-test depending on the exact procedure employed. Quantification of the moisture content is best accomplished using the standard Karl Fischer titration procedure. Anti-wear, extreme pressure and some rust inhibiting additives may interfere with the accuracy of the test. Co-distillation Karl Fischer testing is the most accurate.

- FTIR Spectroscopy - FTIR serves as an effective screen for moisture above about 1000 ppm for mineral oils.

FTIR will also signal the presence of glycol if leakage is from a cooler that uses glycol-based antifreeze.

Secondary Tests:

- Viscosity - Often, when high levels of water contaminates oil an emulsion is formed. The viscosity, as measured by traditional viscometers, will increase under these conditions.

- Elemental Spectroscopy - Often, metals accompany the ingested water. For instance, hard water brings calcium. Salt water brings sodium. Water and glycol bring sodium, boron and potassium depending on the corrosion inhibitors used in the antifreeze. The source of the water can often be localized by examining the relative concentration of these trace metals.

Field Methods:

- Hot plate crackle-test
- Clear and bright test (visual)
- Various other field instruments

6.2.6 Additive Depletion - Additives are among the most difficult parameters to measure using oil analysis. The additives exist as organic, inorganic or organo-metallic compounds that improve base oil performance. Often, it is easier to assess the performance characteristic than the additive itself. Still it is possible to estimate the remaining useful life of the additive package using conventional oil analysis techniques.

Primary Tests:

- Elemental Spectroscopy - Many additives are organometallic compounds employing zinc, phosphorous, magnesium, silicon, etc. These levels can be effectively assessed using elemental spectroscopy. The technique has two primary limitations:

> 1) Additives can be decomposed and their constituent elements transformed into other molecules with no visible change in elemental concentration.
>
> 2) Many additives have elements similar to wear metals and contaminants. For instance, dirt and some anti-foaming agents both appear on the oil analysis report as silicon.

- FTIR Spectroscopy - FTIR spectroscopy differs from elemental spectroscopy in that it evaluates the presence of molecules, not atoms. Therefore, it can effectively measure the presence of active additive molecules, including organic molecules. It is limited by its poor ability to quantify results and interferences that might occur.

- TBN - For engines, the oil's reserve alkalinity (detergent additive) is measured using the total base number (TBN) test. As TBN declines, the oils' ability to counteract the ingress of combustion acids is weakened. This signals the need for an oil change or top-off.

- RBOT - This test can reliably estimate the condition of antioxidants.

Secondary Tests:

- TAN - Industrial oils formulated with anti-wear, extreme pressure and some anti-rust additives produce an elevated total acid number originally in the formulated oil. As the additive depletes, the TAN usually decreases. This decrease is usually followed by an increase once base oil oxidation begins.

Field Methods:

- Field TAN/TBN kits
- Cyclic Voltametry - This is a portable instrument with sensitivity to certain antioxidants and antiwear additives.

6.2.7 Oxidation Stability - Oxidation stability is an indication of the oil’s lasting ability to resist oxidation (a common form of oil degradation). Heat and contamination over time will deteriorate an oil’s resistance to oxidation. Some oil analysis tests measure the byproducts of oxidation while others attempt to measure the oil’s ability to resist oxidation.

Primary Tests:

- TAN - As an oil oxidizes, organic acids are produced. Measuring the concentration of these acids is a measure of oxidative damage that has occurred. The reliability of this measurement may be impaired by the presence of anti-wear, extreme pressure and some rust-inhibiting additives.

- FTIR Spectroscopy - During oxidation the oil’s base molecules (hydrocarbon) are turned into ketones, aldehydes, carboxylates and other transition molecules. These new molecules can be measured with FTIR spectroscopy. Likewise, FTIR provides some resolution in the measurement of oxidation inhibiting additives, providing evidence of the oxidation stability.

- RBOT - This test specifically measures the oil's ability to resist oxidation under highly controlled testing conditions. It is, therefore, the most definitive test of the oil's remaining useful life available.

Secondary Tests:

- Viscosity - Typically, as the oil oxidizes, its viscosity rises. As such, viscosity trending is not a good forecasting technique for oxidation stability but is rather a positive indication of the onset of oxidation.

Field Methods:

- Field TAN kits - oxidation increases TAN
- Cyclic Voltametry - This instrument can estimate TAN values
- Field viscometers of various types. Oxidation increases viscosity

6.2.8 Glycol Contamination - Glycol (antifreeze) enters lubricating oils from the cooler. Leakage from corrosion, seal failure, cooler core damage, and cavitation are the most common causes of glycol contamination. Glycol is extremely harmful to the lubricant (promotes oxidation and deposit formation), its additives (forms abrasive oil balls), filtration (plugs pores prematurely), and the engine (corrosion, wear, etc.). With so much at risk, the routine monitoring for trace glycol contamination in crankcase lubricants is a must.

Primary Tests:

- Elemental Spectroscopy - Most commercial antifreeze formulations include corrosion inhibitors that contain sodium, boron and/or potassium. The inhibitors transfer into the oil with coolant (glycol) contamination. As such, they can be detected elementally by trending boron, sodium, and/or potassium. The presence of these elements effectively serves as "markers" in detecting and quantifying glycol contamination. Because some aftermarket antifreeze formulations contain different additive chemistry (some without organo-metallic additives) it is best to baseline the antifreeze being used for the inhibitor

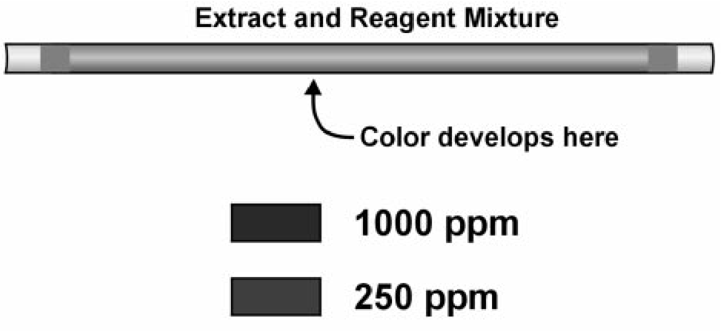


Figure 6-9

elements. This is done by sending a sample of the antifreeze to the lab in advance for elemental analysis. By knowing the relative concentrations of the additive elements in the antifreeze it is easy to identify glycol contamination and to quantify its ingression in the oil. Lubricants with glycol above 50 ppm should be flagged.

Secondary Tests:

- Viscosity - When a significant amount of glycol is present in used oil there will typically be an increase in oil viscosity. Therefore, an increase in oil viscosity should be investigated as possible antifreeze contamination.

- FTIR Spectroscopy - Because it is so common to analyze crankcase lubricants using infrared spectroscopy (for soot, fuel dilution, oxidation, etc.) it is practical to deploy its use in detecting glycol as well. Despite a number of possible interferences (water, antioxidants, oxidation products, etc.) and sensitivity to reference oil mismatch, FTIR is an important confirming test method.

Field Methods:

- Schiff's Reagent Method - This is a colorimetric procedure used in the field and in the lab. If there is antifreeze in the oil there will be a distinctive color produced by the chemical change of the glycol-contaminated oil when mixed with the Schiff's reagent (see Figure 6-9). The procedure is described in ASTM D 2982.

- Blotter Spot Test - By placing a couple drops of oil on common blotter paper or card stock a qualitative assessment of glycol contamination can be obtained. Permit the oil to wick into the blotter paper for at least a couple of hours. Glycol will often leave a pasty center on the blotter or a patch-like outward structure.

- Field viscometers of various types. Glycol raises viscosity.

6.2.9 Fuel Dilution - Fuel typically gets into the crankcase as an incomplete combustion byproduct (blowby) or by leakage. Either way the influence of the fuel on lubrication can be substantial. For instance, just 10 percent fuel dilution can be enough to reduce an SAE 30 viscosity to an SAE 20. The reduced oil viscosity can alter critical oil film thickness in engine components. Additionally, the fuel dilutes additive concentrations. If excessive fuel levels are measured (above 3%) the source of the fuel needs to be determined and remedied.

Primary Tests:

- Flash Point Testing - When a lubricant is properly baselined, a sudden drop in flashpoint is a positive indication of fuel dilution. Typically labs will flag an oil that exhibits a 20 to 30-degree C reduction in flash point. Rather than determining the actual flash point temperature, most labs set thresholds and run this as a pass/fail test.

- FTIR Spectroscopy - There are specific search areas in the infrared spectra that can be used to assess the presence of gasoline, diesel, and jet fuels in lubricants. While the procedure is very sensitive to reference oil mismatch and certain interferences, FTIR is considered to be a valuable test for fuel dilution. Many FTIR spectrometers use calibration curves to estimate the percent fuel dilution and report these values.

Secondary Tests:

- Viscosity - Fuel contamination of crankcase oils sharply influences the blended viscosity. Fuel that enters the crankcase through the combustion chamber (blowby) may consist of the heavier molecules only, i.e., reducing the resultant viscosity impact. However, raw fuel from leakage will sharply lower viscosity and oil film thickness.
- Elemental Spectroscopy - As previously mentioned, fuel dilution will dilute additive concentration. While a significant amount of fuel would be needed to produce a reduction in all additives measured by elemental analysis is observed, it is still a common occurrence.

Field Methods:

- Field viscometers of various types. Fuel lowers viscosity.

6.2.10 Soot Load and Dispersancy - Soot enters crankcase oil from combustion blowby. Excessive amounts occur when oil drains are over-extended, air cleaners are plugged, rings/liners are worn, and/or over-fueling conditions occur. As soot builds in the oil the performance of the oil can degrade to eventually impair lubrication and result in the formation of sludge and deposits. Soot load and the quality of soot dispersancy (influenced by additives) have a lot to due with the timing of a condition-

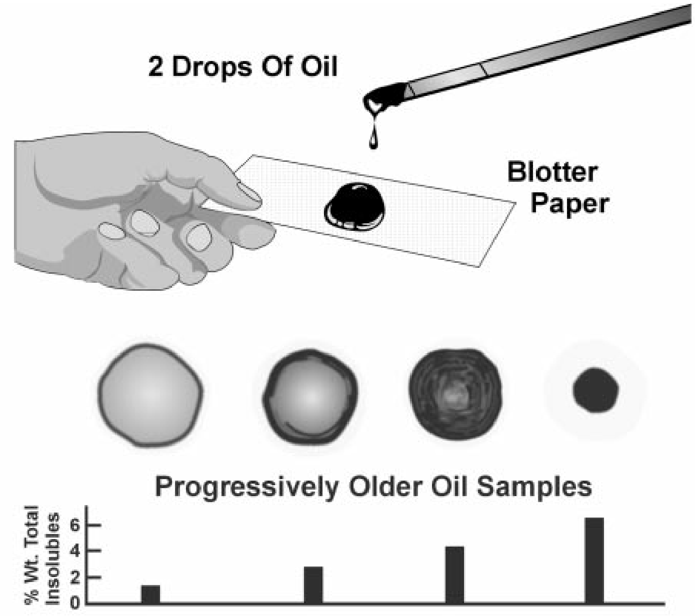


Figure 6-10

based oil change for crankcase lubricants. Conversely, when lubricants are changed on a schedule basis there is less need for routine monitoring of soot load and dispersancy. Dispersancy is considered impaired when soot particles coagulate, forming carbon suspensions larger than one micron. Depending on the grade of oil, soot concentrations in the range of 2-5% are typically flagged as abnormal.

Primary Tests:

- FTIR Spectroscopy - Infrared provides a reliable, time-efficient test for soot load. It does not evaluate the quality of dispersancy however. Because soot absorbs infrared energy across the full spectrum its concentration is quantified by the resulting baseline shift (spectral shift). It is typically presented as percent soot or percent transmittance (for infrared).

Secondary Tests:

- Viscosity - Viscosity will generally rise with increasing concentrations of soot. There is even a sharper impact on viscosity when dispersancy is lost. Occasionally, soot and fuel build as contaminants in a crankcase oil together. The resulting viscosity effect may be negligible, i.e., offsetting.

Field Methods:

- Blotter Spot Test - By placing a couple drops of oil on common blotter paper or card stock a qualitative assessment of soot load can be determined. The oil should be allowed to wick into the blotter paper for at least a couple of hours (see Figure 6-10). In addition to soot load, the appearance of well-defined annular structure (rings, halos, dark center spot, etc.) points to loss of dispersancy. The blotter spot procedure for assessing dispersancy is also commonly performed in oil analysis labs.
- Field viscometers of various types. Soot raises viscosity.

6.2.11 Alkalinity Reserve - Monitoring and controlling the reserve alkalinity of crankcase oils is key to any extended, condition-based oil drain strategy. Certain additives, like detergents, contribute to original alkalinity of the new oil. These additives essentially provide an antacid quality (by neutralizing) to the resulting formulation in combating acids that form from combustion and oxidation. Certain fuels (high in sulfur for instance) and operating conditions (cold climates, short trips, etc.) contribute to loss of alkalinity reserve. High blowby from worn engines can also lead to corrosive conditions.

Primary Test:

- Base Number (TBN) - This particular test has been performed for many years to assess alkalinity reserve by oil labs. The preferred procedure is ASTM D 4739 or ASTM D 5984-96. Typically crankcase oils are scheduled for change when TBN drops to 50% of the original, new-oil TBN. TBN results below two are considered critical (corrosive).

Field Methods:

- Field TBN test kits.

6.2.12 Wrong Oil - One of the most common abnormal conditions detected by oil analysis is a wrong or non-complying oil. This can occur during an oil change, the addition of makeup oil, or from additive top-treatments. In many applications the use of a wrong oil can be as detrimental as a defective oil or a contaminated oil. As such, the oil analysis test slate must have the ability to effectively recognize wrong or non-complying lubricants in use.

Primary Tests:

- FTIR Spectroscopy - The infrared spectrum is, in essence, a fingerprint of many properties of a formulated oil. If the basestock or additive package has changed sharply this should be noticed by the laboratory spectroscopist.
- Viscosity - Often the only meaningful difference when a wrong oil is applied is its viscosity.
- Elemental Analysis - The additive elements in a lubricant provide another way to fingerprint an oil at an atomic level. When elemental concentrations increase or decrease suddenly this is a tip-off that the oil has been altered.

Secondary Tests:

- Flash Point - Oils of different viscosities, refining methods, or base oil types (synthetic, natural esters, mineral, etc.) will tend to exhibit different flash points.
- TAN/TBN - Additives contribute considerably to TBN and TAN values in most oils. A sudden shift in TAN or TBN may be due to wrong or mixed oils.

Field Methods:

- Color/Odor - A noticeable change in oil color or odor is always suspect. Occasionally this is due to wrong, incompatible, or mixed oils.
- Field Viscometers of various types. Viscosity may rise or fall, depending upon the nature of the problem.

6.2.13 Thermal Failure - Lubricants can thermally degrade for a variety of reasons and causes. Unlike oxidation, thermal failure can occur in new lubricants with healthy additive packages. However, many of the symptoms of oxidation are also symptoms of thermal degradation. One of the most common causes of thermal failure in hydraulic fluids and some lubricating oils relates to aeration, i.e., entrained air bubbles. These bubbles can become rapidly compressed in hydraulic pumps and in the squeeze zones of bearings. This results in extremely high localized temperatures (adiabatic compression) leading to sudden formation of carbon fines (see Figure 6-11). Hot surface carbonization is another form of thermal failure. When an oil thermally degrades, problems associated with sludge, varnish, deposits, viscosity change, and additive decomposition will often occur.

Primary Tests:

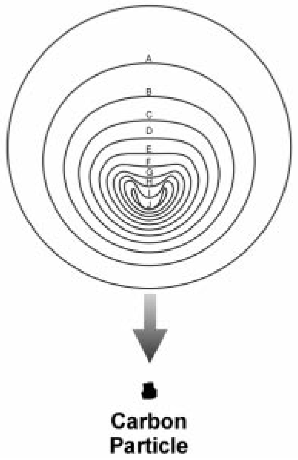
- Viscosity - Thermal degradation can lead to either an increase or decrease in oil viscosity. Mild cases of thermal failure generally result in evaporative losses of the lighter fractions in the oil leading to increased viscosity. Heat is also a primary factor in oxidation which generally leads to increased viscosity. Extreme high temperatures (above 500°F) can crack the oil's hydrocarbon molecules causing the oil to thin. If the extreme high temperature is due to aeration and adiabatic compression of air bubbles, it is possible that no change in viscosity will occur.

- Ultracentrifuge - Some labs utilize a sedimentation rating system employing the use of ultra-centrifugation. A small amount of sample is placed in a special plastic test tube without solvent-dilution. The tube is placed in a ultracentrifuge for 30 minutes at 20,000 rpm. The test subjects the oil to gravitational forces reaching 34,800 g's. This effectively extracts carbon insolubles, sludge and varnish precursors, driving them to the bottom of the tube. The density of the concentrated material is then compared to a visual sediment-rating scale.

- Flash Point - For the same reasons viscosity changes due to thermal degradation, flash point will generally change in the same direction. High viscosity is generally associated with a high flash point while low viscosity is associated with a low flash point. In the case of aeration and air bubble compression, this can often lead to gas evolution (from cracking) in the oil which would show up as a lower flash point.

Field Methods:

- Blotter Spot Test - By placing a couple drops of oil on



Zone	Pressure	Temperature
A	Atmospheric (pump inlet)	100°F
F	1000 psi	1410°F
H	2000 psi	1820°F
I	3000 psi	2100°F

Figure 6-11

common blotter paper or card stock a qualitative assessment of carbon insolubles can be determined. The oil should be allowed to wick into the blotter paper for at least a couple of hours. A dark spot or defined annular structure is a reliable indicator of carbon insolubles.

- Color/Odor - Thermal failure is almost always accompanied by a sharp darkening of the oil color. Sometimes the odor will also change as well, ranging from a burnt food smell to no odor at all (the heat drives off all volatile, odor-bearing constituents).

6.2.14 Corrosive Conditions - A lubricant can become corrosive due to contamination of acids or the formation of acids through oxidative pathways. For instance, sulfuric and nitric acids can be produced from combustion blowby products in engine crankcase oils. Phosphoric acids can come from additive breakdown and contamination. Other corrosive contaminants include hydrochloric and hydrofluoric acids. Regardless of the source or mode of acid formation the risk is real and requires monitoring in most applications. Recognizing and correcting corrosive lubricating conditions can prevent very costly repairs and production losses.

Primary Test:

- TAN/TBN - It is rare to have a serious corrosive condition without a significant change in TAN in industrial lubricants and TBN in crankcase oils. Therefore these tests are typically selected to identify the increasing concentration of acidic compounds in lube oils and hydraulic fluids. Likewise, they provide trending capability for the depletion of certain corrosion inhibitors.

Secondary Tests:

- FTIR Spectroscopy - As previously described, this test can detect acid products from oxidation as well as sulfation and nitration, associated with sulfuric acid and nitric acid.
- Elemental Analysis - Increasing wear metals are very often caused by corrosive wear not mechanical wear.
- Moisture Tests - When free and emulsified water contaminates an oil suspended acids have much stronger corrosive potential.

Field Methods:

- Field TAN/TBN Tests.

6.4 Documenting and Reporting Oil Analysis Results

There are two specific reasons for which to document oil analysis results. First, proper documentation improves the technical quality of the oil analysis program, thus, improving the effectiveness of maintenance and operations decisions. Also, good oil analysis reporting should facilitate financial justification of projects by trending performance to recognize productivity improvements resulting from effective lubrication management and/or oil analysis. A good oil analysis information management program has the following characteristics:

- Computer software that places the user in control of the data and maintains a permanent record of data and activities in-house.
- Supports on-site testing activities.
- Electronically downloads data generated by the laboratory.
- Is open architecture, not tying you to a specific laboratory or oil supplier.
- Provides effective routing and work management capabilities.
- Has user definable report formatting capabilities.
- Integrates diagnostic notes to maintain a history of activities.
- Can be accessed by all those who require the data, with appropriate clearance assignment.
- Can work as a single station program, or can be networked on a LAN or a WAN system.
- Is easy to learn and use.

The information should be in a format that is easy to understand and use to facilitate robust analysis. People tend to prefer graphic displays of data in the form of graphs and plots, to plain numerical or text data. These tools allow the compression of large amounts of data, or derived values, to be viewed efficiently for analysis. Oil analysis data is typically reported and analyzed in a combination of data display types described below.

- Multiple-parameter, Single Sample Data - Often, we need to analyze multiple data parameters from a single sample to draw meaningful conclusions. An example is the elemental spectrum where individual elements are defined on one axis of a table or bar chart, and amplitude is defined on the other axis. Tables and bar-charts are the most commonly used data display methods to report multiple-parameter, single sample data.

- Single-parameter, Multiple Sample Data - On other occasions, we need to look at the performance of a single parameter relative to time. This is a trend plot with time defined on the X axis, and amplitude of the parameter of interest defined on the Y axis. This data display enables analysis with respect to absolute, relative or statistical limits, and supports rate-of-change based alarming mechanisms.

- X vs. Y Data Plots - Occasionally, we wish to look at the performance of one variable relative to another to identify a visual trend, or to calculate a coefficient of correlation. For example, ZDDP acts to improve the apparent lubricity of a fluid by reducing potential frictional forces. An examination of zinc levels vs. iron levels might indicate a correlation that would help us optimize fluid specification, fluid change intervals or fluid reconditioning schedules. The X vs. Y plot data display supports this sophisticated type of analysis.

6.3 Integrating Oil Analysis with Other Condition Monitoring Techniques

Oil analysis should not stand alone in the fight against machinery failure and unreliability. History has proven that there are numerous benefits gained from the use of complementary technologies for detecting abnormal machine conditions and for managing important failure root causes like misalignment and unbalance. Some of the most widely used complements to oil analysis include:

- Vibration analysis
- Thermography and thermometry
- Ultrasonic analysis
- Motor current evaluation

7. Guidelines for Selecting and Working with a Commercial Oil Analysis Laboratory

Selecting a commercial oil analysis lab is a process that involves many different considerations. No two labs are exactly the same and they vary in many significant ways. Currently there are no accreditation services for used oil analysis laboratories which means that users must go through the process of evaluating their options with limited guidance. This can be so complicated that for most users, word-of-mouth and price tend to drive the selection decision.

It is usually best to begin with a detailed description of the task the lab is to perform. The more detailed and specific the work scope the more satisfied users will be with the service. Leave as little to chance as possible. Several specific requirements should be spelled out. Below are some the issues to consider when selecting a lab:

Location - Where should the lab be located? Many organizations prefer the lab to be geographically close to their plant so they can "run over" a sample if required. However, it may be just as efficient to express ship samples across the country as sending them across town. There is some benefit to having the lab in the same time zone when questions arise. Still, for most users, the location of the lab is relatively low on the list of priorities for lab selection.

Industry Orientation - Many labs specialize in certain industries or even industry segments. For instance, there are labs that specialize in locomotives, aviation, trucking, off-road equipment, nuclear power plants, rotating equipment, hydraulic systems, and steel industry. Most labs advertise general, full-service capabilities but a closer look might reveal a distinct area of specialty.

Turnaround Time - A fault that is detected too late cannot be corrected in time to save the machine. It is therefore important that the lab commit to a reasonable turnaround time as requested by the customer. The lab's turnaround commitment is often reflected in the price charged. It is not unusual for a lab that guarantees 48-hour turnaround on routine samples to charge considerably more than a lab that offers no guarantee. In may be required to ask the lab for 24-hour turnaround for exception samples.

Test Capability - There are a great many differences between labs in the area of capability. Some labs offer a wide array of ASTM testing capabilities while others emphasize a narrow group of tests designed to satisfy the maintenance technologist concerned with the reliability of equipment and the health of lubricating oils. Refer to the recommended test slate previously described to ensure the lab can meet the minimum requirements.

Flexible Testing - Many labs do not let customers design there own test bundles for machine types. Nor do they permit flexibility when it comes to exception testing. Flexibility from the lab may be required in order to develop appropriate test bundles for routine or exception testing.

Targets and Limits - Certain labs permit customers to set limits for their equipment while others do not. Requiring a customer to conform to a rigid set of limits may reduce the overall effectiveness of the oil analysis program.

Report Style - The oil analysis report needs to conform to the needs of the customer. There should be both tabular and graphic presentation of oil analysis data.

Likewise, the limits and targets set by the customer need to be visible on the report. Finally, the new oil baseline data needs to be shown next to the used oil data.

Quality Assurance - Test accuracy is one of the most common complaints from customers about commercial oil analysis lab services. Presently, there is no independent control or verification of used oil analysis quality. Nor is there a licensing body for used oil analysis labs. Therefore, it is important to look at what the lab is doing to monitor itself. Here are some questions to ask:

- Is the lab ISO 9002 certified?
- Does it perform daily instrument calibration verification?
- Are blind control samples processed by the lab to assess accuracy and performance?
- Are control charts being maintained for each instrument showing test frequency and precision of calibration tests?
- What quality assurance procedures have been put in place by the lab to manage its own quality?
- Are lab technicians required to receive on-going training to keep their skills current and to avoid "drift" into poor practice?

Electronic Data Service - Modern oil analysis programs are generally paper-less. It is far more efficient to spend time troubleshooting and examining the data of only machines that are non-conforming. Sophisticated oil analysis software programs are widely available that interface to commercial laboratory services.

Price - This should be the last and least important consideration in selecting a lab. Oil analysis services are not a commodity just as the services of a cardiologist should not be viewed as a commodity. The quality and effectiveness of oil analysis services will influence the overall effectiveness of the program and benefits received. The customer should expect to pay a fair price for timely and high quality laboratory services.

Final Selection Process - Once a work scope has been developed, the process described below is used to make the final selection:

- Send out the request for bid to several labs that might meet requirements.
- Interview (by phone) the labs that submit acceptable responses by phone.
- Select the top two or three labs and ask them to submit references.
- Select the top choice and an alternate.
- Visit the the top choice to see the operation and meet the people. If acceptable, award this lab the contract.

Glossary of Terms

Abrasion – a general wearing away of a surface by constant scratching, usually due to the presence of foreign matter such as dirt, grit, or metallic particles in the lubricant. It may also cause a break down of the material (such as the tooth surfaces of gears). Lack of proper lubrication may result in abrasion.

Abrasive wear – (or cutting wear) comes about when hard surface asperities or hard particles that have embedded themselves into a soft surface and plough grooves into the opposing harder surface, e.g., a journal.

Absolute filtration rating – the diameter of the largest hard spherical particle that will pass through a filter under specified test conditions. This is an indication of the largest opening in the filter elements.

Absolute Viscosity – a term used interchangeably with viscosity to distinguish it from either kinematic viscosity or commercial viscosity. Absolute viscosity is the ratio of shear stress to shear rate. It is a fluid's internal resistance to flow. The common unit of absolute viscosity is the poise. Absolute viscosity divided by fluid density equals kinematic viscosity. It is occasionally referred to as dynamic viscosity. Absolute viscosity and kinematic viscosity are expressed in fundamental units. Commercial viscosity such as Saybolt viscosity is expressed in arbitrary units of time, usually seconds.

Absorbent filter – a filter medium that holds contaminant by mechanical means.

Absorption – the assimilation of one material into another; in petroleum refining, the use of an absorptive liquid to selectively remove components from a process stream.

AC Fine Test Dust (ACFTD)– A test contaminant used to assess both filters and the contaminant sensitivity of all types of tribological mechanisms.

Accumulator – a container in which fluid is stored under pressure as a source of fluid power.

Acid – in a restricted sense, any substance containing hydrogen in combination with a nonmetal or nonmetallic radical and capable of producing hydrogen ions in solution.

Acidity – in lubricants, acidity denotes the presence of acid-type constituents whose concentration is usually defined in terms of total acid number. The constituents vary in nature and may or may not markedly influence the behavior of the lubricant.

Additive – a compound that enhances some property of, or imparts some new property to, the base fluid. In some hydraulic fluid formulations, the additive volume may constitute as much as 20 percent of the final composition. The more important types of additives include anti-oxidants, anti-wear additives, corrosion inhibitors, viscosity index improvers, and foam suppressants.

Additive stability – the ability of additives in the fluid to resist changes in their performance during storage or use.

Adhesion – the property of a lubricant that causes it to cling or adhere to a solid surface.

Adhesive wear – is often referred to as galling, scuffing, scoring, or seizing. It happens when sliding surfaces contact one another, causing fragments to be pulled from one surface and to adhere to the other.

Adsorbent filter – a filter medium primarily intended to hold soluble and insoluble contaminants on its surface by molecular adhesion.

Adsorption – adhesion of the molecules of gases, liquids, or dissolved substances to a solid surface, resulting in relatively high concentration of the molecules at the place of contact; e.g. the plating out of an anti-wear additive on metal surfaces.

Adsorptive filtration – the attraction to, and retention of particles in, a filter medium by electrostatic forces, or by molecular attraction between the particles and the medium.

Aeration – the state of air being suspended in a liquid such as a lubricant or hydraulic fluid.

A.G.M.A. – abbreviation for "American Gear Manufacturers Associations," an organization serving the gear industry.

Agglomeration – the potential of the system for particle attraction and adhesion.

Air, Compressed – air at any pressure greater than atmospheric pressure.

Air Breather – a device permitting air movement between atmosphere and the component in/on which it is installed.

Alkali – any substance having basic (as opposed to acidic) properties. In a restricted sense it is applied to the hydroxides of ammonium, lithium, potassium and sodium. Alkaline materials in lubricating oils neutralize acids to prevent acidic and corrosive wear in internal combustion engines.

Analytical ferrography – the magnetic precipitation and subsequent analysis of wear debris from a fluid sample This approach involves passing a volume of fluid over a chemically treated microscope slide which is supported over a magnetic field. Permanent magnets are arranged in such a way as to create a varying field strength over the length of the substrate. This varying strength causes wear debris to precipitate in a distribution with respect to size and mass over the Ferrogram. Once rinsed and fixed to the substrate, this debris deposit serves as an excellent media for optical analysis of the composite wear particulates.

Anhydrous – devoid of water.

Anti-foam agent – one of two types of additives used to reduce foaming in petroleum products: silicone oil to break up large surface bubbles, and various kinds of polymers that decrease the amount of small bubbles entrained in the oils.

Anti-friction bearing – a rolling contact type bearing in which the rotating or moving member is supported or guided by means of ball or roller elements. Does not mean without friction.

Anti-oxidants – prolong the induction period of a base oil in the presence of oxidizing conditions and catalyst metals at elevated temperatures. The additive is consumed and degradation products increase not only with increasing and sustained temperature, but also with increases in mechanical agitation or turbulence and contamination – air, water, metallic particles, and dust.

Antistatic additive – an additive that increases the conductivity of a hydrocarbon fuel to hasten the dissipation of electrostatic charges during high-speed dispensing, thereby reducing the fire/explosion hazard.

Antiwear additives – improve the service life of tribological elements operating in the boundary lubrication regime. Antiwear compounds (for example, ZDDP and TCP) start decomposing at 90° to 100°C and even at a lower temperature if water (25 to 50 ppm) is present.

API engine service categories – gasoline and diesel engine oil quality levels established jointly by API, SAE, and ASTM, and sometimes called SAE or API/SAE categories; formerly called API Engine Service Classifications.

API gravity – a gravity scale established by the American Petroleum Institute and in general use in the petroleum industry, the unit being called "the A.P.I. degree." This unit is defined in terms of specific gravity as follows:

API Gravity = 141.5/Specific Gravity @ 60°F/60° - 131.5

Ash – a measure of the amount of inorganic material in lubricating oil. Determined by burning the oil and weighing the residue. Results expressed as percent by weight.

Asperities – microscopic projections on metal surfaces resulting from normal surface-finishing processes. Interference between opposing asperities in sliding or rolling applications is a source of friction, and can lead to metal welding and scoring. Ideally, the lubricating film between two moving surfaces should be thicker than the combined height of the opposing asperities.

A.S.T.M. - American Society for Testing Materials" – a society for developing standards for materials and test methods.

Atomic absorption spectroscopy – measures the radiation absorbed by chemically unbound atoms by analyzing the transmitted energy relative to the incident energy at each frequency. The procedure consists of diluting the fluid sample with methyl isobutyl ketone (MIBK) and directly aspirating the solution. The actual process of atomization involves reducing the solution to a fine spray, dissolving it, and finally vaporizing it with a flame. The vaporization of the metal particles depends upon their time in the flame, the flame temperature, and the composition of the flame gas. The spectrum occurs because atoms in the vapor state can absorb radiation at certain well-defined characteristic wave lengths. The wave length bands absorbed are very narrow and differ for each element. In addition, the absorption of radiant energy by electronic transitions from ground to excited state is essentially and absolute measure of the number of atoms in the flame and is, therefore, the concentration of the element in a sample.

Automatic Transmission Fluid (ATF) – fluid for automatic, hydraulic transmissions in motor vehicles.

Axial-load bearing – a bearing in which the load acts in the direction of the axis of rotation.

Babbitt – a soft, white, non-ferrous alloy bearing material composed principally of copper, antimony, tin and lead.

Bactericide – additive included in the formulations of water-mixed cutting fluids to inhibit the growth of bacteria promoted by the presence of water, thus preventing odors that can result from bacterial action.

Ball bearing – an antifriction rolling type bearing containing rolling elements in the form of balls.

Barrel – a unit of liquid volume of petroleum oils equal to 42 U.S. gallons or approximately 35 Imperial gallons.

Base – a material which neutralizes acids. An oil additive containing colloidally dispersed metal carbonate, used to reduce corrosive wear.

Base stock – the base fluid, usually a refined petroleum fraction or a selected synthetic material, into which additives are blended to produce finished lubricants.

Bearing – a support or guide by means of which a moving part such as a shaft or axle is positioned with respect to the other parts of a mechanism.

Beta Rating – the method of comparing filter performance based on efficiency. This is done using the Multi-Pass Test which counts the number of particles of a given size before and after fluid passes through a filter.

Beta-Ratio (ß-Ratio) – the ratio of the number of particles greater than a given size in the influent fluid to the number of particles greater than the same size in the effluent fluid, under specified test conditions (see "Multi-Pass Test").

Bitumen – also called asphalt or tar, bitumen is the brown or black viscous residue from the vacuum distillation of crude petroleum. It also occurs in nature as asphalt "lakes" and "tar sands." It consists of high molecular weight hydrocarbons and minor amounts of sulfur and nitrogen compounds.

Black oils – lubricants containing asphaltic materials, which impart extra adhesiveness, that are used for open gears and steel cables.

Blow-by – passage of unburned fuel and combustion gases past the piston rings of internal combustion engines, resulting in fuel dilution and contamination of the crankcase oil.

Boundary lubrication – form of lubrication between two rubbing surfaces without development of a full-fluid lubricating film. Boundary lubrication can be made more effective by including additives in the lubricating oil that provide a stronger oil film, thus preventing excessive friction and possible scoring. There are varying degrees of boundary lubrication, depending on the severity of service. For mild conditions, oiliness agents may be used; by plating out on metal surfaces in a thin but durable film, oiliness agents prevent scoring under some conditions that are too severe for a straight mineral oil. Compounded oils, which are formulated with polar fatty oils, are sometimes used for this purpose. Anti-wear additives are commonly used in more severe boundary lubrication applications. The more severe cases of boundary lubrication are defined as extreme pressure conditions; they are met with lubricants containing EP additives that prevent sliding surfaces from fusing together at high local temperatures and pressures.

Breakdown maintenance – maintenance performed after a machine has failed to return it to an operating state.

Bridging – a condition of filter element loading in which contaminant spans the space between adjacent sections of a filter element, thus blocking a portion of the useful filtration.

Bright stock – a heavy residual lubricant stock with low pour point, used in finished blends to provide good bearing film strength, prevent scuffing, and reduce oil consumption. Usually identified by its viscosity, SUS at 210°F or cSt at 100°C.

Brinelling – permanent deformation of the bearing surfaces where the rollers (or balls) contact the races. Brinelling results from excessive load or impact on stationary bearings. It is a form of mechanical damage in which metal is displaced or upset without attrition.

Brookfield viscosity – apparent viscosity in cP determined by Brookfield viscometer, which measures the torque required to rotate a spindle at constant speed in oil of a given temperature. Basis for ASTM Method D 2983; used for measuring low temperature viscosity of lubricants.

BTU – British thermal unit. The amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

Bubble point – the differential gas pressure at which the first steady stream of gas bubbles is emitted from a wetted filter element under specified test conditions.

Built-in-dirt – Material passed into the effluent stream composed of foreign materials incorporated into the filter medium.

Bulk modulus (of elasticity) – a ratio of normal stress to a change in volume. A term used in determining the compressibility of a fluid. Data for petroleum products can be found in the International Critical Tables.

Burst pressure rating – the maximum specified inside-out differential pressure that can be applied to a filter element without outward structural or filter-medium failure.

Bushing – a short, externally threaded connector with a smaller size internal thread.

Bypass Filtration – a system of filtration in which only a portion of the total flow of a circulating fluid system passes through a filter at any instant or in which a filter having its own circulating pump operates in parallel to the main flow.

Bypass valve (Relief valve) – a valve mechanism that assures system fluid flow when a preselected differential pressure across the filter element is exceeded; the valve allows all or part of the flow to bypass the filter element.

Cams – eccentric shafts used in most internal combustion engines to open and close valves.

Capacity – the amount of contaminants a filter will hold before an excessive pressure drop is caused. Most filters have bypass valves which open when a filter reaches its rated capacity.

Capillarity – a property of a solid-liquid system manifested by the tendency of the liquid in contact with the solid to rise above or fall below the level of the surrounding liquid; this phenomenon is seen in a smallbore (capillary) tube.

Carbon – a non-metallic element - No. 6 in the periodic table. Diamonds and graphite are pure forms of carbon. Carbon is a constituent of all organic compounds. It also occurs in combined form in many inorganic substances; i.e., carbon dioxide, limestone, etc.

Carbon residue – coked material remaining after an oil has been exposed to high temperatures under controlled conditions.

Carbonyl iron powder – a contaminant which consists of up to 99.5% pure iron spheres.

Case drain filter – a filter located in a line conducting fluid from a pump or motor housing to reservoir.

Catalyst – a substance which speeds a chemical action without undergoing a chemical change itself during the process. Now used in catalytic converters to control amount of unburned hydrocarbons and CO in automobile exhaust.

Catalytic converter – an integral part of vehicle emission control systems since 1975. Oxidizing converters remove hydrocarbons and carbon monoxide (CO) from exhaust gases, while reducing converters control nitrogen oxide (NOx) emissions. Both use noble metal (platinum, palladium or rhodium) catalysts that can be "poisoned" by lead compounds in the fuel or lubricant.

Catastrophic failure – sudden, unexpected failure of a machine resulting in considerable cost and downtime.

Cavitation – formation of an air or vapor pocket (or bubble) due to lowering of pressure in a liquid, often as a result of a solid body, such as a propeller or piston, moving through the liquid; also, the pitting or wearing away of a solid surface as a result of the collapse of a vapor bubble. Cavitation can occur in a hydraulic system as a result of low fluid levels that draw air into the system, producing tiny bubbles that expand explosively at the pump outlet, causing metal erosion and eventual pump destruction.

Cavitation erosion – a material-damaging process which occurs as a result of vaporous cavitation. "Cavitation" refers to the occurrence or formation of gas- or vapor-filled pockets in flowing liquids due to the hydrodynamic generation of low pressure (below atmospheric pressure). This damage results from the hammering action when cavitation bubbles implode in the flow stream. Ultra-high pressures caused by the collapse of the vapor bubbles produce deformation, material failure and, finally, erosion of the surfaces.

Cellulose Media – a filter material made from plant fibers. Because cellulose is a natural material, its fibers are rough in texture and vary in size and shape. Compared to synthetic media, these characteristics create a higher restriction to the flow of fluids.

Centipoise (cp) – a unit of absolute viscosity. 1 centipoise = 0.01 poise.

Centistoke (cst) – a unit of kinematic viscosity. 1 centistoke = 0.01 stoke.

Centralized lubrication – a system of lubrication in which a metered amount of lubricant or lubricants for the bearing surfaces of a machine or group of machines are supplied from a central location.

Centrifugal separator – a separator that removes immiscible fluid and solid contaminants that have a different specific gravity than the fluid being purified by accelerating the fluid mechanically in a circular path and using the radial acceleration component to isolate these contaminants.

Chemical stability – the tendency of a substance or mixture to resist chemical change.

Chip control (grit control, last-chance) filter – a filter intended to prevent only large particles from entering a component immediately downstream.

Circulating lubrication – a system of lubrication in which the lubricant, after having passed through a bearing or group of bearings, is recirculated by means of a pump.

Cleanable – a filter element which, when loaded, can be restored by a suitable process, to an acceptable percentage of its original dirt capacity.

Clean room – a facility or enclosure in which air content and other conditions (such as temperature, humidity, and pressure) are controlled and maintained at a specific level by special facilities and operating processes and by trained personnel.

Cleanliness level (CL) – a measure of relative freedom from contaminants.

Clearance bearing – a journal bearing in which the radius of the bearing surface is greater than the radius of the journal surface.

Cloud point – the temperature at which waxy crystals in an oil or fuel form a cloudy appearance.

Coalescor – a separator that divides a mixture or emulsion of two immiscible liquids using the interfacial tension between the two liquids and the difference in wetting of the two liquids on a particular porous medium.

Coefficient of friction – the number obtained by dividing the friction force resisting motion between two bodies by the normal force pressing the bodies together.

Cohesion – that property of a substance that causes it to resist being pulled apart by mechanical means.

Cold cranking simulator (CCS) – an intermediate shear rate viscometer that predicts the ability of an oil to permit a satisfactory cranking speed to be developed in a cold engine.

Collapse – an inward structural failure of a filter element which can occur due to abnormally high pressure drop (differential pressure) or resistance to flow.

Collapse pressure – the minimum differential pressure that an element is designed to withstand without permanent deformation.

Compound – (1) chemically speaking, a distinct substance formed by the combination of two or more elements in definite proportions by weight and possessing physical and chemical properties different from those of the combining elements. (2) in petroleum processing, generally connotes fatty oils and similar materials foreign to petroleum added to lubricants to impart special properties.

Compounded oil – a petroleum oil to which has been added other chemical substances.

Compressibility – the change in volume of a unit volume of a fluid when subjected to a unit change of pressure.

Compression ratio – in an internal combustion engine, the ratio of the volume of combustion space at bottom dead center to that at top dead center.

Compressor – a device which converts mechanical force and motion into pneumatic fluid power.

Consistency – the degree to which a semisolid material such as grease resists deformation. (See ASTM designation D 217.) Sometimes used qualitatively to denote viscosity of liquids.

Contaminant – any foreign or unwanted substance that can have a negative effect on system operation, life or reliability.

Contaminant (Dirt, ACFTD) capacity – the weight of a specified artificial contaminant that must be added to the influent to produce a given differential pressure across a filter at specified conditions. Used as an indication of relative service life.

Contaminant Failure – any loss of performance due to the presence of contamination. Two basic types of contamination failure are: Perceptible – gradual loss of efficiency or performance, and Catastrophic – dramatic, unexpected failure.

Contaminant lock – a particle or fiber-induced jam caused by solid contaminants.

Contamination control – a broad subject which applies to all types of material systems (including both biological and engineering). It is concerned with planning, organizing, managing, and implementing all activities required to determine, achieve and maintain a specified contamination level.

Coolant – a fluid used to remove heat. See Cutting fluid.

Copper strip corrosion – a qualitative measure of the tendency of a petroleum product to corrode pure copper.

Core – the internal duct and filter media support.

% Correl – the percentage of peaks in the used oil infrared spectrum which match those in the reference oil. A sudden decrease in this value usually means that the oil was mixed with a different type.

Corrosion – the decay and loss of a metal due to a chemical reaction between the metal and its environment. It is a transformation process in which the metal passes from its elemental form to a combined (or compound) form.

Corrosion inhibitor – additive for protecting lubricated metal surfaces against chemical attack by water or other contaminants. There are several types of corrosion inhibitors. Polar compounds wet the metal surface preferentially, protecting it with a film of oil. Other compounds may absorb water by incorporating it in a water-in-oil emulsion so that only the oil touches the metal surface. Another type of corrosion inhibitor combines chemically with the metal to present a non-reactive surface.

Coupling, quick disconnect – a coupling which can quickly join or separate lines.

Coupling – a straight connector for fluid lines.

Cracking – the process whereby large molecules are broken down by the application of heat and pressure to form smaller molecules.

Crown – the top of the piston in an internal combustion engine above the fire ring, exposed to direct flame impingement.

Cryogenics – the branch of physics relating to the production and effects of very low temperatures.

Cutting fluid – any fluid applied to a cutting tool to assist in the cutting operation by cooling, lubricating or other means.

Cycle – a single complete operation consisting of progressive phases starting and ending at the neutral position.

Cylinder – a device which converts fluid power into linear mechanical force and motion. It usually consists of a moveable element such as a piston and piston rod, plunger rod, plunger or ram, operating with in a cylindrical bore.

Deaerator – a separator that removes air from the system fluid through the application of bubble dynamics.

Degas – removing air from a liquid, usually by ultrasonic and/or vacuum methods.

Degradation – the progressive failure of a machine or lubricant.

Dehydrator – a separator that removes water from the system fluid.

Delamination wear – a complex wear process where a machine surface is peeled away or otherwise removed by forces of another surface acting on it in a sliding motion.

Demulsibility – the ability of a fluid that is insoluble in water to separate from water with which it may be mixed in the form of an emulsion.

Density – the mass of a unit volume of a substance. Its numerical value varies with the units used.

Deposits – oil-insoluble materials that result from oxidation and decomposition of lube oil and contamination from external sources and engine blow-by. These can settle out on machine or engine parts. Examples are sludge, varnish, lacquer and carbon.

Depth filter – a filter medium that retains contaminants primarily within tortuous passages.

Desorption – opposite of absorption or adsorption. In filtration, it relates to the downstream release of particles previously retained by the filter.

Detergent – in lubrication, either an additive or a compounded lubricant having the property of keeping insoluble matter in suspension thus preventing its deposition where it would be harmful. A detergent may also redisperse deposits already formed.

Dielectric Strength – a measure of the ability of an insulating material to withstand electric stress (voltage) without failure. Fluids with high dielectric strength (usually expressed in volts or kilovolts) are good electrical insulators. (ASTM Designation D 877.)

Differential pressure indicator – an indicator which signals the difference in pressure between any two points of a system or a component.

Dirt capacity (dust capacity) (contaminant capacity) – the weight of a specified artificial contaminant which must be added to the influent to produce a given differential pressure across a filter at specified conditions. Used as an indication of relative service life.

Dispersant – in lubrication, a term usually used interchangeably with detergent. An additive, usually nonmetallic ("ashless"), which keeps fine particles of insoluble materials in a homogeneous solution. Hence, particles are not permitted to settle out and accumulate.

Disposable – a filter element intended to be discarded and replaced after one service cycle.

Dissolved gases – those gases that enter into solution with a fluid and are neither free nor entrained gases.

Distillation method (ASTM D-95) – a method involving distilling the fluid sample in the presence of a solvent that is miscible in the sample but immiscible in water. The water distilled from the fluid is condensed and segregated in a specially-designed receiving tube or tray graduated to directly indicate the volume of water distilled.

Drum – a container with a capacity of 55 U.S. gallons.

Duplex filter – an assembly of two filters with valving for selection of either or both filters.

Effluent – the fluid leaving a component.

Elastohydrodynamic lubrication – in rolling element bearings, the elastic deformation of the bearing (flattening) as it rolls, under load, in the bearing race. This momentary flattening improves the hydrodynamic lubrication properties by converting point or line contact to surface-to-surface contact.

Electrostatic separator – a separator that removes contaminant from dielectric fluids by applying an electrical charge to the contaminant that is then attracted to a collection device of different electrical charge.

Element (Cartridge) – the porous device that performs the actual process of filtration.

Emission spectrometer – works on the basis that atoms of metallic and other particular elements emit light at characteristic wavelengths when they are excited in a flame, arc, or spark. Excited light is directed through an entrance slit in the spectrometer. This light penetrates the slit, falls on a grate, and is dispersed and reflected. The spectrometer is calibrated by a series of standard samples containing known amounts of the elements of interest. By exciting these standard samples, an analytical curve can be established which gives the relationship between the light intensity and its concentration in the fluid.

Emulsibility – the ability of a non-water-soluble fluid to form an emulsion with water.

Emulsifier – additive that promotes the formation of a stable mixture, or emulsion, of oil and water. Common emulsifiers are: metallic soaps, certain animal and vegetable oils, and various polar compounds.

Emulsion – intimate mixture of oil and water, generally of a milky or cloudy appearance. Emulsions may be of two types: oil-in water (where water is the continuous phase) and water-in-oil (where water is the discontinuous phase).

End cap – a ported or closed cover for the end of a filter element.

Engine deposits – hard or persistent accumulation of sludge, varnish and carbonaceous residues due to blow-by of unburned and partially burned fuel, or the partial breakdown of the crankcase lubricant. Water from the condensation of combustion products, carbon, residues from fuel or lubricating oil additives, dust and metal particles also contribute.

Environmental contaminant – all material and energy present in and around an operating system, such as dust, air moisture, chemicals, and thermal energy.

EP (Extreme Pressure) lubricants – lubricants that impart to rubbing surfaces the ability to carry appreciably greater loads than would be possible with ordinary lubricants without excessive wear or damage.

Erosion – the progressive removal of a machine surface by cavitation or by particle impingement at high velocities.

Extreme pressure (EP) additive – lubricant additive that prevents sliding metal surfaces from seizing under conditions of extreme pressure. At the high local temperatures associated with metal-to-metal contact, an EP additive combines chemically with the metal to form a surface film that prevents the welding of opposing asperities, and the consequent scoring that is destructive to sliding surfaces under high loads. Reactive compounds of sulfur, chlorine, or phosphorus are used to form these inorganic films.

Fabrication integrity point – the differential gas pressure at which the first stream of gas bubbles are emitted from a wetted filter element under standard test conditions.

False brinelling – false brinelling of needle roller bearings is actually a fretting corrosion of the surface since the rollers are the I.D. of the bearing. Although its appearance is similar to that of brinelling, false brinelling is characterized by attrition of the steel, and the load on the bearing is less than that required to produce the resulting impression. It is the result of a combination of mechanical and chemical action that is not completely understood, and occurs when a small relative motion or vibration is accompanied by some loading, in the presence of oxygen.

Fatigue chunks – thick three-dimensional particles exceeding 50 microns indicating severe wear of gear teeth.

Fatigue platelets – normal particles between 20 and 40 microns found in gear box and rolling element bearing oil samples observed by analytical ferrography. A sudden increase in the size and quantity of these particles indicates excessive wear.

Fatigued – a structural failure of the filter medium due to flexing caused by cyclic differential pressure.

Ferrography – an analytical method of assessing machine health by quantifying and examining ferrous wear particles suspended in the lubricant or hydraulic fluid.

Film strength – property of a lubricant that acts to prevent scuffing or scoring of metal parts.

Filter – any device or porous substance used as a strainer for cleaning fluids by removing suspended matter.

Filter Efficiency – method of expressing a filter's ability to trap and retain contaminants of a given size.

Filter element – the porous device which performs the actual process of filtration.

Filter head – an end closure for the filter case or bowl that contains one or more ports.

Filter housing – a ported enclosure that directs the flow of fluid through the filter element.

Filter life test – a type of filter capacity test in which a clogging contaminant is added to the influent of a filter, under specified test conditions, to produce a given rise in pressure drop across the filter or until a specified reduction of flow is reached. Filter life may be expressed as test time required to reach terminal conditions at a specified contaminant addition rate.

Filter media, depth – porous materials which primarily retain contaminants within a tortuous path, performing the actual process of filtration.

Filter media, surface – porous materials which primarily retain contaminants on the influent face, performing the actual process of filtration.

Filtration (Beta) ratio – the ratio of the number of particles greater than a given size in the influent fluid to the number of particles greater than the same size in the effluent fluid.

Filtration – the physical or mechanical process of separating insoluble particulate matter from a fluid, such as air or liquid, by passing the fluid through a filter medium that will not allow the particulates to pass through it.

Fire point (Clevelend Open Cup) – the temperature to which a combustible liquid must be heated so that the released vapor will burn continuously when ignited under specified conditions.

Fire-resistant fluid – lubricant used especially in high-temperature or hazardous hydraulic applications. Three common types of fire-resistant fluids are: (1) water-petroleum oil emulsions, in which the water prevents burning of the petroleum constituent; (2) water-glycol fluids; and (3) non-aqueous fluids of low volatility, such as phosphate esters, silicones, and halogenated hydrocarbon-type fluids.

Flash point (Cleveland Open Cup) – the temperature to which a combustible liquid must be heated to give off sufficient vapor to form momentarily a flammable mixture with air when a small flame is applied under specified conditions. (ASTM Designation D 92.)

Flow, laminar – a flow situation in which fluid moves in parallel lamina or layers.

Flow, turbulent – a flow situation in which the fluid particles move in a random manner.

Flow fatigue rating – the ability of a filter element to resist a structural failure of the filter medium due to flexing caused by cyclic differential pressure.

Flow rate – the volume, mass, or weight of a fluid passing through any conductor per unit of time.

Flowmeter – a device which indicates either flow rate, total flow, or a combination of both.

Fluid – a general classification including liquids and gases.

Fluid, fire resistant – a fluid difficult to ignite which shows little tendency to propagate flame.

Fluid compatibility – the suitability of filtration medium and seal materials for service with the fluid involved.

Fluid friction – friction due to the viscosity of fluids.

Fluid opacity – related to the ability of a fluid to pass light.

Fluid power – energy transmitted and controlled through use of a pressurized fluid.

Flushing – a fluid circulation process designed to remove contamination from the wetted surfaces of a fluid system.

Force feed lubrication – a system of lubrication in which the lubricant is supplied to the bearing surface under pressure.

Fretting – wear phenomena taking place between two surfaces having oscillatory relative motion of small amplitude.

Fretting corrosion – can take place when two metals are held in contact and subjected to repeated small sliding, relative motions. Other names for this type of corrosion include wear oxidation, friction oxidation, chafing, and brinelling.

Friction – the resisting force encountered at the common boundary between two bodies when, under the action of an external force, one body, moves or tends to move relative to the surface of the other.

FTIR = Fourier Transform Infrared Spectroscopy – a test where infrared light absorption is used for assessing levels of soot, sulfates, oxidation, nitro-oxidation, glycol, fuel, and water contaminants.

Full flow filter – a filter that, under specified conditions, filters all influent flow.

Full-flow filtration – a system of filtration in which the total flow of a circulating fluid system passes through a filter.

Full-fluid-film lubrication – presence of a continuous lubricating film sufficient to completely separate two surfaces, as distinct from boundary lubrication. Full-fluid-film lubrication is normally hydrodynamic lubrication, whereby the oil adheres to the moving part and is drawn into the area between the sliding surfaces, where it forms a pressure – or hydrodynamic – wedge.

Gage – an instrument or device for measuring, indicating or comparing a physical characteristic.

Galling – a form of wear in which seizing or tearing of the gear or bearing surface occurs.

Gasohol – a blend of 10% anhydrous ethanol (ethyl alcohol) and 90% gasoline, by volume. Used as a motor fuel.

Generated contaminant – caused by a deterioration of critical wetted surfaces and materials or by a breakdown of the fluid itself.

Graphite – a crystalline form of carbon having a laminar structure, which is used as a lubricant. It may be of natural or synthetic origin.

Gravimetric analysis – a method of analysis whereby the dry weight of contaminant per unit volume of fluid can be measured showing the degree of contamination in terms of milligrams of contaminant per litre of fluid.

Gravity – See Specific Gravity; API Gravity.

Grease – a lubricant composed of an oil or oils thickened with a soap, soaps or other thickener to a semisolid or solid consistency.

Hardness – the resistance of a substance to surface abrasion.

Head – an end closure for the filter case or bowl which contains one or more ports.

Heat exchanger – a device which transfers heat through a conducting wall from one fluid to another.

Housing – a ported enclosure which directs the flow of fluid through the filter element.

Hydraulic Fluid – fluid serving as the power transmission medium in a hydraulic system. The most commonly used fluids are petroleum oils, synthetic lubricants, oil-water emulsions, and water-glycol mixtures. The principal requirements of a premium hydraulic fluid are proper viscosity, high viscosity index, anti-wear protection (if needed), good oxidation stability, adequate pour point, good demulsibility, rust inhibition, resistance to foaming, and compatibility with seal materials. Anti-wear oils are frequently used in compact, high-pressure, and capacity pumps that require extra lubrication protection.

Hydraulic Oil – an oil specially suited for use as either the specific gravity or the API gravity of a liquid.

Hydraulics – engineering science pertaining to liquid pressure and flow.

Hydrocarbons – compounds containing only carbon and hydrogen. Petroleum consists chiefly of hydrocarbons.

Hydrodynamic lubrication – a system of lubrication in which the shape and relative motion of the sliding surfaces causes the formation of a fluid film having sufficient pressure to separate the surfaces.

Hydrofinishing – a process for treating raw extracted base stocks with hydrogen to saturate them for improved stability.

Hydrolysis – breakdown process that occurs in anhydrous hydraulic fluids as a result of heat, water, and metal catalysts (iron, steel, copper, etc.)

Hydrolytic stability – ability of additives and certain synthetic lubricants to resist chemical decomposition (hydrolysis) in the presence of water.

Hydrometer – an instrument for determining either the specific gravity of a liquid or the API gravity.

Hydrostatic lubrication – a system of lubrication in which the lubricant is supplied under sufficient external pressure to separate the opposing surfaces by a fluid film.

Hypoid gear lubricant – a gear lubricant having extreme pressure characteristics for use with a hypoid type of gear as in the differential of an automobile.

Image analyzer – a sophisticated microscopic system involving a microscope, a television camera, a dedicated computer, and a viewing monitor similar to a television screen.

Immiscible – incapable of being mixed without separation of phases. Water and petroleum oil are immiscible under most conditions, although they can be made miscible with the addition of an emulsifier.

In-line filter – a filter assembly in which the inlet, outlet and filter element axes are in a straight line.

Indicator – a device which provides external evidence of sensed phenomena.

Indicator, pressure – an indicator that signals pressure conditions.

Indicator, differential pressure – an indicator which signals the difference in pressure between two points, typically between the upstream and downstream sides of a filter element.

Influent – the fluid entering a component.

Infrared spectroscopy – an analytical method using infrared absorption for assessing the properties of used oil and certain contaminants suspended therein. See FTIR.

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 and the previous samples are usually compared.

Ingested contaminants – environmental contaminant that ingresses due to the action of the system or machine.

Ingression level – particles added per unit of circulating fluid volume.

Inhibitor – any substance that slows or prevents such chemical reactions as corrosion or oxidation.

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

Intensifier – a device which converts low pressure fluid power into higher pressure fluid power.

Interfacial tension (IFT) – the energy per unit area present at the boundary of two immiscible liquids. It is usually expressed in dynes/cm (ASTM Designation D 971.)

ISO Solid Contaminant Code (ISO 4406) – a code assigned on the basis of the number of particles per unit volume greater than 5 and 15 micrometers in size. Range numbers identify each increment in the particle population throughout the spectrum of levels.

ISO Standard 4021 – the accepted procedure for extracting samples from dynamic fluid lines.

ISO viscosity grade – a number indicating the nominal viscosity of an industrial fluid lubricant at 40°C (104°F) as defined by ASTM Standard Viscosity System for Industrial Fluid Lubricants D 2422. Essentially identical to ISO Standard 3448.

Journal – that part of a shaft or axle that rotates or angularly oscillates in or against a bearing or about which a bearing rotates or angularly oscillates.

Journal bearing – a sliding type of bearing having either rotating or oscillatory motion and in conjunction with which a journal operates. In a full or sleeve type journal bearing, the bearing surface is 360° in extent. In a partial bearing, the bearing surface is less than 360° in extent, i.e., 150°, 120°, etc.

Karl Fischer Reagent Method (ASTM D-1744-64) – the standard laboratory test to measure the water content of mineral base fluids. In this method, water reacts quantitatively with the Karl Fischer reagent. This reagent is a mixture of iodine, sulfur dioxide, pyridine, and methanol. When excess iodine exists, electric current can pass between two platinum electrodes or plates. The water in the sample reacts with the iodine. When the water is no longer free to react with iodine, an excess of iodine depolarizes the electrodes, signaling the end of the test.

Kinematic viscosity – the time required for a fixed amount of an oil to flow through a capillary tube under the force of gravity. The unit of kinematic viscosity is the stoke or centistoke (1/100 of a stoke). Kinematic viscosity may be defined as the quotient of the absolute viscosity in centipoises divided by the specific gravity of a fluid, both at the same temperature–

Centipoises

Specific Gravity = Centistokes

Lacquer – a deposit resulting from the oxidation and polymerization of fuels and lubricants when exposed to high temperatures. Similar to, but harder, than varnish.

Laminar particles – particles generated in rolling element bearings which have been flattened out by a rolling contact.

Lead naphthenate – a lead soap of naphthenic acids, the latter occurring naturally in petroleum.

Light obscuration – the degree of light blockage as reflected in the transmitted light impinging on the photodiode.

Liquid – any substance that flows readily or changes in response to the smallest influence. More generally, any substance in which the force required to produce a deformation depends on the rate of deformation rather than on the magnitude of the deformation.

Load-carrying capacity – property of a lubricant to form a film on the lubricated surface, which resists rupture under given load conditions. Expressed as maximum load the lubricated system can support without failure or excessive wear.

Lubricant – any substance interposed between two surfaces in relative motion for the purpose of reducing the friction and/or the wear between them.

Lubricity – ability of an oil or grease to lubricate; also called film strength.

Magnetic – a separator that uses a magnetic field to attract and hold ferromagnetic particles.

Magnetic filter – a filter element that, in addition to its filter medium, has a magnet or magnets incorporated into its structure to attract and hold ferromagnetic particles.

Magnetic plug – strategically located in the flow stream to collect a representative sample of wear debris circulating in the system: for example, engine swarf, bearing flakes, and fatigue chunks. The rate of buildup of wear debris reflects degradation of critical surfaces.

Manifold – a filter assembly containing multiple ports and integral relating components which services more than one fluid circuit.

Manifold filter – a filter in which the inlet and outlet port axes are at right angles, and the filter element axis is parallel to either port axis.

Media migration – material passed into the effluent stream composed of the materials making up the filter medium.

Medium – the porous material that performs the actual process of filtration. The plural of this word is "media".

Metal oxides – oxidized ferrous particles which are very old or have been recently produced by conditions of inadequate lubrication. Trend is important.

Micrometre (µm) – See Micron.

Micron – a unit of length. One Micron = 39 millionths of an inch (.000039"). Contaminant size is usually described in microns. Relatively speaking, a grain of salt is about 60 microns and the eye can see particles to about 40 microns.

Many hydraulic filters are required to be efficient in capturing a substantial percentage of contaminant particles as small as 5 microns. A micron is also known as a micrometre, and exhibited as µm

Microscope method – a method of particle counting which measures or sizes particles using an optical microscope.

Mineral oil – oil derived from a mineral source, such as petroleum, as opposed to oils derived from plants and animals.

Miscible – capable of being mixed in any concentration without separation of phases; e.g., water and ethyl alcohol are miscible.

Moly – Molybdenum disulfide, a solid lubricant and friction reducer, colloidally dispersed in some oils and greases.

Motor – a device which converts fluid power into mechanical force and motion. It usually provides rotary mechanical motion.

Multigrade oil – an oil meeting the requirements of more than one SAE viscosity grade classification, and may therefore be suitable for use over a wider temperature range than a single-grade oil.

Multipass or recirculation test – filter performance tests in which the contaminated fluid is allowed to recirculate through the filter for the duration of the test.

Contaminant is usually added to the test fluid during the test. The test is used to determine the Beta-Ratio (q.v.) of an element.

Naphthenic – a type of petroleum fluid derived from naphthenic crude oil, containing a high proportion of closed-ring methylene groups.

Needle bearing – a rolling type of bearing containing rolling elements that are relatively long compared to their diameter.

Neutralization number – a measure of the total acidity or basicity of an oil; this includes organic or inorganic acids or bases or a combination thereof (ASTM Designation D974-58T)

Newtonian fluid – a fluid with a constant viscosity at a given temperature regardless of the rate of shear. Single-grade oils are Newtonian fluids. Multigrade oils are NON-Newtonian fluids because viscosity varies with shear rate.

Nitration – nitration products are formed during the fuel combustion process in internal combustion engines. Most nitration products are formed when an excess of oxygen is present. These products are highly acidic, form deposits in combustion areas and rapidly accelerate oxidation.

Nominal filtration rating – an arbitrary micrometer value indicated by a filter manufacturer. Due to lack of reproducibility this rating is deprecated.

Non-Newtonian fluid – fluid, such as a grease or a polymer-containing oil (e.g., multi-grade oil), in which shear stress is not proportional to shear rate.

Nonwoven medium – a filter medium composed of a mat of fibers.

Obliteration – a synergistic phenomenon of both particle silting and polar adhesion. When water and silt particles co-exist in a fluid containing long-chain molecules, the tendency for valves to undergo obliteration increases.

Oil – a greasy, unctuous liquid of vegetable, animal, mineral or synthetic origin.

Oiliness – that property of a lubricant that produces low friction under conditions of boundary lubrication. The lower the friction, the greater the oiliness.

Oil ring – a loose ring, the inner surface of which rides a shaft or journal and dips into a reservoir of lubricant from which it carries the lubricant to the top of a bearing by its rotation with the shaft.

Open bubble point (boil point) – the differential gas pressure at which gas bubbles are profusely emitted from the entire surface of a wetted filter element under specified test conditions.

Oxidation – occurs when oxygen attacks petroleum fluids. The process is accelerated by heat, light, metal catalysts and the presence of water, acids, or solid contaminants. It leads to increased viscosity and deposit formation.

Oxidation inhibitor – substance added in small quantities to a petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called anti-oxidant. An oxidation inhibitor may work in one of these ways: (1) by combining with and modifying peroxides (initial oxidation products) to render them harmless, (2) by decomposing the peroxides, or (3) by rendering an oxidation catalyst inert.

Oxidation stability – ability of a lubricant to resist natural degradation upon contact with oxygen.

Paper chromatography – a method which involves placing a drop of fluid on a permeable piece of paper and noting the development and nature of the halos, or rings, surrounding the drop through time. The roots of this test can be traced to the 1940s, when railroads used the "blotter spot" tests.

Paraffinic – a type of petroleum fluid derived from paraffinic crude oil and containing a high proportion of straight chain saturated hydrocarbons. Often susceptible to cold flow problems.

Particle count – the number of particles present greater than a particular micron size per unit volume of fluid often stated as particles > 10 microns per milliliter.

Particle density – an important parameter in establishing an entrained particle's potential to impinge on control surfaces and cause erosion.

Particle erosion – occurs when fluid-entrained particles moving at high velocity pass through orifices or impinge on metering surfaces or sharp angle turns.

Particle impingement erosion – a particulate wear process where high velocity, fluid-entrained particles are directed at target surfaces.

Patch test – a method by which a specified volume of fluid is filtered through a membrane filter of known pore structure. All particulate matter in excess of an "average size," determined by the membrane characteristics, is retained on its surface. Thus, the membrane is discolored by an amount proportional to the particulate level of the fluid sample. Visually comparing the test filter with standard patches of known contamination levels determines acceptability for a given fluid.

Permeability – the relationship of flow per unit area to differential pressure across a filter medium.

pH – measure of alkalinity or acidity in water and water-containing fluids. pH can be used to determine the corrosion-inhibiting characteristic in water-based fluids. Typically, pH > 8.0 is required to inhibit corrosion of iron and ferrous alloys in water-based fluids.

Pinion – the smaller of two mating or meshing gears; can be either the driving or the driven gear.

Pitting – a form of extremely localized attack characterized by holes in the metal. Pitting is one of the most destructive and insidious forms of corrosion. Depending on the environment and the material, a pit may take months, or even years, to become visible.

Pleated filter – a filter element whose medium consists of a series of uniform folds and has the geometric form of a cylinder, cone, disc, plate, etc. Synonymous with "convoluted" and "corrugated".

Pneumatics – engineering science pertaining to gaseous pressure and flow.

Poise (absolute viscosity) – a measure of viscosity numerically equal to the force required to move a plane surface of one square centimeter per second when the surfaces are separated by a layer of fluid one centimeter in thickness. It is the ratio of the shearing stress to the shear rate of a fluid and is expressed in dyne seconds per square centimeter (DYNE SEC/CM2); 1 centipoise equals .01 poise.

Polar compound – a chemical compound whose molecules exhibit electrically positive characteristics at one extremity and negative characteristics at the other. Polar compounds are used as additives in many petroleum products. Polarity gives certain molecules a strong affinity for solid surfaces; as lubricant additives (oiliness agents), such molecules plate out to form a tenacious, friction-reducing film. Some polar molecules are oil-soluble at one end and water-soluble at the other end; in lubricants, they act as emulsifiers, helping to form stable oil-water emulsions. Such lubricants are said to have good metal-wetting properties. Polar compounds with a strong attraction for solid contaminants act as detergents in engine oils by keeping contaminants finely dispersed.

Polishing (bore) – excessive smoothing of the surface finish of the cylinder bore or cylinder liner in an engine to a mirror-like appearance, resulting in depreciation of ring sealing and oil consumption performance.

Polymerization – the chemical combination of similar-type molecules to form larger molecules.

Pore – a small channel or opening in a filter medium which allows passage of fluid.

Pore size distribution – the ratio of the number of effective holes of a given size to the total number of effective holes per unit area expressed as a percent and as a function of hole size.

Porosity – the ratio of pore volume to total volume of a filter medium expressed as a percent.

Positive crankcase ventilation (PCV) – system for removing blow-by gases from the crankcase and returning them through the carburetor intake manifold to the combustion chamber where the recirculated hydrocarbons are burned. A PC valve controls the flow of gases from the crankcase to reduce hydrocarbon emissions.

Pour point – lowest temperature at which an oil or distillate fuel is observed to flow, when cooled under conditions prescribed by test method ASTM D 97. The pour point is 3°C (5°F) above the temperature at which the oil in a test vessel shows no movement when the container is held horizontally for five seconds.

Pour point depressant – an additive which retards the adverse effects of wax crystallization, and lowers the pour point.

Power unit – a combination of pump, pump drive, reservoir, controls and conditioning components which may be required for its application.

Predictive maintenance – a type of condition-based maintenance emphasizing early prediction of failure using non-destructive techniques such as vibration analysis, thermography, and wear debris analysis.

Pressure – force per unit area, usually expressed in pounds per square inch.

Pressure, absolute – the sum of atmospheric and gage pressures.

Pressure, atmospheric – pressure exerted by the atmosphere at any specific location. (Sea level pressure is approximately 14.7 pounds per square inch absolute.)

Pressure, back – the pressure encountered on the return side of a system.

Pressure, cracking – the pressure at which a pressure operated valve begins to pass fluid.

Pressure, rated – the qualified operating pressure which is recommended for a component or a system by the manufacturer.

Pressure, system – the pressure which overcomes the total resistances in a system. It includes all losses as well as useful work.

Pressure Drop – Resistance to flow created by the element (media) in a filter. Defined as the difference in pressure upstream (inlet side of the filter) and downstream (outlet side of the filter).

Pressure gage – pressure differential above or below atmospheric pressure.

Pressure line filter – a filter located in a line conducting working fluid to a working device or devices.

Preventive maintenance – maintenance performed according to a fixed schedule involving the routine repair and replacement of machine parts and components.

Proactive maintenance – a type of condition-based maintenance emphasizing the routine detection and correction of root cause conditions that would otherwise lead to failure. Such root causes as high lubricant contaminant, alignment and balance are among the most critical.

PSIA – pounds per square inch absolute. (PSIG + 14.696)

PSID – pounds per square inch differential.

PSIG – pounds per square inch gauge (PSIA - 14.696)

Pump – a device which converts mechanical force and motion into hydraulic fluid power.

Pumpability – the low temperature, low shear stress-shear rate viscosity characteristics of an oil that permit satisfactory flow to and from the engine oil pump and subsequent lubrication of moving components.

Pump, fixed displacement – a pump in which the displacement per cycle cannot be varied.

Pump, variable displacement – a pump in which the displacement per cycle can be varied.

Rate of shear – the difference between the velocities along the parallel faces of a fluid element divided by the distance between the faces.

Reducer – a connector having a smaller line size at one end than the other.

Refraction – the change of direction or speed of light as it passes from one medium to another.

Rerefining – a process of reclaiming used lubricant oils and restoring them to a condition similar to that of virgin stocks by filtration, clay adsorption or more elaborate methods.

Reservoir – a container for storage of liquid in a fluid power system.

Reservoir (sump) filter - a filter installed in a reservoir in series with a suction or return line.

Residual dirt capacity – the dirt capacity remaining in a service loaded filter element after use, but before cleaning, measured under the same conditions as the dirt capacity of a new filter element.

Return line – a location in a line conducting fluid from working device to reservoir.

Return Line Filtration – filters located upstream of the reservoir but after fluid has passed through the system's output components (cylinders, motors, etc.).

Ring lubrication – a system of lubrication in which the lubricant is supplied to the bearing by an oil ring.

Rings – circular metallic elements that ride in the grooves of a piston and provide compression sealing during combustion. Also used to spread oil for lubrication.

Ring sticking – freezing of a piston ring in its groove in a piston engine or reciprocating compressor due to heavy deposits in the piston ring zone.

Roll-off cleanliness – the fluid system contamination level at the time of release from an assembly or overhaul line. Fluid system life can be shortened significantly by full-load operation under a high fluid contamination condition for just a few hours. Contaminant implanted and generated during the break-in period can devastate critical components unless removed under controlled operating and high performance filtering conditions.

Roller bearing – an antifriction bearing comprising rolling elements in the form of rollers.

Rust prevention test (turbine oils) – a test for determining the ability of an oil to aid in preventing the rusting of ferrous parts in the presence of water.

Sample preparation – fluid factors that can enhance the accuracy of the particulate analysis. Such factors include particle dispersion, particle settling, and sample dilution.

Saturation level – the amount of water that can dissolve in a fluid.

Saybolt Universal Viscosity (SUV) or Saybolt Universal Seconds, (SUS) – the time in seconds required for 60 cubic centimeters of a fluid to flow through the orifice of the Standard Saybolt Universal Viscometer at a given temperature under specified conditions. (ASTM Designation D 88.)

Scuffing – abnormal engine wear due to localized welding and fracture. It can be prevented through the use of antiwear, extreme-pressure and friction modifier additives.

Scuffing particles – large twisted and discolored metallic particles resulting from adhesive wear due to complete lubricant film breakdown.

Semisolid – any substance having the attributes of both a solid and a liquid. Similar to semiliquid but being more closely related to a solid than a liquid. More generally, any substance in which the force required to produce a deformation depends both on the magnitude and on the rate of the deformation.

Shear rate – rate at which adjacent layers of fluid move with respect to each other, usually expressed as reciprocal seconds.

Shear stress – frictional force overcome in sliding one "layer" of fluid along another, as in any fluid flow. The shear stress of a petroleum oil or other Newtonian fluid at a given temperature varies directly with shear rate (velocity). The ratio between shear stress and shear rate is constant; this ratio is termed viscosity of a Newtonian fluid, the greater the shear stress as a function of rate of shear. In a non-Newtonian fluid – such as a grease or a polymer-containing oil (e.g. multi-grade oil) – shear stress is not proportional to the rate of shear. A non-Newtonian fluid may be said to have an apparent viscosity, a viscosity that holds only for the shear rate (and temperature) at which the viscosity is determined.

Silt – contaminant particles 5 µm and less in size.

Silting – a failure generally associated with a valve which movements are restricted due to small particles that have wedged in between critical clearances (e.g., the spool and bore.)

Single-pass test – filter performance tests in which contaminant which passes through a test filter is not allowed to recirculate back to the test filter.

Sintered medium – a metallic or nonmetallic filter medium processed to cause diffusion bonds at all contacting points.

Sleeve bearing – a journal bearing, usually a full journal bearing.

Sludge – insoluble material formed as a result either of deterioration reactions in an oil or of contamination of an oil, or both.

Solid – any substance having a definite shape which it does not readily relinquish. More generally, any substance in which the force required to produce a deformation depends upon the magnitude of the deformation rather than upon the rate of deformation.

Solvency – ability of a fluid to dissolve inorganic materials and polymers, which is a function of aromaticity.

Specific gravity (liquid) – the ratio of the weight of a given volume of liquid to the weight of an equal volume of water.

Specific gravity – the ratio of the weight of a given volume of material to the weight of an equal volume of water.

Spectrographic analysis – determines the concentration of elements represented in the entrained fluid contaminant.

Spectrographic Oil Analysis Program (SOAP) – procedures for extracting fluid samples from operating systems and analyzing them spectrographically for the presence of key elements.

Spin-on filter – a throw-away type bowl and element assembly that mates with a permanently installed head.

Spindle oil – a light-bodied oil used principally for lubricating textile spindles and for light, high-speed machinery.

Splash lubrication – a system of lubrication in which parts of a mechanism dip into and splash the lubricant onto themselves and/or other parts of the mechanism.

Static friction – the force just sufficient to initiate relative motion between two bodies under load. The value of the static friction at the instant relative motion begins is termed break-away friction.

Stoke (St) – kinematic measurement of a fluid's resistance to flow defined by the ratio of the fluid's dynamic viscosity to its density.

Strainer – a coarse filter element (pore size over approximately 40 µm)

Suction filter – a pump intake-line filter in which the fluid is below atmospheric pressure.

Sulfated ash – the ash content of fresh, compounded lubricating oil as determined by ASTM Method D 874. Indicates level of metallic additives in the oil.

Sulfurized oil – oil to which sulfur or sulfur compounds have been added.

Surface fatigue wear – the formation of surface or subsurface cracks and fatigue crack propagation. It results from cyclic loading of a surface.

Surface filtration – filtration which primarily retains contaminant on the influent surface.

Surface tension – the contractile surface force of a liquid by which it tends to assume a spherical form and to present the least possible surface. It is expressed in dynes/cm or ergs/cm2.

Surfactant – surface-active agent that reduces interfacial tension of a liquid. A surfactant used in a petroleum oil may increase the oil's affinity for metals and other materials.

Surge – a momentary rise of pressure in a circuit.

Swarf – the cuttings, and grinding fines that result from metal working operations.

Switch, pressure – an electric switch operated by fluid pressure.

Synthetic lubricant – a lubricant produced by chemical synthesis rather than by extraction or refinement of petroleum to produce a compound with planned and predictable properties.

Synthetic hydrocarbon – oil molecule with superior oxidation quality tailored primarily out of paraffinic materials.

Thermography – the use of infrared thermography whereby temperatures of a wide variety of targets can be measured remotely and without contact. This is accomplished by measuring the infrared energy radiating from the surface of the target and converting this measurement to an equivalent surface temperature.

Thermal conductivity – measure of the ability of a solid or liquid to transfer heat.

Thermal stability – ability of a fuel or lubricant to resist oxidation under high temperature operating conditions.

Thin film lubrication – a condition of lubrication in which the film thickness of the lubricant is such that the friction between the surfaces is determined by the properties of the surfaces as well as by the viscosity of the lubricant.

Thixotropy – that property of a lubricating grease which is manifested by a softening in consistency as a result of shearing followed by a hardening in consistency starting immediately after the shearing is stopped.

Three-body abrasion – a particulate wear process by which particles are pressed between two sliding surfaces.

Thrust Bearing – an axial-load bearing.

Timken OK Load – the heaviest load that a test lubricant will sustain without scoring the test block in the Timken Test procedures, ASTM Methods D 2509 (greases) and D 2782 (oils).

Total Acid Number (TAN) – the quantity of base, expressed in milligrams of potassium hydroxide, that is required to neutralize all acidic constituents present in 1 gram of sample. (ASTM Designation D 974.)

Total Base Number (TBN) – the quantity of acid, expressed in terms of the equivalent number of milligrams of potassium hydroxide that is required to neutralize all basic constituents present in 1 gram of sample. (ASTM Designation D 974.)

Tribology – the science and technology of interacting surfaces in relative motion, including the study of lubrication, friction and wear. Tribological wear is wear that occurs as a result of relative motion at the surface.

Turbidity – the degree of opacity of a fluid.

Turbulent flow sampler – a sampler that contains a flow path in which turbulence is induced in the main stream by abruptly changing the direction of the fluid.

Unloading – the release of contaminant that was initially captured by the filter medium.

Vacuum separator – a separator that utilizes subatmospheric pressure to remove certain gases and liquids from another liquid because of their difference in vapor pressure.

Valve, by-pass – a valve whose primary function is to provide an alternate flow path.

Valve, directional control – a valve whose primary function is to direct or prevent flow through selected passages.

Valve, directional control, servo – a directional control valve which modulates flow or pressure as a function of its input signal.

Valve, flow control – a valve whose primary function is to control flow rate.

Valve, pressure control, relief – a pressure control valve whose primary function is to limit system pressure.

Valve, relief, differential pressure – a valve whose primary function is to limit differential pressure.

Valve – a device which controls fluid flow direction, pressure, or flow rate.

Valve lifter – sometimes called a "cam follower," a component in engine designs that use a linkage system between a cam and the valve it operates. The lifter typically translates the rotational motion of the cam to a reciprocating linear motion in the linkage system.

Vapor pressure – pressure of a confined vapor in equilibrium with its liquid at specified temperature thus, a measure of a liquid's volatility.

Vapor Pressure-Reid (RVP) – measure of the pressure of vapor accumulated above a sample of gasoline or other volatile fuel in a standard bomb at 100°F (37.8°C). Used to predict the vapor locking tendencies of the fuel in a vehicle's fuel system. Controlled by law in some areas to limit air pollution from hydrocarbon evaporation while dispensing.

Varnish – when applied to lubrication, a thin, insoluble, nonwipeable film deposit occurring on interior parts, resulting from the oxidation and polymerization of fuels and lubricants. Can cause sticking and malfunction of close-clearance moving parts. Similar to, but softer, than lacquer.

Viscometer or Viscosimeter – an apparatus for determining the viscosity of a fluid.

Viscosity – measurement of a fluid's resistance to flow. The common metric unit of absolute viscosity is the poise, which is defined as the force in dynes required to move a surface one square centimeter in area past a parallel surface at a speed of one centimeter per second, with the surfaces separated by a fluid film one centimeter thick. In addition to kinematic viscosity, there are other methods for determining viscosity, including Saybolt Universal Viscosity (SUV), Saybolt Furol viscosity, Engier viscosity, and Redwood viscosity. Since viscosity varies in inversely with temperature, its value is meaningless until the temperature at which it is determined is reported.

Viscosity, absolute – the ration of the shearing stress to the shear rate of a fluid. It is usually expressed in centipoise (cP).

Viscosity, kinematic – the absolute viscosity divided by the density of the fluid. It is usually expressed in centistokes (cSt).

Viscosity, SUS – Saybolt Universal Seconds (SUS), which is the time in seconds for 60 milliliters of oil to flow through a standard orifice at a given temperature. (ASTM Designation D88-56.)

Viscosity grade – any of a number of systems which characterize lubricants according to viscosity for particular applications, such as industrial oils, gear oils, automotive engine oils, automotive gear oils, and aircraft piston engine oils.

Viscosity index (VI) – a commonly used measure of a fluid's change of viscosity with temperature. The higher the viscosity index, the smaller the relative change in viscosity with temperature.

Viscosity index improvers – additives that increase the viscosity of the fluid throughout its useful temperature range. Such additives are polymers that possess thickening power as a result of their high molecular weight and are necessary for formulation of multi-grade engine oils.

Viscosity modifier – lubricant additive, usually a high molecular weight polymer, that reduces the tendency of an oil's viscosity to change with temperature.

Viscous – possessing viscosity. Frequently used to imply high viscosity.

Volatility – this property describes the degree and rate at which a liquid will vaporize under given conditions of temperature and pressure. When liquid stability changes, this property is often reduced in value.

Wear – the attrition or rubbing away of the surface of a material as a result of mechanical action.

Wicking – the vertical absorption of a liquid into a porous material by capillary forces.

ZDDP – an antiwear additive found in many types of hydraulic and lubricating fluids. Zinc dialkyldithiophosphate.

ABBREVIATIONS, PREFIXES, AND LETTER SYMBOLS

amp – ampere

ARP – Aeronautical Recommended Practice

ASLE – American Society of Lubrication Engineers. Changed now to Society of Tribologist and Lubrication Engineers (STLE).

ASME – American Society of Mechanical Engineers

ASTM – American Society for Testing Materials

ANSI – American National Standards Institute

atm – atmosphere

BTU – British thermal unit

C or cent. – centigrade

cc – cubic centimeter

cm – centimeter

cfm – cubic feet per minute

GPM – gallons per minute

hp or HP – horsepower

HVI – High Viscosity Index, typically from 80 to 110 VI units.

Hz – Hertz (cycles per second)

ISO – International Standards Organization, sets viscosity reference scales.

JIC – Joint Industry Conference

kg – kilograms

km – kilometer

kHz – thousand Hertz (cycles per second)

log – logarithm (common)

LVI – Low Viscosity Index, typically below 40 VI units.

MIL – military

M – meter

µm – micron (micro-meter)

NFPA – National Fluid Power Association

NEMA – National Electrical Manufacturers Association

NEC – National Electrical Code

NAS – National Aerospace Standard

NASA – National Aeronautics and Space Administration

psi – pounds per square inch

psia – pounds per square inch absolute

rpm – revolutions per minute

SAE – Society of Automotive Engineers, an organization serving the automotive industry.

SSU – Saybolt Universal Seconds (or SUS), a unit of measure used to indicate viscosity, e.g., SSU @ 100° F

STLE – Society of Tribologist and Lubrication Engineers, formerly ASLE, American Society of Lubrication Engineers.

P – pressure - psi

PPM – parts per million (1/ppm = 0.000001). Generally by weight. 100 ppm = 0.01%; 10,000 ppm = 1%

Q – flow rate - GPM

t – time in seconds

P – pressure drop psid

T – temperature change, Fahrenheit

V – total volume (gals)

PREFIXES - U.S. TERM

kilo – Thousand

mega – Million

centi – Hundredth

milli – Thousandth

micro – Millionth

CLEANLINESS DEFINITIONS

Clean– 100 particles >10 micron per milliliter

Superclean– 10 particles >10 micron per milliliter

Ultraclean– 1 particle >10 micron per milliliter