Elements of a Successful Oil Analysis Program - Part I

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This piece is an excerpt from the CRC Press and STLE Tribology Data Handbook, edited by E. Richard Booser.

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Most often, users associate an oil analysis program with a systematic early alert to oil or machine failure, i.e., damage control. While these benefits are helpful and frequently achieved, they should be regarded as low on the scale of importance compared to the more rewarding objective of failure avoidance.

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 simply 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 then be achieved and sustained. This is the second step and often includes an audit of how fluids become contaminated and then systematically eliminating these entry points. Often better filtration and the use of separators are required.

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.

Finally, 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. Following the oil sampling procedures, selection of appropriate sample testing procedures, and interpretation of test results outlined in this section, immediate corrective action can then be directed to effectively avoid failure chain reactions and further self-destruction.

OIL SAMPLING METHODS

Optimal performance in oil sampling depends directly on succeeding in the following three areas:

Selecting Optimum Sampling Point

In circulating oil systems such as shown in Figs. 1 and 2, the best location is a live zone of the system upstream of filters where particles from ingression and wear debris are the most concentrated. Usually, this means sampling on fluid return or drain lines. In some cases where oil drains back to sumps without being directed through a line (e.g., a diesel engine), the pressure line downstream of the pump (before filter) must be used. Always avoid sampling from dead zones such as static tanks and reservoirs. Splash, slinger ring, and flood-lubricated components are best sampled from drain

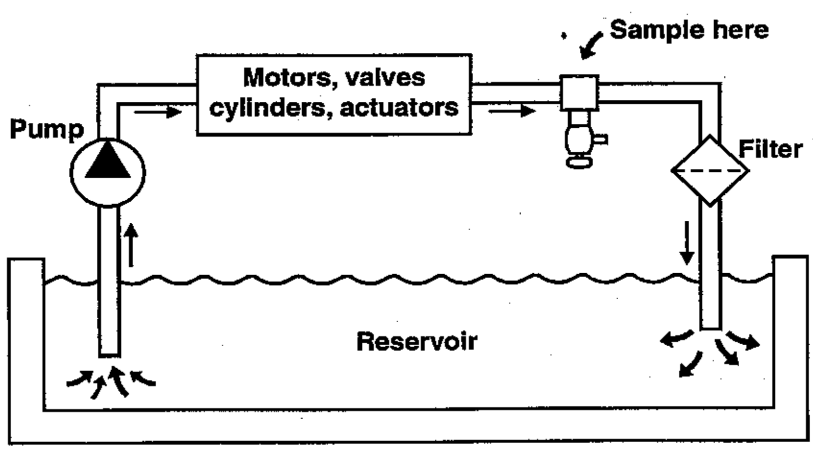

Fig.1-Hydraulic system fluid sampling on return lines upstream of filters for routine analysis.

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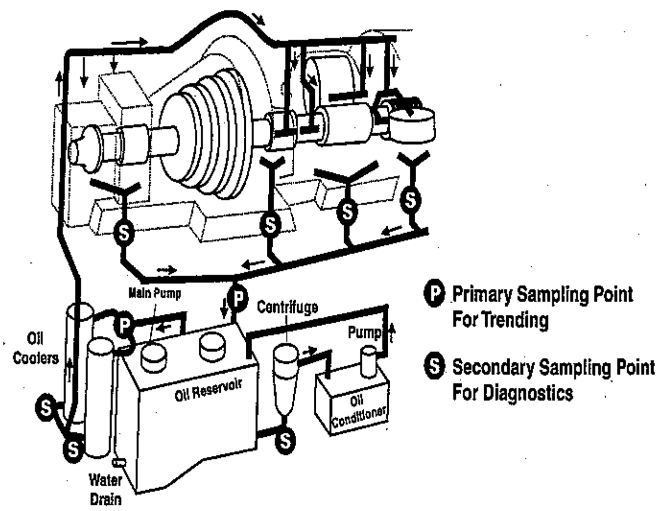

Fig. 2-Primary sampling location for large circulating systems is on main return line, with secondary points for trouble-shooting on individual drain lines from bearings and gearing. A probe-on vacuum sampler will be required with insufficient drain pressure.

plugs after considerable flushing or preferably, using a portable circulating off-line sampler.

Collecting Representative Samples

Once a sampling point is properly selected and validated, a sample must be extracted without disturbing the integrity of the data. When a sample is pulled from turbulent zones such as at an elbow as in Fig. 3, particles, moisture, and other contaminants enter the bottle at representative concentrations. Moreover, machines should always be sampled in their typical work environment, ideally while they are running with the lubricant at normal operating temperature. Likewise, during (or just prior to) sampling, machines should be run at normal loads, speeds, and work cycles.

Sampling valves should be flushed well prior to sampling. Never fill a sample bottle more than three-fourths full to enable adequate agitation by the lab. Avoid sampling methods that involve removing the bottle cap, especially where significant atmospheric contamination is present.

With many noncirculating systems, static sampling is the only option. Often this can be done effectively from drain ports if a sufficient volume of fluid is flushed through prior to the actual sample. Alternatively, drop-tube vacuum samplers could be used, especially for larger fluid systems (Fig. 4). Care should be taken to always sample a fixed distance into the sump. Flushing of the suction tube is also important. Never reuse suction tubes to avoid cross contamination and mixing of fluids.

Static sampling using a vacuum sampler can be improved by installing a quick-connect sampling valve to which the vacuum tube is attached. Often this will require drilling and tapping, preferably in a wall of the sump or casing. It is best if the valve can be located near return lines and where turbulence is highest. Sometimes it is desirable to install a short length of stainless steel tubing inward from the valve.

Minimizing Data Contamination

Since an important objective in oil analysis is the routine monitoring of oil contamination, considerable care must be taken to avoid "contaminating the contaminant." Once atmospheric contamination is allowed to contact the oil sample, it cannot he distinguished from the original contamination.

Three levels of bottle cleanliness are identified by bottle suppliers: clean (fewer than 100 particles >10 µm\ml), superclean (fewer than 10), and ultraclean (fewer than 1). Selecting the correct bottle cleanliness to match the type of sampling is important to oil analysis results.

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. Based on trends, these intervals may be adjusted for the degree of atmospheric contamination and the need for machine cleanliness. For very dirty conditions around critical machinery, on-site particle counting may be scheduled every other day. The particle count is often used as a screen for more comprehensive laboratory analysis.

The most sophisticated oil analysis programs include a combination of on-site and laboratory oil analysis. The decision tree of Fig. 5 is very useful in defining the oil analysis requirements for a range of equipment applications. Machines with high mission criticality are those that can cause excessive downtime costs as the result of failure. Fluid environment severity (FES) rates the operating and environmental stress on the health/condition of the lubricant. If a user is trying to maintain a cool, dry, and clean oil in a hot, humid, and dusty environment, frequent monitoring is a must. Operating loads, pressures, and speeds also influence fluid environment severity. Wear debris analysis (ferrous density and analytical ferrography) is most efficiently performed on an exception basis triggered by either spectroscopy or particle counting.

BIBLIOGRAPHY

Fitch, J. C., *The 10 Most Common Reasons Why Oil Analysis Programs Fail and the Strategies That Effectively Overcome Them*, Diagnetics, Inc., Tulsa, OK, (1995).

Fitch, J. C., *Oil Analysis and Proactive Maintenance Seminar Workbook*, Diagnetics, Inc., Tulsa, OK, (1996).

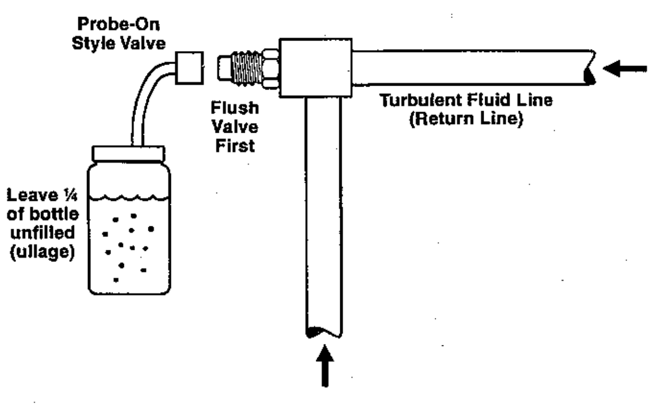

Fig. 3-Elbow sampling locations insure turbulent conditions to provide representative contaminant concentration.

Table 1-Recommended Oil Sampling Frequencies	
	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

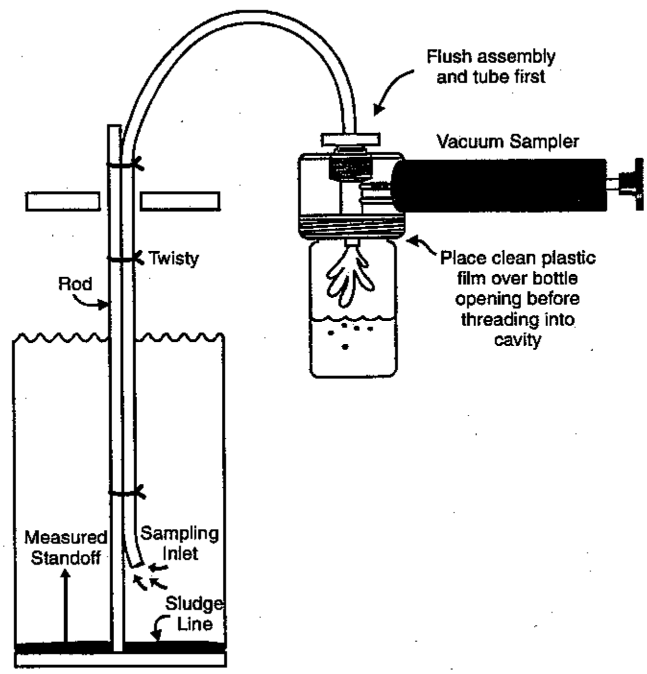

Fig.4-Drop-tube static sampling can be used with many noncirculating systems.

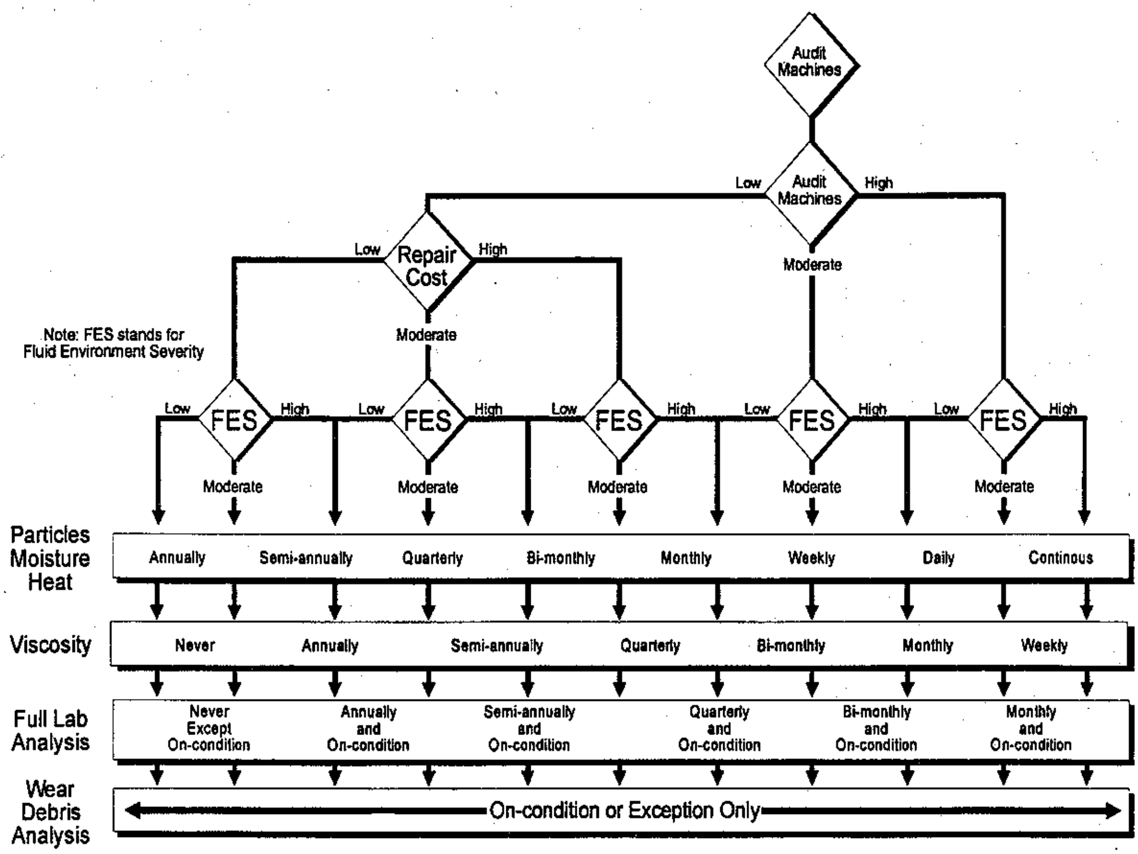

Fig.5-Decision Tree for Defining Oil Analysis Requirements

Fitch, J. C., *Three-Step Implementation of Fluid Contamination Control*, Diagnetics, Inc., Tulsa, OK, (1990).

Troyer, Drew, D., *Three Dimensions of Equipment Condition Monitoring with Oil Analysis*, P/PM Technology, Minden, NV, April, (1995).

Fitch, E. C., *Fluid Contamination Control*, FES, Inc., Stillwater, OK, (1988).

Troyer, Drew, D., *Oil Analysis and Machine Condition Monitoring: A General Introduction and Workshop*, The Vibration Institute Proceedings, Willowbrook, IL, (1996).

Troyer, Drew, D. and Borden, H. B., *Streamlining Oil Analysis With Field Testing*, P/PM Technology, Minden, NV, April, (1994). ■

Elements of a Successful Oil Analysis Program - Part II

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SELECTION OF OIL ANALYSIS TESTS

To be thoroughly effective, a program must encompass three categories of analysis: (1) fluid properties, (2) fluid contamination, and (3) fluid wear debris.

Fluid Properties Analysis

This essential function of oil analysis helps insure the fundamental quality of the lubricating fluid. The standard to which a used oil's properties should be routinely compared are the new oil's properties; a listing of each of the new oil properties should be a standard fixture on used oil analysis reports. Examples of common tests include viscosity, total acid number, total base number, infrared for oxidation, emission spectroscopy for additive elements, flash point, specific gravity, and rotating bomb oxidation test (RBOT).

Fluid Contamination Analysis

Despite the use of filters and separators, contaminants are the most common destroyers of machine surfaces that ultimately lead to failure and downtime. For most machines, solid contamination is the number one cause of wear related failure. Likewise, particles, moisture, and other contaminants are the principal root cause of additive and base stock failure of lubricants. It is important to perform basic tests such as particle counting, moisture analysis, glycol testing, and fuel dilution as directed by a well-designed proactive maintenance program.

Fluid Wear Debris Analysis

Unlike fluid properties and contamination analysis, wear debris analysis relates specifically to the health of the machine. Owing to the tendency of machine surfaces to shed increasing numbers of larger and larger particles as wear advances, the size, shape, and concentration of these particles tell a revealing story of the internal-state condition of the machine. Two methods are commonly employed:

- The first method is emission spectroscopy, which evaluates several elements present in the oil such as iron, aluminum, copper, chromium, and lead. While not truly quantitative due to an in-built bias towards only small particles, spectroscopy has been found to be exceedingly useful in numerous applications.
- The second method, known as analytical ferrography, overcomes the particle size bias of spectroscopy but has only limited ability to distinguish the elemental qualities of the particles. This is due in part to the fact that it is a visual examination of the particles on a slide (ferrogram). The overriding benefit of ferrography is its unique ability to detect many common wear mechanisms through the skillful eye of an experienced tribologist. Typically, wear debris density analysis or ferrous particle counting is performed as a screen prior to analytical ferrography. This insures that a sufficient number of particles are present prior to the preparation of a ferrogram.

Streamlining oil analysis can be effectively done when on-site oil analysis tools are available. For many machines, the particle counter serves as the best first line of defense. Only when particle counts exceed preset limits is exception testing performed. The best exception test is ferrous particle analysis, such as a ferrous particle counter. When ferrous levels are high, a failure condition exists, triggering yet further testing and analysis. In addition to on-site particle counting, on-site moisture analyzers and viscometers also assess important root cause conditions.

Table 2 lists the most common oil analysis tests for various types of machines and whether they are scheduled on-site or in the laboratory.

Table 3 gives typical targets and limits in oil analysis. For optimum results, these limits should be influenced by the machine, its application, and the goals of the user. Where possible, targets and limits should be quantifiable and directed towards producing a specific benefit, such as machine/lubricant life extension. Rate-of-change of certain tests values, such as elemental spectroscopy, is an important indicator of condition.

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TABLE 2
Utility of Oil Analysis Tests for Monitoring Various Machine Conditions

Oil Analysis Test	Failed Filter	Ingested Dirt	Ingested Moisture	Coolant Leak	Additive Depletion	Base Stock Oxidation	Component Wear Detection	Component Wear Analysis	Misalignment/ Balance In Overloading	Wrong Lubricant	Air Contamination/ Foaming	Over-heating	Fuel Dilution	Abrasive Wear	Corrosive Wear
Particle count	G	G	P	P	F	P	G	F	G	F	P	F	P	G	F
Moisture measurement	N	N	G	G	P	P	N	N	N	N	N	N	N	N	G
Viscosity	N	N	F	F	G	G	N	N	P	G	F	G	G	N	N
TAN/TBN	N	N	G	G	G	G	N	N	N	F	F	F	P	N	G
Infrared (FTIR) spectroscopy	P	P	F	F	G	G	N	N	N	G	P	F	F	N	P
Elemental emission spectroscopy	P	P	P	G	G	P	F	G	F	G	P	N	F	P	F
Wear density analysis	F	F	F	P	F	P	G	F	G	G	P	P	P	G	F
Analytical ferrography	F	F	F	P	P	P	G	G	G	P	N	F	N	G	G

Note: G = good, F = fair, P = poor, N = no benefit.

INTERPRETING TEST RESULTS

Most machines are highly complex, consisting of exotic metallurgy and intricate mechanisms. The numerous frictional and sealing surfaces usually employ varying contact dynamics and loads, all sharing a common lubricant. A failure to gain knowledge about these many internal machine details as a reference base for use in interpreting oil analysis data may lead to confusion and indecision in response to oil analysis results. A good approach is to build a three-ring binder with index tabs for each machine type. Include in this binder photocopied pages from the service and operation manuals plus other accumulated information. The following are examples of data and information to include:

1. Identify types of bearings in use and their metallurgy.
2. Identify input and output shaft speeds/torques.
3. Identify type of gears in use, speeds, and loads. Determine gear metal hardness, surface treatments, alloying metals.
4. Locate and identify all other frictional surfaces, such as cams, pistons, bushings, swash-plates, etc. Determine metallurgy of surface treatments.
5. Locate and identify coolers and heat exchangers and type of fluids used.
6. Obtain fluid flow circuit diagrams/schematics.
7. Locate and determine the types of seals in use, both external and internal.
8. Identify possible contacts with process chemicals and types.
9. Record lubricant flow rates, lubricant bulk oil temperatures, bearing drain and inlet temperatures, and oil pressures.
10. Record detailed lubricant specification and compartment capacity.
11. Record filter performance specification and location.

In many cases oil analysis data can be inconclusive when used alone. When combined with sensory inspection information, however, a reliable, more certain, determination can be made. Likewise, the application of companion maintenance technologies (like vibration and thermography) can help support a conclusion prior to expensive machine teardown or repair. Table 4 gives examples for combining analytical data with simple sensory and inspection data in defining operating problems. The analytical data are primarily generated from on-site or laboratory oil analysis tests.

REFERENCES

Fitch, J. C., *The 10 Most Common Reasons Why Oil Analysis Programs Fail and the Strategies That Effectively Overcome Them*, Diagnetics, Inc., Tulsa, OK, (1995).

Fitch, J. C., *Oil Analysis and Proactive Maintenance Seminar Workbook*, Diagnetics, Inc., Tulsa, OK, (1996).

TABLE 3
Oil Analysis Tests to be Performed by Machine Application

Test	Equipment Type: Air/Gas Compressors	Diesel Engines	Hydraulic Systems	Large Gear Boxes	Large Rolling Element Bearings	Industrial Turbines
Particle count	S_I	S	S_I	S_I	S_I	S_I
Ferrous particle count	E_I	S	E_I	E_I	E_I	E_I
Analytical ferrography	E_L	E_L	E_L	E_L	E_L	E_L
Spectrometric analysis	S	S	E_L	E_L	S	S
FTIR	S	S				S
TAN	S		S	S	S	S
TBN		S				
Viscosity	S	S	S	S	S	S
Moisture	S_I	S	S	S	S	S_I

Note: S, Routinely scheduled analysis performed by a commercial or in-house lab; S_I, routinely scheduled analysis performed in-house at fairly high frequencies; E_I, test performed on exception basis triggered by out-of-limit particle counts; and E_L, tests performed on exception basis by either a commercial or in-house lab, triggered by out-of-limit ferrous particle counts.

TABLE 4
Suggested Targets and Limits in Oil Analysis

	Upper Limit	Lower Limit	Rate of Change
Fluid Properties			
Viscosity	+10%	−10%	
TAN (mineral base)	+1 Acid no.		
TBN		−50%	
Oxidation Products (e.g., FTIR)	Test dependent	Test dependent	Yes
Elemental	Application dependent	−25%	Yes
FTIR	Test dependent	Test dependent	Yes
Flash point		20°–30°C drop	
RBOT/TOST		−20%	Yes
Contaminants			
Particles	CLI[a]/LEM[b]		Yes
Water	LEM[b]		Yes
Glycol (coolant)	Test dependent		
Fuel–FTIR	3%		
Wear debris			
Ferrous density	Test dependent		Yes
Elemental density	Application dependent		Yes
Analytical ferrography	Visual only		Yes

[a] CLI = Contaminant life index (see Reference 3).
[b] LEM = Life extension method (see Reference 3).

Fitch, J. C., *Three-Step Implementation of Fluid Contamination Control*, Diagnetics, Inc., Tulsa, OK, (1990).

Troyer, Drew, D., *Three Dimensions of Equipment Condition Monitoring with Oil Analysis*, P/PM Technology, Minden, NV, April, (1995).

Fitch, E. C., *Fluid Contamination Control*, FES, Inc., Stillwater, OK, (1988).

Troyer, Drew, D., *Oil Analysis and Machine Condition Monitoring: A General Introduction and Workshop*, The Vibration Institute Proceedings, Willowbrook, IL, (1996).

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