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WHITE PAPER

THE IMPORTANCE OF LUBRICANT AND FLUID ANALYSIS IN PREDICTIVE MAINTENANCE

Yuegang Zhao VP, Sales | Spectro Scientific

Synopsis

Machine condition monitoring or predictive maintenance is the practice of assessing a machine's condition by periodically gathering data on key machine-health indicators to determine when to schedule maintenance.

One of the keys to keeping machinery operating at optimal performance involves monitoring and analyzing lubricant oils for characteristics such as contamination, chemical content and viscosity. Billions of dollars are spent annually replacing machinery components that have worn out due to the inability of the lubricants to perform the required task. Knowing how to interpret changing lubricant properties can increase both the uptime and the life of your mission critical capital equipment. The existence or amount of debris and particles from wearing parts, erosion and contamination provide insights about the issues affecting performance and reliability.

Lubricant, fuel and other key fluid analyses provide critical early warning information indicative of machine failure. Analyzing and trending the data means you can schedule maintenance before a critical failure occurs. The result – higher equipment availability and productivity, lower maintenance costs, lower total cost of ownership (TCO), fewer outages, optimal equipment performance and a greener operation.

Immediate Benefit of In-service Oil Analysis

Lubricants are the life blood of oil wetted machinery. As an important element of predictive maintenance technologies, in-service oil analysis can provide trace information about machine wear condition, lubricant contamination as well as lubricant condition (Figure 1). Reliability engineers and maintenance professionals can make maintenance decisions based on the oil analysis results. The immediate benefits of in-service oil analysis include avoiding oil mix up, contamination control, condition based maintenance and failure analysis, as described in the following paragraphs.

Figure 1: Information provided by in-service oil analysis

Avoid Oil Mix Up

The old saying of "Oil is oil" or "when in doubt, put engine oil in," really highlights the under-education of lubricating oils and the importance of optimized lubrication. Oil mix up is one of the most common lubrication problems contributing to machinery failure. Putting the right lubricating oil in the equipment is one of the simplest tasks to improve equipment reliability. Checking the viscosity, brand and grade of incoming new oil, and checking any contamination of alien fluids help reduce the chances of oil mix up and keeps the machine operating.

Contamination Control

Solid contamination (sand and dirt) accelerates the generation of abrasive wear. Liquid contamination such as moisture in oil accelerates machine corrosion. Fuel or coolant dilution in engine oil will decrease the viscosity therefore generating more adhesive wear (rubbing wear). It is critical to keep the lubricating oil clean and dry all the time. This requires that you set cleanliness limits and continue monitoring the contamination during the machine operation.

Oil Condition Based Maintenance

A well balanced oil analysis program can monitor machine wear condition, oil contamination and oil degradation at the same time (Figure 1). Key parameters are continuously tested and trending of those parameters is monitored. If a change of rate is accelerated or if a parameter exceeds an alarm limit, reliability engineers are alerted and maintenance actions may be required to resolve the potential problems.

Failure Analysis

A comprehensive oil analysis suite may include tests such as Ferrography, or SEM/EDX which are both time consuming and expensive. However, these tests provide detailed and definitive information about machinery wear, such as what the wear particles are made of, where they come from, and how severe they are. Such information provides reliability professionals with information on a past or imminent failure.

Common In-service Oil Analysis Techniques

Table 1 shows typical oil analysis parameters and common analytical techniques to monitor machine wear, contamination and degradation.

Because different types of mechanical components tend to have various oil related issues, different oil analysis techniques might be applied. For example, reciprocal engines tend to generate fine wear particles. Coolant leak, soot buildup and fuel dilution are common problems in lubricants. On the other hand, rotating machinery such as gear boxes tend to generate large wear particles. Acidity increase and moisture contamination are among common parameters monitoring lubricant condition to prevent corrosion. In almost in all cases, monitoring and maintaining lubricant viscosity within specification is critical to ensure mechanical components are well lubricated. Table 2 shows typical oil analysis parameters and how they relate to problems by equipment types.

CATEGORY	KEY ANALYSIS	ANALYTICAL TECHNIQUES
Machine wear	Fine wear metal elements	Rotating Disc Electrode (RDE) Spectroscopy, Inductive Coupling Plasma (ICP) Spectroscopy
	Large wear metal elements	Rotrode Filtration Spectroscopy (RFS), FPQ, XRF
	Particle count and distribution	Particle count, LaserNet Fines (LNF)
	Wear particle shape analysis	LNF, Ferrography, Wear Debris Analysis (WDA)
Contamination	Sand and Dirt	Particle count, LaserNet Fines (LNF)
	Fuel Dilution	Fuel Sniffer, Gas Chromatography (GC)
	Water/Moisture	Infrared (IR), Karl Fischer Titration (KF)
	Glycol/Coolant	Infrared Spectroscopy
	Soot	Sootmeter, IR
	Alien Fluid	IR

Table 1: Key oil analysis parameters and corresponding analytical techniques.

Common Oil Analysis Practices

There are several ways to perform in-service oil analysis. The most common ones are outsourcing to an off-site laboratory, using an on-site laboratory, or performing routebased oil analysis using portable tools.

Off-site Laboratories (Commercial labs, third party labs, central industrial labs)

Outsourcing oil analysis to an off-site oil laboratory is probably the oldest and most common approach in the industry. Every year millions of oil samples are analyzed by laboratories worldwide. A typical process flow involves a user collecting oil samples from equipment and shipping them to a lab, lab technicians performing requested oil analysis tests, and an analyst reviewing the data and providing

CATEGORY	DIESEL ENGINE	GEAR SYSTEMS	HYDRAULIC SYSTEMS
Elemental	Wear, contaminants, additives Viscosity – contamination from soot, or fuel	Gear boxes generate all sorts of wear, but the levels can sometimes get confusing	Will often validate or clarify particle count; added value for additives and contamination
Particle Count			Quantitative, somewhat holistic
Ferrography		Tracks the large iron-laden particles for Analytical Ferrography trigger	
FTIR	Oxidation, nitration combustion byproducts, glycol contamination	Oxidation, base stock integrity	Oxidation, base stock integrity
Viscosity	Contamination from soot, or fuel	Always useful and worthwhile	Always useful and worthwhile
TAN		Contamination or degradation	Contamination/ degradation
TBN	Reserve alkalinity, detergency		
Water	Mostly to identify	To validate the sample	Any detectable amount is probably adnormal or critical need particle count validity check
Fuel Dilution	Excessive idling or mechanical issue, such as a nozzle dribbling or leaking injector seal		
Fuel Soot	Combustion cycle indicator, Air fuel ratio		

Table 2: Different oil analysis parameters by machine applications

recommendations. The report is then sent to the management team for review and if needed, maintenance actions are performed

taking into account the recommendation and maintenance schedule (Figure 2).

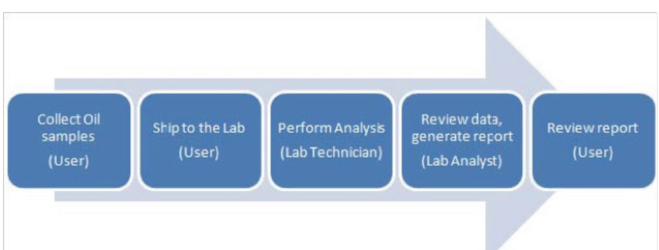
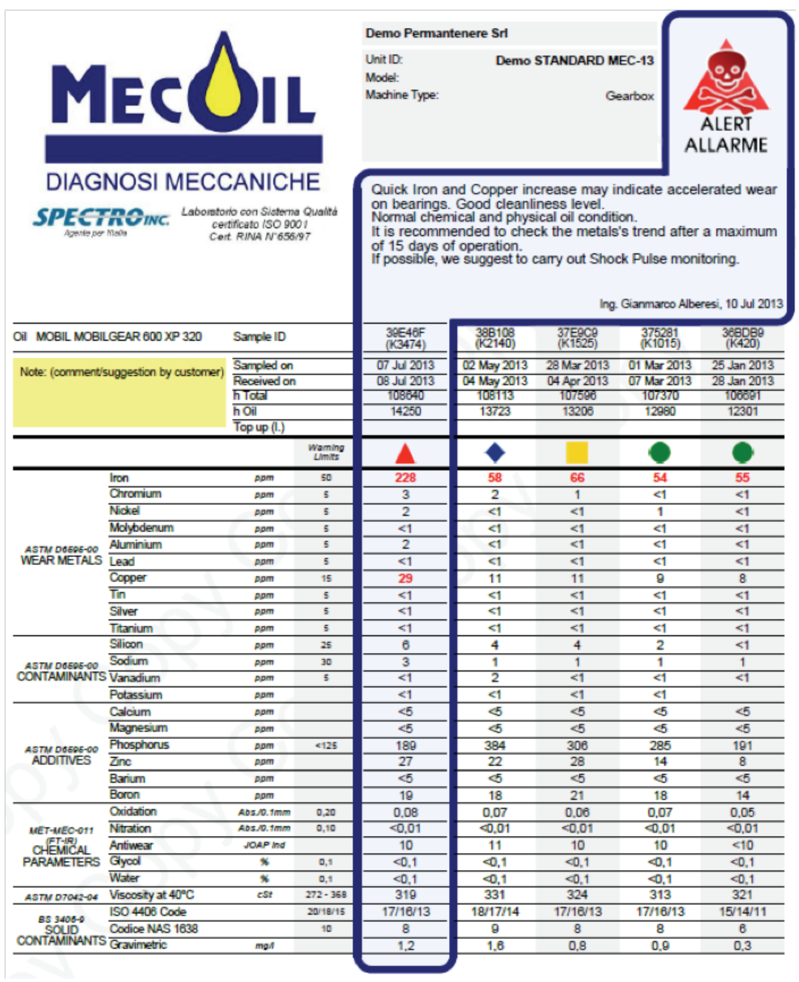


Figure 2: Off-site oil analysis flow chart

The benefit of this approach is that an off-site commercial laboratory will have a complete set of oil analysis instruments and experienced technicians to run the tests and an experienced analyst to review the data. The ramp up time is faster and the up-front capital investment is relatively low.

Figure 3 shows a typical laboratory report with all the measurement data regarding oil condition and recommendations from the lab.

Figure 3: A typical oil analysis report from an oil lab. Notice the diagnostics and recommendations on the top of the report from the analyst based on the oil type, machine type and oil analysis results. Appendix One shows a full lab report. (Courtesy of Mecoil) Facility under the ONR CBM program. These tests were conducted on single-reduction 10 hp gearboxes. The gearboxes were run-in for approximately four days at maximum normal load provided by an electric generator on the output shaft. After that, a 3X over torque was applied and the system then ran to failure. The system was stopped approximately every two hours for bore site inspection and oil sampling.



MECOIL
DIAGNOSI MECCANICHE
SPECTRO INC. Agente per l'Italia
Laboratorio con Sistema Qualità certificato ISO 9001 Cert. RINA N°656/97

Demo Permantenere Srl
Unit ID: Demo STANDARD MEC-13
Model:
Machine Type: Gearbox

ALERT
ALLARME

Quick Iron and Copper increase may indicate accelerated wear on bearings. Good cleanliness level.
Normal chemical and physical oil condition.
It is recommended to check the metals's trend after a maximum of 15 days of operation.
If possible, we suggest to carry out Shock Pulse monitoring.

Ing. Gianmarco Alberesi, 10 Jul 2013

Oil MOBIL MOBILGEAR 600 XP 320

Note: (comment/suggestion by customer)

			Warning Limits	39E46F (K3474)	38B108 (K2140)	37E9C9 (K1525)	375281 (K1015)	36BDB9 (K420)
	Sample ID			39E46F (K3474)	38B108 (K2140)	37E9C9 (K1525)	375281 (K1015)	36BDB9 (K420)
	Sampled on			07 Jul 2013	02 May 2013	28 Mar 2013	01 Mar 2013	25 Jan 2013
	Received on			08 Jul 2013	04 May 2013	04 Apr 2013	07 Mar 2013	28 Jan 2013
	h Total			108640	108113	107596	107370	106691
	h Oil			14250	13723	13206	12980	12301
	Top up (l.)							
ASTM D6595-00 WEAR METALS	Iron	ppm	50	228	58	66	54	55
	Chromium	ppm	5	3	2	1	<1	<1
	Nickel	ppm	5	2	<1	<1	1	<1
	Molybdenum	ppm	5	<1	<1	<1	<1	<1
	Aluminium	ppm	5	2	<1	<1	<1	<1
	Lead	ppm	5	<1	<1	<1	<1	<1
	Copper	ppm	15	29	11	11	9	8
	Tin	ppm	5	<1	<1	<1	<1	<1
	Silver	ppm	5	<1	<1	<1	<1	<1
	Titanium	ppm	5	<1	<1	<1	<1	<1
ASTM D6595-00 CONTAMINANTS	Silicon	ppm	25	6	4	4	2	<1
	Sodium	ppm	30	3	1	1	1	1
	Vanadium	ppm	5	<1	2	<1	<1	<1
	Potassium	ppm		<1	<1	<1	<1	
ASTM D6595-00 ADDITIVES	Calcium	ppm		<5	<5	<5	<5	<5
	Magnesium	ppm		<5	<5	<5	<5	<5
	Phosphorus	ppm	<125	189	384	306	285	191
	Zinc	ppm		27	22	28	14	8
	Barium	ppm		<5	<5	<5	<5	<5
	Boron	ppm		19	18	21	18	14
MET-MEC-011 (FT-IR) CHEMICAL PARAMETERS	Oxidation	Abs./0.1mm	0,20	0,08	0,07	0,06	0,07	0,05
	Nitration	Abs./0.1mm	0,10	<0,01	<0,01	<0,01	<0,01	<0,01
	Antiwear	JOAP Ind		10	11	10	10	<10
	Glycol	%	0,1	<0,1	<0,1	<0,1	<0,1	<0,1
	Water	%	0,1	<0,1	<0,1	<0,1	<0,1	<0,1
ASTM D7042-04	Viscosity at 40°C	cSt	272 - 368	319	331	324	313	321
BS 3406-9 SOLID CONTAMINANTS	ISO 4406 Code		20/18/15	17/16/13	18/17/14	17/16/13	17/16/13	15/14/11
	Codice NAS 1638		10	8	9	8	8	6
	Gravimetric	mg/l		1,2	1,6	0,8	0,9	0,3

On-site Laboratories

Modern predictive maintenance practices require real-time data and immediate feedback so reliability engineers can make maintenance decisions on the spot. Advances in oil analysis instrumentation technologies also make it possible for reliability engineers to perform on-site oil analysis without years of training or deep knowledge of oil chemistry and testing. There are two common approaches to develop an on-site oil lab.

Depending on the industries and applications one can either set up a Trivector™ Minilab or an Industrial Tribology Lab (ITL).

Trivector™ Minilab

A Trivector™ Minilab (Figure 4) was designed to meet the needs of industrial reliability engineers to monitor oil conditions of rotating equipment such as gearboxes, compressors, and turbines. It is the most cost effective approach for a comprehensive on-site oil analysis test lab. It provides oil parameters indicative of machine wear, contamination and degradation (chemistry) and plots the information on an innovative and straightforward Trivector™ chart. In addition, the oil condition information can then be integrated into other predictive maintenance techniques such as vibration and thermal imaging which provide a comprehensive overview of machine condition. The comprehensive Minilab includes tests such as dielectric (oil degradation), water contamination, ferrous particles, particle count, viscosity and wear debris analysis. It is easy to use and the entire test suite can be completed in less than 10 minutes.

Figure 4: Trivector™ Minilab and Trivector™ plot

Industrial Tribology Lab (ITL)

A total Industrial Tribology Lab (ITL) contains a complete set of oil analysis instruments suitable for performing the most demanding in-service oil analysis tasks commonly performed in a commercial laboratory (Figure 6). However, the instruments in an ITL may be different from a high volume commercial lab. It is designed for small footprint (suitable for on-site or in a trailer), no sample preparation (suitable for reliability professionals), low consumable cost, low waste stream, and ease of use. In fact, the original ITL concept was designed for military applications where the tests are performed by soldiers in the field and where ease of use is a must. The ITL is configurable based on the types of tests required. It is commonly used for remote mining sites, railway repair depot, shipboard, or the central lab in an industrial plant.

The core instrumentation of an ITL includes a Rotating Disc Electrode (RDE) Optical Emission Spectrometer (OES), a direct imaging particle analyzer based on LaserNet Fines technology, a temperature controlled viscometer, and an infrared spectrometer and information management software (see Figure 5).

The RDE-OES (Spectroil Q100) provides an elemental breakdown of fine and dissolved wear metal particle concentration in parts per million (ppm). It uses 2ml of oil sample and only takes 30 seconds to analyze up to 32 elements at once and complies to ASTM D6595. In addition to in-service oil analysis, calibration programs including coolant, light fuel, heavy fuel, and wash down water can be added to the instruments.

Grease can also be analyzed on the instrument with little sample preparation for trending purposes. Compared to ICP, which is commonly seen in high volume commercial labs, the advantage of the RDE-OES is flexibility, ease of use and no sample preparation. The results from RDE-OES correlate with those from ICP really well.

The LaserNet Fines (LNF) particle analyzer uses direct imaging technique with a high speed CCD camera to capture particles in oil and with Neural Network the software automatically classifies particles larger than 20mm into cutting wear, sliding wear and fatigue wear based on shape analysis.

The whole process takes less than 5 minutes comparing 30 to 60 minutes for ferrography. It complies with ASTM D7596. Bitmap images of wear particles from the camera display on the final report.

The viscometer (SpectroVisc Q300 or Q310) is a temperature controlled high speed semiautomatic viscometer compliant with ASTM D7279. If the number of samples per day is low, a manual viscometer (SpectroVisc Q3050) can be used. The advantage of the manual viscometer is that no solvent is needed for after test cleaning.

The infrared spectrometer (FluidScan) is based on diffraction grating optics instead of the FTIR technique. It complies with ASTM D7889 which provides a dedicated oil analysis spectrometer based on diffraction grating and more repeatable and reproducible oil chemistry information than the FTIR method. It also includes a large on-board oil library with accurate TAN, TBN and dissolved water information without the needs of titrators. Data from all the pieces of instruments can be exported to the SpectroTrack information management software which can be installed on site as well as hosted in the cloud.

With additional requirements, a fuel sniffer or/and a soot meter (ASTM D7686) can be added to the ITL configuration, commonly used for maintaining a fleet of diesel engines, such as railway and mining applications. Ferrography (ASTM D7684, ASTM D7690) can be added in the ITL configuration as well for advanced failure analysis.

The ITL configuration is compact, with low oil consumption (low waste stream), low solvent consumption (low recycle cost), and low consumable cost (low cost of ownership). No annual calibration is required on instruments, only standardization and a regular performance check is needed.

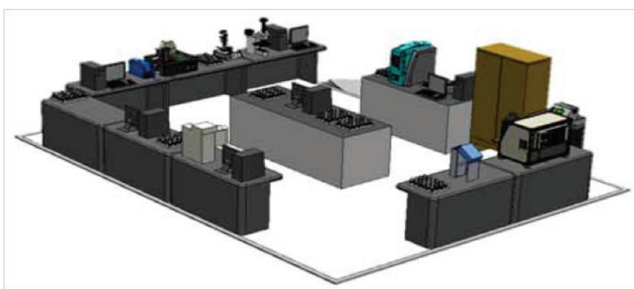


Figure 5: Example of an ITL configuration

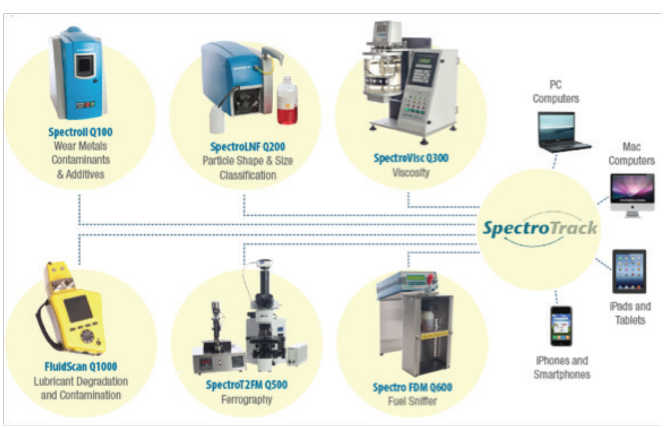


Figure 6: Minimum ITL configuration

Mobile Oil Analysis Tools and Route Based Oil Analysis

The advancement of technology makes it possible to have portable, battery powered oil analysis tools with similar analytical power of those instruments used in the labs. Increasingly, more new products are introduced to enable reliability and service engineers to make oil analysis decisions right at the equipment site instead of collecting oil in bottles. This is similar to the ways vibration and thermal imaging is done in an industrial plant.

Now reliability service engineers can combine the information from oil analysis and vibration analysis in real-time, which empowers them to make much more informed decisions about machine maintenance. Figure 7 shows two examples of portable oil analysis tools. The product to the left is a FluidScan and viscometer combination kit for route-based oil condition monitoring. The product to the right is the Q5800 Expeditionary Fluid Analysis System including a particle counter, a patch maker for microscopy, an XRF for wear particle elemental analysis, a direct IR spectrometer (FluidScan) for oil chemistry and a temperature controlled kinematic viscometer.

All the technologies in the Q5800 are packaged in a suitcase and powered by a lithium ion battery for up to 4 hours of continuous testing. It is very powerful to have the analytical capability of an oil analysis lab in a suitcase so that reliability service professionals can carry it around to critical equipment for just in time oil analysis. In addition, communication options such as cellular modem, wifi or Bluetooth can be employed to transfer the data to a LIMS such as SpectroTrack, so customers may review the data as soon as it is complete.

Figure 7: Examples of portable oil analysis tools. FluidScan and Viscometer Combo (left) and Q5800 Expeditionary Fluid Analysis System (right)

Conclusion

In summary, in-service oil analysis provides critical information about machine condition and oil condition. There are many different approaches to implement an oil analysis program, depending on the application and maintenance objectives. Modern technologies have enabled reliability professionals to use new tools for the highest level of efficiency and effective maintenance.

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Spectro Scientific | One Executive Drive, Suite 101, Chelmsford, MA 01824-2563 | 978-431-1120
sales@spectrosci.com | sales@spectroinc.com An ISO 9001:2008 company