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.
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 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.

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 onsite laboratory, or performing route-based 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
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).

Table 2: Different oil analysis parameters by machine applications

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

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.
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.

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.

**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.
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.