THE ROLE OF LUBRICANT ANALYSIS IN MAXIMIZING LUBRICANT AND EQUIPMENT LIFE

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1. INTRODUCTION

Lubricant analysis has always played an important yet somewhat invisible role in equipment health monitoring. At its most primitive, simple observations and field testing alert equipment operators to changing conditions. At its most advanced, data from performance and analytical tests are used to develop or select optimum lubricants for service, stretch drain intervals, predict remaining equipment life and identify potential equipment or system problems at an incipient stage. Coupled with thermography and vibration analysis, lubricant analysis can become a major component of a comprehensive predictive maintenance (PM) program.

Ontario Hydro finds itself at a turning point regarding the use and monitoring of lubricants. Increasing emphasis on equipment reliability and plant life extension, coupled with major, recent changes in lubricant composition in response to environmental, energy and safety concerns, forces an upgrading of many aspects of lubricant monitoring so that it may establish itself as a key part of modern PM practices. This paper discusses some of these aspects.

2. LUBRICANT TESTS & LIMITS

Modern lubricant monitoring builds upon the standard tests and limits used in the past, but tailors or adds to these to suit the changing times. The following are general principles that are used to develop guidelines: (1) the lubricant should match the application so that frequent testing is not required, (2) tests that are required the most often should be simple enough to carry out in the field; (3) tests should provide information on the mechanical system as well as the lubricant, (4) the test techniques should not produce noisy data nor should the limits result in too many false alarms, and (5) for large volume or critical applications the data should be complete enough to allow alternatives to replacement.

2.1 Screening Tests

As noted in Table 1, the conventional suite of tests for most oils (acidity, viscosity, colour and an appearance check) has changed little over the years, although particle count (PC) and trace metals (TM) have been added recently to provide data on equipment health and additive concentrations.

Maintaining low particle counts is seen as a way of extending bearing life while monitoring TM provides early warning of system wear and, for products such as ball screw greases, provides some measure of remaining life based on additive element contents.

The above tests are still usually sufficient for routine monitoring, and most can be automated in a site laboratory. However, if they identify an abnormal state, or a more detailed check is required periodically or as part of a failure analysis, there is a host of important methods available to provide additional information. Some of these are noted in Table 2 and described below.

2.2 Oxidation & Remaining Life

Oxidation tests such as Rotating Bomb (RBOT), and ASTM 2440 Oxidation Stability are used in the OHT Petroleum Products Laboratory (PPL) to determine remaining oil life, while Infrared (IR) and TM methods track additive depletion and degradation product buildup in oils and greases. The data can be used to determine if re-inhibition is warranted, then the same methods can be used to evaluate the remaining life of the addified product.

2.3 Particles , Sediments & Deposits

Unusual particulate, sediments and deposits can now be routinely analyzed in detail via Energy Dispersive X-ray (EDX) techniques, coupled with IR, at relatively modest cost. The analyses provide elemental composition for elements as light as carbon, so both organic and inorganic components are detectable. The PPL considers the EDX-IR technique to be superior to Ferrography, another relatively new method widely used for lubricant particulate analysis, because it provides data on a wider variety of materials.

Particle counting data is typically very noisy and there are systematic differences in what is counted by different techniques. This problem is addressed to a large extent by comparing data via International Standards Organization (ISO) contaminant codes rather than by absolute particle counts. A ratio of ISO codes characterize the particle distribution in a 100 mL sample by, approximately:

$\log_2(\text{particles}>5\mu m)/\log_2(\text{particles}>10\mu m)$

The size of the range number gives a measure of total loading while the ratio of the two numbers indicates the skew toward small or large particulate.

2.4 Dispersed Contaminants or Emulsified Condition

American Society for Testing and Materials (ASTM) methods D 892 Foam, D 3427 Air Release Value (ARV), D 1401 and D 1935 Emulsion tests, D 665 rust test, plus various hydrolytic stability, flash point and water content tests, are available to check on fluid degradation, contamination or additive loss. Coupled with TM and IR, the test data indicate the nature of the condition and its severity.

With knowledge of the constituents in the new lubricant, the laboratory can often recommend additives such as defoamers or corrosion inhibitors to correct the condition.

Reports on contamination can sometimes identify harmful maintenance practices, such as overuse of liquid silicone gasket repair materials which can bleed low molecular weight polymers into oils and cause air entrainment problems.

2.5 Wear Tests

Wear and load tests on bearing rigs or pumps are sometimes required to evaluate lubricant film strength or the effectiveness of anti-wear (AW) or extreme pressure (EP) additives.

Special testers such as Timken load (EP products), four-ball wear (AW products), pin-on-disk, Vickers vane pump (hydraulic fluids) and high speed bearing rigs are used to rate new and used materials.

Recent advancements include the use of very small samples to accommodate the testing of radioactive materials in Timken test, the use of start-stop and reverse motion in pin-on-disk tests to simulate various field conditions, and the use of force transducers to monitor friction in bearing rigs. The modification of a Vickers system to test synthetic fluids in high pressure hydraulic valves is also being considered.

3. TRENDS

The following issues are having an impact on the role of lubricant testing.

3.1 Waste Minimization

Lubricant monitoring has always assisted waste minimization by such things as reducing the number of unnecessary changeouts and by assessing the condition of pooled oil collected over time from turbine operations. However, minimization efforts have recently included fluid reconditioning of turbine oil charges. Additive concentrates are now available from lubricant suppliers and reclaimers for treating turbine oils to extend oil life and new testing techniques are required for their evaluation.

For example, in 1992 candidate additive packages and filtration treatments for use on Unit 4 turbine oil at Pickering NGS were evaluated by accelerated aging of treated oil blends. A modified D 2440 oxidation test for insulating oil was adapted for use. The test method determined that the optimum reinhibited blend had about 60% of the life of new turbine oil.

Waste minimization also includes labour minimization and radioactive dose reduction. This can be accomplished by pushing changeout and sampling intervals to their limits while maintaining acceptable lubricant performance. However, there is a tradeoff between extended intervals and the testing required for the lubricants. Because the lubricant is seen less frequently, more tests have to be performed when the lubricant is obtained to assure continued performance. Also, significant extension is sometimes only possible by using new synthetic products which may require some form of initial acceptance testing.

3.2 On-Line Monitoring and Field Testing

PM programs can benefit from real-time monitoring systems. However, at present, few on-line lubricant monitors exist. Real time particle counters have been used with considerable success for monitoring standby generator systems, and hand-held particle counting systems are available for field testing small samples. Viscosity measurement could be placed on-line, but it is usually not considered. Capacitance probes for dissolved water exist and may be useful for some systems.

For most conservatively designed equipment in Ontario Hydro, on-line data is not required because the lubricant properties do not usually change quickly with time. However, portable field systems would be convenient as they could be merged with vibration analysis monitoring routines.

Approaches considered for field monitors include cyclic voltammetry, microwave resonance, spectrometry and various auto-titration systems. More development work is needed in this area.

3.3 Electronic Data Handling

The computer networking capabilities of Ontario Hydro provides a method of obtaining and interpreting lubrication data in a timely fashion. The PPL sees three areas emerging: (1) electronic transfer of test data from laboratories, (2) data interpretation via software, and (3) enhanced case history record keeping and lubrication list updating.

Ideally, the act of logging samples at the station laboratories will generate electronic data forms to be accessed and completed by those doing the work, regardless of the physical location of the lubricant testing laboratories.

	Application	Screening Test Limits [1, 2]				
		TAN (mg KOH per g)	Particle Count (ISO Class)	Viscosity Change (% of Grade)	Water Content (mg/kg)	Trace Elements (mg/kg)
1	Turbine and H_2 Seal Oils	0.25	16/13	-5 to 5	100	all <10
2	F/M Hydraulics	0.25	15/12	-5 to 5	100	all <10
3	Air Compressors	0.25	17/14	-5 to 5	100	all <10
4	BFP	0.35	17/14	-5 to 5	100	all <10
5	HTP & Gen. Use in Pumps	0.35	17/14	-5 to 5	100	all <10
6	AW Hydraulic Oils-Gears	0.90	-	-5 to 10	100	Fe <250 WM < 30
7	AW Hydraulic Oil-Gen. Use	0.70	-	-5 to 10	100	Fe <250 WM < 30
8	EP Gears	+ 3 from new oil	-	-5 to 25	-	-
9	CTU	1-warn 2-max	16/13	-5 to 20	500 (ester) 100 (SHC)	-
10	FRF Governors	0.20	15/12	-17 to 6	1000	Cl <100 Mg+Ca < 30 Na+Al < 30
11	Refrigeration Compressors	0.05	-	-20 to 20	35	Al <15 Ca <20 Fe <30

[1] **Appearance limits** (applies to all fluids): abnormal darkness, cloudiness, foam or sediment.

[2] **Abbreviations**: TAN = total acid number, WM = Cu,Pb,Al,Sn wear metals, AW = antiwear, EP = extreme pressure, FRF = fire resistant fluid, F/M = fuelling machine, BFP = boiler feed pump, HTP = heat transport pump, CTU = combustion turbine unit, ISO = International Standards Organization.

Table 1: **Test Limits for Initial Screening**

In most cases, data interpretation logic can be flowcharted to provide consistent guidance. However, the process is sometimes complicated by a requirement for re-sampling and waiting for additional analyses.

Electronic database versions of the lubrication lists exist or are being prepared for all Ontario Hydro nuclear stations. Over time it is expected these will be linked to records containing historical data on testing and lubricant selection for important equipment.

The electronic form also facilitates changes and updates of lubricants if required. For example, a major supplier recently changed the phosphorus additive content by almost 50% in its EP gear oil, but this trace element is sometimes used to monitor remaining additive content. The electronic form allows for convenient flagging of such changes.

3.4 Synthetic Lubricants

While synthetic hydrocarbon, silicone fluid and ester-based synthetic lubricants are used in Ontario Hydro in adverse environments such as some rotary screw compressors, high temperature applications and combustion turbines, more extensive use is being recommended by lubricant suppliers as a way of increasing changeout intervals, consolidating inventory and reducing energy consumption.

Equipment likely to benefit from synthetics are: air compressors, heavily loaded gear sets, refrigeration compressors, and fans in containment or other hard to reach locations.

Problems seen with synthetics include: loss of expensive synthetic during water draining of air compressors with low duty cycle, poor radiation resistance of some SHC products, too low a grade recommendation in an effort to gain energy efficiency, incompatibility with materials of construction and incompatibility of specialty greases.

Monitoring the condition of synthetics is a challenging problem area that is becoming more important as new products move into service. For example, in the PPL an aggressive oxidation technique, pressurized differential scanning calorimetry (DSC) is sometimes required to evaluate highly stable materials and special hydrolytic stability procedures are required to evaluate phosphate ester electrohydraulic control fluids.

Because they are expensive, degraded synthetics are often worth reclaiming using filters or other plant equipment. Both filtering media and treated fluids require special monitoring.

4. LUBRICANT RATIONALIZATION AND SPECIFICATIONS

Lubricant performance testing and analysis plays a large role in reducing the number of lubricants carried in inventory. This is mostly achieved by matching performance characteristics of inventoried materials

Application		Additional Requirements For Service
1	Turbine & H_2 Gen. Seal oil & BFP	Paddle emulsion test - emulsified layer < 3 mL @ 20 min Rotating bomb oxidation test (RBOT) - life > 100 min Foam < 400 mL @ 5 min blowing, NIL @ 10 min standing Air Release Value < 10 min (for ISO 46 oil), < 8 min (for ISO 32 oil)
2	F/M Hydraulics	RBOT > 150 min. Other tests/limits as for turbine oils.
3	HTP	RBOT > 75 min. (if wet, trace metals used to identify source)
4	Air Compressors & General pumps	RBOT > 75 min.
5	AW hydraulic oils	Sediment < 0.1%, 4-ball scar < 0.5 mm dia, acidity after D 943 oxidation < 2 mg KOH/g,Vickers D 2882 vane wear @ 100 h < 50 mg
6	EP Gear Oil	Timken OK Load > 30 lbs
7	FRF Governors	Resistivity > 5,000 MΩ-cm
8	unusual sediments deposits, and particulates	Normal levels of wear metals and oxidation products in SEM-EDX/IR tests.

Table 2: **Some Extended Tests and Limits**

with the field requirements. This may require laboratory simulation of the operating environment and comparison testing, as sometimes the match of operating conditions and lubricant or equipment supplier's performance data is not clear or OEM data is not available.

For the existing inventory to be suitable for many applications and adverse conditions, products selected for use must be known to meet a wide variety of conditions. This can be ensured only if the products are known to meet appropriate acceptance specifications. It is only by screening products through rigorous acceptance testing that in-service programs can monitor lubricant and equipment health with any degree of confidence and yet be based on a minimal amount of testing.

The PPL is in favor of formalized specifications for all major lubricant types used in Ontario Hydro. Further, if possible, such specifications should be similar to "Mil. Specs." in that all products meeting a specification must be compatible with one another to provide options for change. The challenge here is to set the specification requirements in a comprehensive manner such that all operating conditions and mixing effects are taken into account. This requires a combination of performance tests on mixtures of new products and also analytical tests to characterize base materials and additives. In particular, high performance liquid chromatography (HPLC) and IR techniques are extremely valuable for identifying lubricant components. If the components are known with confidence, then many time consuming performance tests to confirm compatibility are not required.

Lubricant rationalization is being both aided and threatened by modern developments in lubrication and product distribution and inventory control.

Advances in synthetic lubricants mean it is possible to optimize performance and lengthen changeout intervals considerably in some special applications, but this implies a proliferation of special products in inventory. While it is true that premium synthetics may be technically capable of replacing several non-synthetic materials, their high cost will probably keep them in small volume, harsh environment applications for some time.

Streamlined, computerized methods of purchasing and inventory management may make it possible to either maintain an expanded inventory of specialty products or to consolidate materials via such initiatives as Commodity Management or other bulk purchasing arrangements.

5. SUMMARY

Lubricant condition monitoring techniques available in Ontario Hydro are adequate for the present and near future. However, the test methods and limits used in the past for qualifying new lubricants and monitoring lubricants in service require major updating to allow Ontario Hydro to keep pace with technological advances and meet the demanding maintenance requirements of the future.

Electronic data handling procedures and new laboratory and field instrumentation require development to aid predictive maintenance programs.

The development of more Corporate Specifications for lubricants is recommended.