Condition-Monitoring of Phosphate Ester Hydraulic Fluids

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One of the most interesting synthetic base fluids is phosphate esters. It is the product of choice for the electrohydraulic control (EHC) system in steam turbines for electrical power generation. These fluids have a balance of desirable and undesirable properties that may create a bit of a love-hate relationship for many users, especially if they do not maintain them properly.

Phosphate esters have good thermal stability, excellent boundary lubrication properties, low volatility and fair hydrolytic stability (chemical stability in the presence of water). Unfortunately, phosphate esters can be hard on some elastomers such as Buna-N or nitrile, PVC coatings and paints. However, they are not as hard on butyl, nylon, PTFE, EPR, Viton and epoxy-based paints. Because phosphate ester degradation products can catalyze further degradation, they require vigilant condition monitoring and specialized reconditioning.

Given the need for extra in-service attention, relatively high purchase cost (from $18 to $30 per gallon) and cradle-to-grave lifecycle management to limit environmental risk, why is this category of synthetic fluid consistently selected for use in power generation plants?

The triaryl version of the phosphate ester is relatively unique among hydraulic fluids because it's self-extinguishing. The fluid doesn't create enough energy to support its own combustion in a fire. Other lubricants can burn readily once they reach their 'fire' points. In addition, phosphate esters tend to have higher flash and fire points, higher autoignition temperatures and perform better in spray flammability and wick-type fire propagation tests.

This article is about fire-resistant phosphate esters used in EHC systems on steam turbines.

Managing Phosphate Ester Lubricants

Although they have reasonable thermal and acceptable hydrolytic stability properties, phosphate ester lubricants require routine attention to maintain stability throughout the turbine's service life. Fluids can remain in service for 15 years or more unless they are exposed to conditions that contribute to premature degradation. Examples of such conditions include:

1. The purification media is not changed often enough or it is changed incorrectly.
2. The purification system flow rate is wrong (too high or too low) and/or it is not in-service continuously.
3. The facility is using inferior or dated parts and/or following bad procedures, especially on fluid top-ups and media changes.
4. The facility is using the wrong type of phosphate ester and/or one that does not meet the specifications for that turbine.
5. The facility is not using suitable condition-monitoring devices. For example, working media and filter housing pressure gauges.
6. The facility is not using current or correct OEM maintenance and operating procedures.
7. The facility is following inappropriate OEM documen- tation or procedures.

Determining the failure root cause (and there may be more than one) requires proper fluid testing and a careful review of the fluid and equipment history. Many of these systems have been in service for 20 years or more, during which numerous improvements were likely made.

Figure 1. Purification Media Housing on an EHC System. Each Housing Takes One 718 Cartridge.

Figure 1 illustrates the case of an OEM who provided incorrect information on the use of OEM-provided media housings. The actual maximum flow with fuller's earth is supposed to be 0.5 GPM (1.9 LPM) per cartridge, or in this case 1 GPM (3.8 LMP) total, but the documentation mistakenly said 2.4 GPM (9 LPM). The result can be acid control but not resistivity control, and possible release of fines from the purification media. The flow rate may differ for other types of purification media, such as Selexsorb and ion exchange resins.

Condition Monitoring

Most of the tests recommended for phosphate esters are similar to those recommended for mineral oil condition monitoring. However, because of differences in chemistry, experience with mineral oil testing does not necessarily mean competence with phosphate ester analysis. For instance, there are limits on the chlorine content and on resistivity for these fluids when used in servo-controlled hydraulic systems. Tests for chlorine and resistivity are seldom conducted for mineral oil but are required to prevent electrokinetic erosion of the servo valve metering edges.

Click Here to See Table 1. Table 1 shows the recommended tests and their frequencies.

Most fluid suppliers offer some tests as a free service to accompany the use of their fluid brand. While this certainly simplifies the challenge of initiating an oil analysis program, it does not promise success. The full slate of tests should be correctly selected even if the test is not offered as a free service.

Taking Action

If a parameter is trending out of specification, consider the risk (likelihood X consequence of failure) and take the corrective action within the appropriate time frame. Table 2 presents some common tests and brief explanations.

Table 2. Explanation of Test Terms

Parameter	Explanation
Color	Scale goes from 0 (clear) to 8 (black). Darkening in-service is typical but a rapid change is of concern.
Appearance	No visible oil (on top), water (on top), particulates, fibers or cloudiness.
Viscosity	Fluid is an ISO VG 46. Viscosity should not normally vary if the make-up is the same viscosity. A significant change may be the result of contamination or testing.
Acidity/AN/Neutralization Number	As fluid is used, acidic compounds can be formed. Normally controlled at <0.20 mg KOH/g by purification media. Too high at any time can lead to later problems and shortened fluid life.
Chlorine Content	A high value can cause servo valve electrokinetic wear. The source can be chlorinated solvents.
Water Content	Esters can hydrolyze so the water content must be controlled. Water can also reduce the effectiveness of most purification media and cause rusting.
Particle Count	Too high can lead to shorter fluid lives, servo and or solenoid valve problems with sticking and screen/filter blockage. Resample and determine source if still high.
Mineral Oil Content	Even a little can impair fire resistance, soften ethylene propylene rubber (EPR) or butyl seals and/or shorten fluid life.
Electrical Resistivity	Must be kept high to prevent electrokinetic wear of servo valve internals. Normally controlled by fuller's earth or Selexsorb purification media.
Elemental Spectroscopy	High amounts of magnesium (Mg), calcium (Ca) or sodium (Na) may be from the purification media. Can lead to the formation of soaps and/or gels and have a negative effect on foaming and/or air release times.
Foaming	Excessive foaming can affect the pumps and level controls and impair air/water release.
Air Release	A failure of the fluid to detrain air bubbles is an indication of degradation or contamination.

Stabilizing the acid number of these fluids is the most basic phosphate ester control fluid requirement. Most turbine suppliers set a maximum limit of 0.20 mg KOH/g. With good control, less than 0.10 mg KOH/g should be achievable.

Moisture Challenges

The concern about the water in phosphate esters is two-fold. First, because the base fluid is a product of a reaction between an acid and an alcohol, and because the reaction can be reversed, too much water creates a risk of hydrolysis and fluid degradation. Fluid oxidation and contamination from the aggregate-type purification media (fuller's earth, activated alumina, etc.) can increase this risk. Secondly, steel components in the system are prone to rusting in the presence of too much moisture. It is important to gauge the sensitivity of each EHC system, and to maintain the moisture levels as low as is reasonably achievable. Some systems can tolerate higher water concentrations without apparent difficulty.

Figure 2. Standard Desiccant Breather Used on a GE Reservoir

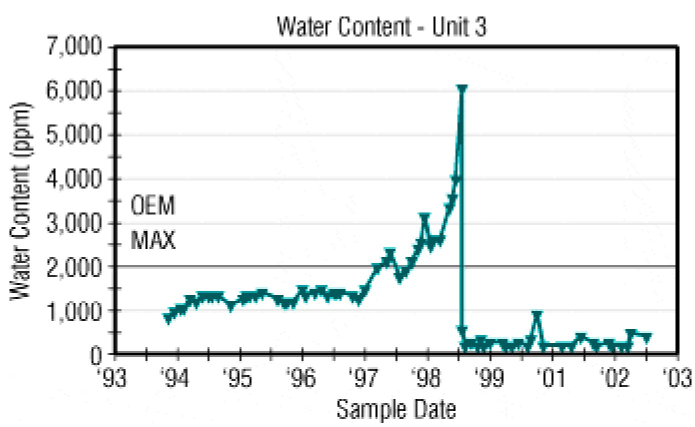

Figure 3. Rise in Water Content Because of a Cooler Leak and then a Very Low Level with Reservoir Purge Air

Figure 3 shows a moisture trend on a system designed with moisture control mechanisms featuring a large desiccant breather on the reservoir (Figure 2). The water content was well under control in the early 1990s with little seasonal variation, but then it started to increase. The cause, a cooler leak, was eventually found and corrected. Additionally, a dry air purge on the reservoir headspace was added. This drove the water content even lower.

Particle Counts

Most turbine OEMs recommend ISO particle count targets in the 14/11 to 15/12 range. However, use caution when developing oil analysis and contamination control programs to limit or eliminate as much variability as possible. Development of effective sampling, collection and analysis procedures, including installation of sample points at the correct location, is critical. It is also necessary to verify the lab's sample preparation procedure and method of particle counting when interpreting questionable or problematic data. Poor preparation of the sample can lead to erroneous results and misguided operational decisions in response.

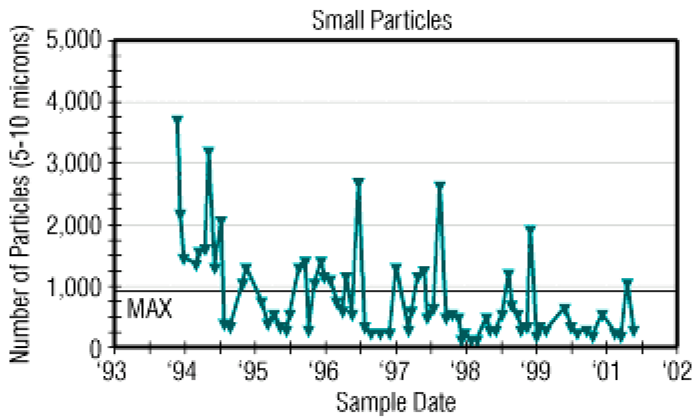

Figure 4. Improvement, but Periodic High Particle Counts

Figure 4 shows another case in which the particle counts were generally acceptable, with the exception of a few instances of very high counts. However, variations of this magnitude should be investigated because they can lead to an increase of fines in purification media (fuller's earth, etc.) migrating into the fluid, and/or loss of efficiency. This can result in sticking servo valves and loss in production of electricity.

In this case, the filter housing downstream of the purification unit had an internal pressure relief valve that opened at about 18 PSID. Higher pressure differentials caused by cold fluid or fines migrating from the purification unit can force the filter into bypass, dumping large amounts of particles right into the reservoir.

Fluid contamination by purification media can often be identified spectrometrically through high magnesium and calcium content in the case of fuller's earth and high sodium in the case of activated alumina, zeolites, Selexsorb and ion exchange resins. Note: Some elemental spectrometers do not pick up sodium very well and the alternate use of X-ray fluorescence spectrometers (XRF) can be poor sensitivity for magnesium.

Such media migration contaminants can contribute to deposit formation, foaming and/or decreased air release properties. These conditions can lead to adiabatic compression, fluid darkening, varnish formation, plugging of filters/servo valve screens and/or sticking servo valves and solenoids.

Fluid maintenance issues have also been complicated by formulation changes in the fluid, the purification media and the filter elements. The workplace environment and access to in-house resources have changed as well. These systems can run trouble-free without expensive modifications, so be careful not to substitute one problem for another. Consider the following steps toward effective fluid condition monitoring:

1. Perform all tests necessary to adequately quantify the condition of the fluid in your system. Do this even if there are no known fluid problems. Developing a fluid history can be helpful if problems develop. Avoid conducting only the minimum tests.
2. Take action on all high particle counts and do not permit sloppy fluid sampling. Ignoring a high count can lead to operating problems and possibly a forced outage.
3. Plot the oil analysis trends against time and not the sample number so that seasonal variations are apparent.

4. For personnel taking the samples, operating and maintaining the unit, keep them involved in the fluid condition- monitoring program, and share with them the results.
5. In the monitoring program, include the examination of used purification media cartridges, spent filter elements and servo valve screens as part of condition monitoring.
6. Keep in contact with fluid suppliers, sister power plants and other knowledge sources. If you see a bad practice in your workplace or a procedure you do not understand, ask.