Taking the Mystery out of Phosphate Ester Fluid Maintenance

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Abstract

Electro Hydraulic Control (EHC) systems are critical hydraulic systems used in many steam turbine applications. Due to high operating pressures and proximity to hot sections, fire resistant phosphate ester fluids are often used. Phosphate ester fluids are also used in gas turbine applications, hydraulic systems for steel and aluminum production and navy applications. Maintaining these fluids is not complex, but is often the source of great anxiety and frustration.

This paper will explain the basics of proper fluid maintenance and testing, as well as explaining how to transform your existing practices into a world class program.

With best practices and effective strategies to address common issues established, phosphate ester fluids provide reliable, stable performance without having to compromise on fire safety. Most importantly, implementing best practices allows users to identify and prioritize problem systems so simple steps can be taken to prevent future unit trips or mechanical failures. Saving your company a million dollars might even impress your boss!
Introduction

Phosphate ester hydraulic fluids are one of several lubricant types maintained at plants. Maintenance personnel often view phosphate ester fluids in the same light as mineral based hydraulic or turbine oils – as a consumable; even a commodity. Routine maintenance practices to maintain lubricants include bleed-and-feed or dump-and-recharge operations. Like their mineral oil brethren, phosphate ester reservoirs are often flushed between charges.

The first step in the transition to proper maintenance practices for phosphate ester fluids is a paradigm shift in how these fluids are viewed and the attitude towards maintaining them. Phosphate ester fluids are an expensive asset that requires close attention and care. A simple fluid change-out with proper flushing can easily cost $150,000 or more for a 400-gallon EHC system. The margin of error on these fluids is significantly lower than mineral based lubricants. In other words, if not properly monitored and maintained within a narrow range on several key properties, degradation processes rapidly spiral out of control. Phosphate ester fluids can be a true “fill-for-life” asset that will last the life of the hydraulic system when properly maintained, thus, providing years of excellent performance.

Along with adopting a “fill-for-life” mentality, O&M personnel need to accept that these fluids require a diligent level of care. Plant personnel must understand the basics of phosphate ester degradation and the tools and processes that help keep their fluids and systems in top form.

Phosphate Ester Basics

Industrial phosphate ester hydraulic fluids are comprised of a mixture of synthetic, non-aqueous, triaryl phosphate esters. The fluid’s unique attributes are excellent fire-resistance and the ability to self-extinguish. Although other fluids (polyol ester, polyol ether or polyalkylene glycol) are also considered fire-resistant and are approved by Factory Mutual, phosphate ester chemistry produces a fluid that is extremely difficult to ignite, and once ignited will not sustain a flame. The self-extinguishing properties of phosphate ester are the key reason why the majority of OEMs specify only this fluid type. In areas where hydraulic fluid may come into contact with the extremely hot temperatures like high pressure steam or molten metal, very few appropriate alternatives exist. Phosphate ester fluids have provided significantly safer plant operations and have saved lives.

In addition to outstanding fire-resistant properties, phosphate ester fluids are thermally stable, have low volatility and excellent boundary lubrication properties. The downside is poor hydrolytic stability; phosphate esters decompose in the presence of sufficient water. They also have compatibility issues with many common seal materials (Buna-N, nitrile) and paints.
Although phosphate esters have been used in steam turbine EHC systems for half a century, there are still significant problems reported. Contaminated phosphate ester fluids cause unit “trips” – an extremely costly event in large base-loaded power generation facilities. Contaminated fluids also cause system corrosion and wear and can greatly increase maintenance requirements. There are frequently complaints of black sludge on filters, gel and varnish found throughout the reservoir and deposits in servo-valves.

**Basics of Phosphate Ester Degradation**

Many factors contribute to phosphate ester degradation; however the chemistry is not actually as complex as mineral based fluids. Phosphate esters have a uniform chemistry with a limited number of degradation pathways, while formulated mineral oils contain dozens of different types of molecules. FIG 1. shows a simplified overview of the various contaminants in phosphate ester fluids, their potential sources and the impact on hydraulic system performance. The three general classifications of contaminants are inorganic contaminants, water, and organic contaminants. Organic and inorganic contaminants can be soluble, such as acids and alcohols, or insoluble like varnishes and certain gel components. Some contaminants can exist in both soluble and insoluble forms like metals. This soluble / insoluble distinction is critical and plays a large role in monitoring and maintaining these fluids. It should be noted that in the actual conditions of the EHC system, these contaminants react with each other, which involves chemical reactions beyond the scope of this paper. A reasonable knowledge of the basics is sufficient for adequate phosphate ester fluid maintenance.

**FIG 1. - Simplified Root Causes of EHC Performance Problems**
Soluble Inorganic Contaminants
Soluble inorganic contaminants, almost exclusively dissolved metals, are a cause for immediate concern in EHC systems. Although these soluble metals do not contribute directly to wear, they are chemically reactive. The industry has generally accepted that the effects of soluble metals contamination leads directly to servo valve problems. The metals also act as catalysts to accelerate fluid degradation. Soluble inorganic contaminants also negatively impact air release, increase acid production, lower resistivity, and form deposits on servo valves. Most often these metals originate in one of three places: atmospheric contamination, wear metals and certain types of acid scavenging filters.

Atmospheric Contamination
Any fluid or lubricant reservoir that is not sealed or blanketed will experience atmospheric contamination. Breather filter-elements have relatively short life spans and do not remove soluble contaminants or very fine particulate. Often, they are far down the list of maintenance priorities. Ambient air quality can be impacted by the proximity to surrounding industries or a coastal environment to a surprising degree. These pollutants are literally sucked into the reservoir and then captured by the fluid.

The presence of Cl, Na and Ca in the EHC fluid can often be linked to a sea water environment. There have also been connections made between air pollution from local industries like metals refining. Extensive atmospheric quality studies are available from environmental agencies and a simple internet search may reveal local and regional documents on air quality that offer useful insight.

Wear Metals
It is possible to have an increase in soluble inorganic contaminants from wear metals. Al, Cr, Cu, Fe, Ni and Sn are all possible wear metal sources in an EHC system.

Acid Scavenging Media
The most common contributor of soluble inorganic contaminants to phosphate ester fluids is the acid scavenging media. There are three main classifications of this media:

1. Fuller’s Earth – Consists primary of magnesium oxide and hydroxide, processed from attapulgus clay or attapulgite. This is a naturally occurring material with a wide particle size distribution range. Observations of Mg, Fe and Ca can typically be traced back to Fuller’s Earth filters.
2. Selexsorb - It is well documented in industry that Selexsorb is made from purified activated alumina as a Y-Zeolite. Analysis shows that the chemical composition is primarily sodium aluminum silicate, Na₂Al₂Si₄O₁₂. Analysis showing Na, Al or Si in phosphate ester fluids can most often be traced back to the use of Selexsorb. The Y-Zeolite also contains various metals which have been detected in EHC systems, but it is primarily a silica particle whose shape and structure helps catalyze chemical reactions. These materials have been shown to cause gels, and as a result, this media is not recommended for “older” fluids, according to the
filter media manufacturer. Selexsorb also has a wide particle size distribution range which supplies highly abrasive, sub-micron insoluble contaminants which are addressed in the next section.

![FIG.2 - An SEM Image of a Selexsorb zeolite. There are hundreds of extremely small abrasive particles attached to the zeolite which come loose and contaminate the phosphate ester fluid. Some of these particles are visible in the top right hand section of the image.](image)

3. Ion Exchange – Ion exchange resins typically do not contribute any wear metals to phosphate esters and consisting of a fairly uniform resin bead, do not add submicron material.

The impact of soluble inorganic contaminants from acid scavenging media can be significant. They lie at the root of many system deposits, gels and other significant performance issues. Furthermore, these contaminants place a limit on the life of the fluid and may lead to system flushing.

**Insoluble Inorganic Contaminants**

Suspended metals in the system have the same origins as dissolved metals; however these particles lead directly to wear. Particle counting is the traditional method of detecting insoluble particles. There are countless studies in industry that link elevated particle counts to increased levels of wear and lower life of system components. Unfortunately, ISO particle counts only classify particles 4-microns in size and larger. There are significant dangers of having an elevated level of particles below this typical 4-micron threshold.
To illustrate this point, six EHC fluid reservoirs were analyzed for standard ISO particle code during monthly tests. Although results indicated that ISO code limits were exceeded on only three of the reservoirs, the main pump discharge filters on all 6 units were reaching differential pressure limits and were changed every month. A fluid sample from each system was filtered through a series of tighter and tighter patches so that the contamination within each size range could be isolated. When the weight of each successive patch was extrapolated to the whole reservoir, the systems were shown to contain between 18 and 23 kg of particulate. This described a situation where 82 - 90% of the total particulate contamination was below 5 microns in size. For example, reservoir 6, with the lowest ISO code of 15/13/11, still contained 19 kg of particulate material (FIG. 3).

![Distribution of solid contamination by particle size](image)

**FIG. 3** – Plot of the varying amounts of sub-micron particles in 6-EHC fluid reservoirs.

**Water**

Water in phosphate ester fluids acts as a primary catalyst to create acids through the process of hydrolysis. The rate of acid production in the system from water is not linear, but varies significantly with the acid number: High levels of acid lead to high rates of hydrolysis through a catalytic cycle. Existing specification limits of 2000 ppm are higher than the desirable upper limit of 1000 ppm determined from effective maintenance programs that have been studied.
Interestingly, if well managed, short term water excursions can be tolerated and even be beneficial. Some phosphate ester fluid degradation products are water soluble and others can be captured by filters when water levels are elevated.

There is a common trend for water to increase in EHC systems during summer months due to higher atmospheric humidity levels. The humid air enters the reservoir through the breathing elements. Desiccate breathers may help, but are consumed fairly quickly, and at a faster rate than maintenance personnel became accustomed to in dryer winter months. Once humid air enters the head space of the reservoir, moisture levels in the fluid and air equalize and water levels in the fluid increase.

**Soluble Organic Contaminants**
Soluble organic compounds, like acids and phenols, are fluid degradation products. Acids and phenols are formed through oxidation and hydrolysis of the phosphate esters. The process is catalytic and rapidly increases at Acid Number (AN) levels above 0.18 mgKOH/g. Phenol levels are important to monitor since they can negatively affect air release, resistivity and eventually transition to an insoluble state. FIG 4. shows the RULER results of a test of used phosphate ester fluid. RULER is an instrument that is routinely used to measure phenolic antioxidants in lubricants. In this case the RULER has clearly identified a strong phenolic peak in the used oil (red line) from fluid degradation.

![FIG. 4 – RULER results show phenols from fluid degradation.](image)

**Insoluble Organic Contaminants**
When phenols degrade they are able to transition from a soluble material to an insoluble. This type of oxidation can lead to fluid discoloration and varnish formation in the fluid. Once these “soft contaminants” form and the fluid exceeds its ability to carry further insoluble material, varnish settles out of the system and forms deposits.

Varnishes from oxidized phenols (by-products of oxidation) create a deposit that has a very similar effect as the metal salts in increasing friction. In the same fashion as servo
varnishing in mineral oil combustion turbine control systems, phenol-based varnish severely affects servo valve reliability.

**Effects of Contaminants on Servo Valves**

As insoluble metals levels rise in the fluid, deposition of metals salts can occur throughout the system. Particularly susceptible are the high polar moment surfaces in the servo-valve spool and bore. These bore and spool sets in EHC systems have particularly small clearances, many in the range of 1-4 microns.

Rather than the scoring and mechanical locking that may be seen with large particles entering these areas, metal salts build up in submicron layers to reduce clearances between the land of the spool and bore, or in lower flow areas out of the high pressure flow path. Many of the deposits have a crystalline structure which is highly abrasive. Where the deposits come in contact with other surfaces, wear is increased and the coefficient of friction, particularly static friction from a resting state, increases. Areas on the feedback spring, the slender rod linking the spool and torque motor, may be particularly susceptible to this contamination. When the ball/socket interface between the spring and the spool develops flat spots, or friction increases due to contamination, erratic performance and increased hysteresis can result.

The role of gel material is somewhat different. The oil supply to the pilot section on the Moog servo used in many of these applications is filtered through a metal mesh “pencil” filter which will typically pass a 40-70 micron particle. Good flow must be ensured through this filter or the nozzle/wand section that provides shifting force and feedback for the main spool is starved. When fluid flow begins to be reduced, valve motions can become erratic and overall hysteresis increases.

Varnish contamination in servo valves operating in common mineral oil based hydraulic fluids and turbine oils is fairly well understood and often discussed among gas turbine users and in general manufacturing and industry. Being adhesive and with the ability to increase friction, it combines the effects of both gels and metals contamination. These deposits in areas like the spool and bore or the feedback spring interface can cause jerky, erratic motion. Varnish can cause differential pressure on the spool ends by reducing flows to one side of the spool or other, and the flows to the nozzles in the torque motor can be affected. Finally, varnish, like gel, can restrict flow through the pencil filter to the spool ends and nozzles in the pilot section of the valve.

It is possible for a combination of gel or varnish and hard particulate to reduce flow significantly in a filter. Both materials are far more adhesive than the metal mesh and will hold contaminants that otherwise would have passed through harmlessly. This combination of gel and hard particulate may also affect other areas of the valve, holding contaminants in place to cause increased friction, wear and valve sticking problems.
Auto-Catalytic Oxidation
Once phosphate ester fluids start to degrade, they usually continue to do so automatically. In other words, acids create more acids and oxidation by-products lead to faster rates of oxidation. A simplified picture showing the degradation cycle of phosphate ester fluids due to soluble contaminants can be seen in FIG. 5.

FIG. 5 – Degradation cycle of phosphate ester fluids due to soluble contaminants.
The Three Pillars of Phosphate Ester Fluid Maintenance

Maintaining phosphate ester fluids to optimize performance and approach fill-for-life longevity can be thought of as the Three Pillars of Phosphate Ester Maintenance:

1. Condition Monitoring
2. Operations & Maintenance
3. Contamination Control.

These steps are outlined in FIG. 6.

FIG. 6 – The Three Pillars to Phosphate Ester Maintenance.
Pillar I: Condition Monitoring

The first pillar of phosphate ester maintenance is condition monitoring. Some critical factors of an effective condition monitoring program include:

1. Proper sampling technique
2. Appropriate and consistent sample locations
3. Establishing testing protocol
4. Selecting a laboratory
5. Interpreting the analytical results

Proper sampling technique
Following the old adage “garbage in, garbage out”, obtaining consistent, representative fluid samples is a key to a condition monitoring program. Understandably, good sampling technique is critical to the process. Using clean plastic bottles and purging the sample lines is a must. Containers not designed for samples are not appropriate. Glass sample bottles can be environmentally friendly for users with an on-site lab, provided that these containers are properly cleaned.

Appropriate and consistent sample locations.
An appropriate sample point can be the OEM recommended sample port or a different point in the system in a dynamic location on the low pressure circuit, upstream of the filters. Taking samples after mechanical and acid scavenging filters masks the true fluid conditions in the system, although are adequate secondary sample points to measure the performance of the contamination control system.

Establishing testing protocol
The minimum recommended analytical tests and frequency schedule can be viewed in Table 1.
Table 1: Recommended test protocol and frequency.

<table>
<thead>
<tr>
<th>Test</th>
<th>Method</th>
<th>Monthly</th>
<th>Quarterly</th>
<th>Annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity</td>
<td>D445</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>D792</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Color</td>
<td>D1500</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Water Content</td>
<td>D6304</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Acid Number</td>
<td>D974</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chloride</td>
<td>N/A</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>RULER</td>
<td>D6971</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Resistivity</td>
<td>D1169</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ISO Particle Count</td>
<td>ISO 4406</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mineral Oil %</td>
<td>D02.CS96</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Patch Test (weight)</td>
<td>D 4898</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Patch Test (color)*</td>
<td>D 2276*</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Auto Ignition Temp</td>
<td>D2155</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Foaming</td>
<td>D892</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Metal Content</td>
<td>D5185</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Flash Point</td>
<td>D92</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Air Release Time</td>
<td>D3427</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

* There is an established heptane patch test procedure (EPRI) to filter the fluid mixed with heptane and compare the results to the color scale in D2276. Efforts within ASTM are developing a new test called Membrane Patch Colorimetry which should be used when it is available.

There are several other tests that are valuable when conducting root cause analysis that are outside of a routine condition monitoring program. These tests may include:

- Fourier Transform Infrared Analysis
- Nuclear Magnetic Resonance
- Scanning Electron Microscope/Energy Dispersive X-Ray Spectrometry
- Dissolved Gas Analysis
- Gas Chromatography
- Thermo-gravimetric Analysis
Selecting a laboratory
All testing should be completed by independent labs that follow ASTM procedures and have experience with phosphate ester fluids. For example, one critical test for phosphate ester fluids is acid number. Many commercial laboratories use an abbreviated test protocol for this test. Although this is acceptable when processing many other mineral-based lubricants, it is unacceptable when trying to detect small changes in acid production. As a general rule, phosphate esters must be understood by the analyst and the laboratory must be experienced in running these samples.

Approximately 70% of phosphate ester users rely on the fluid supplier to provide basic and comprehensive analysis due to its negligible cost. This “free analysis” from fluid suppliers tends not to be as thorough as it should be. For example, it often does not include metals (ICP) testing – a key test for early detection of fluid problems. Also, the recommendations may be influenced by the business need to sell more fluid. This “free analysis” may provide some corroborative information, but is simply not suitable for the major expenditures and critical O&M decisions that may hinge on the analysis results.

Interpreting analytical results
Learning to interpret analytical results is not complex, but is often the source of some irritation and confusion. Many users do an adequate job with sampling and testing the fluid, but seldom scrutinize the results and don’t understand the full implications of the analysis.

Table 2 lists a recommended target and warning level for phosphate esters.
**Table 2: Target and Warning Limits for Phosphate Ester Fluids**

<table>
<thead>
<tr>
<th>Test</th>
<th>Method</th>
<th>Suggested Target</th>
<th>Suggested Warning Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity (cSt)</td>
<td>D445</td>
<td>38.4 – 44.2</td>
<td>+/- 10% initial</td>
</tr>
<tr>
<td>Specific Gravity (g/ml)</td>
<td>D792</td>
<td>1.12</td>
<td>1.17</td>
</tr>
<tr>
<td>Color</td>
<td>D1500</td>
<td>1.5</td>
<td>3</td>
</tr>
<tr>
<td>Water Content (ppm)</td>
<td>D6304</td>
<td>&lt;500</td>
<td>800</td>
</tr>
<tr>
<td>Acid Number (mg KOH/g)</td>
<td>D974</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Chloride (ppm)</td>
<td>N/A</td>
<td>10 max</td>
<td>50</td>
</tr>
<tr>
<td>RULER (RULER Number)</td>
<td>D6971</td>
<td>&lt;400</td>
<td>&gt;650</td>
</tr>
<tr>
<td>Resistivity (Gohm·cm)</td>
<td>D1169</td>
<td>&gt;5</td>
<td>5</td>
</tr>
<tr>
<td>ISO Particle Count</td>
<td>ISO 4406</td>
<td>13/10</td>
<td>15/12</td>
</tr>
<tr>
<td>Mineral Oil (%)</td>
<td>D02.CS96</td>
<td>&lt;0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Patch Test (color)</td>
<td>D2276</td>
<td>&lt;B2</td>
<td>B3</td>
</tr>
<tr>
<td>Auto Ignition Temp (°C)</td>
<td>D2155</td>
<td>566</td>
<td>566</td>
</tr>
<tr>
<td>Foaming (tend./stab. (ml))</td>
<td>D892</td>
<td>10/nil</td>
<td>50/nil</td>
</tr>
<tr>
<td>Total Metal Content (ppm)</td>
<td>D5185</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>D92</td>
<td>235</td>
<td>235</td>
</tr>
<tr>
<td>Air Release Time (min)</td>
<td>D3427</td>
<td>&lt;5</td>
<td>7</td>
</tr>
</tbody>
</table>

Although only a color is reported as a specification for the Patch Test - an observation of the filtration rate or presence of material on the Patch can be very important. If the filtration rate is slowed during performance of this test, there are often insoluble materials being deposited on the filter paper patch. This is a sign of material in the 5 to 0.45 micron range. This material can be considered a source of potential problems that need to be addressed by the maintenance program.

**Finding value by trending data**

Graphically trending the analytical data helps reveal patterns and can provide a better understanding of your analysis and EHC system. These trend plots should also include dates of filter changes, new fluid additions, and mechanical problems observed. All of these extra pieces of information strengthen the value of the reporting. They significantly increase the understanding of your fluid’s effects on the mechanical system operation as well as the system’s effect on the fluid.
FIG. 7 shows an example of this graphical trending of the data from a power plant’s EHC system. In this graph, the three ISO codes are plotted against time. Filter changes and mechanical problems are added to show relationships. By studying this graphical data, one can observe there was an increase in the ISO codes after the acid scavenging filter was changed and see subsequent servo valve failures starting to occur.

**Fig. 7 – The value of graphical trending of data.**

*Testing New Fluid*
Always test new fluid from the fluid supplier to verify that basic properties are acceptable and within specifications. It has been widely observed that new fluid quality can vary in competitive situations where the only purchasing decision is price. Users should never assume new fluid has acceptable properties unless they have verified it with 3rd party analysis. Testing should include all the same parameters used to assure the existing fluid’s quality. While it is not unusual that new fluid have higher than desirable particulate levels due to the nature of drums and shipping methods, other parameters such as acid number and metals levels should never vary.
Pillar II: Operations and Maintenance

Operations and maintenance make up the second pillar of phosphate ester maintenance. This is an appropriate pillar to be sandwiched between condition monitoring and contamination control, as these activities are offshoots of operation and maintenance. Most effective condition monitoring and contamination control programs are born from a strong operation and maintenance culture. Furthermore, the information that is gathered from a condition monitoring program is acted upon in the maintenance program. These actions may involve changing filters, a contamination control function. Due to the overlap that operations and maintenance has with the other subjects, this section is intended to only provide some brief recommendations on this broad and deep subject.

A small sampling of some of the operation and maintenance items required for successful phosphate ester maintenance are:

- Use a phosphate ester fluid designed for EHC systems. These fluids usually are a blend of synthetic and natural phosphate esters and provide a balance of hydrolytic stability, air release and oxidative stability.
- Eliminate obvious sources of contamination, such as metals and fine particulate.
- Add flow controls and flow measurement devices to optimize existing acid removal systems.
- Use a pressure-compensated pump and accumulators instead of constant volume pumps to minimize unneeded relief valve flow and stress on the fluid.
- The hydraulic return lines should terminate at least 12” below the air/fluid interface.
- The fluid should have sufficient residence time and proceed through flow diversions like baffles to minimize air bubbles.
- Keep the fluid in the tank at a maximum level.
- Avoid using the same conditioning or transfer equipment or for both mineral oil and phosphate ester fluid.
- Store phosphate ester drums in a clean, dry area and use the oldest fluid first.
- Pre-filter all new fluid prior to adding it to the reservoir.
- Ensure that all system materials are compatible with phosphate esters. Recommended materials include PTFE Teflon, FPM Viton or Butyl Rubber for seals, hoses and bladders; Nylon (PA66) for wire and cable insulation, and cured epoxy paint.
Pillar III: Contamination Control

Contamination Control makes up the third pillar of phosphate ester maintenance. Normal operating conditions in an EHC system expose the fluid to several forces that will cause degradation. An effective contamination control program is designed to minimize the ingress of contaminants and rate of fluid degradation. The OEM provided contamination control technology usually comprise mechanical filters and acid scavenging filters. Often, this provided technology is not adequate to create a balance with the amount of contamination entering the fluid and the degree of fluid degradation. When contamination or degradation overwhelms the fluid, and equilibriums in the fluid are disturbed, that system performance problems begin to occur.

FIG. 8 summarizes the contamination control technologies adequate to address the root causes of fluid degradation as depicted in FIG. 1.
An overview of these solutions is:

- Install an ion exchange acid removal system that is robust and does not introduce additional contaminants.
- Add a dry gas blanketing system to prevent seasonal fluctuations in moisture levels and maintain low levels of moisture in the fluid.
- Install an electrostatic separation system that is capable of removing insoluble organic and inorganic contaminants like varnishes and ultra-fines from previous acid scavenging technology.

_Not all Ion Exchange is the same_

There are several manufacturers of ion exchange technology. This technology provides significant benefits over traditional acid scavenging technologies and can potentially allow phosphate ester fluids to be fill-for-life. However, there are differences between the several ion exchange filter manufacturers. Many ion exchange filters are simply resins residing in conventional filter canisters. Since ion exchange resins can expand in use, these designs may not provide enough resin security (FIG. 9). Most conventional filter designs can easily be ruptured and don’t provide sufficient room for resin expansion. Significant problems can occur if an ion exchange filter ruptures, polluting the system with small resin beads. Be sure to use an ion exchange filter that is burst-proof to pressures above 80PSID (FIG. 10), add gauges to measure differential pressure to the acid scavenging system, and insure that mechanical filtration after the ion exchange filter is of high quality with reliable differential pressure indication.

**FIG. 9** – Ruptured Ion Exchange Filters from poor manufacturing & design

**FIG. 10** – Burst-proof Ion Exchange filters eliminate this risk
Conclusion

Phosphate ester fluids can be used indefinitely if they are properly maintained. With proper testing to understand the state of the fluid and system, and the tools and practices to deal with problems, phosphate ester systems can go from the forefront of maintenance headaches, to the solid reliability of a well controlled system. With these best practices in place, and the understanding necessary to use them, long term stability, safety, and cost control are right around the corner.