WHITE PAPER

Phosphate Ester Fluid Maintenance Challenges and Solutions in EHC Systems

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Despite the excellent lubricating and safety properties of phosphate ester lubricants, many turbine and Electro-Hydraulic Control (EHC) users struggle with their maintenance. While proper EHC fluid maintenance is not difficult, users often lack the tools and the updated technical training for effective maintenance. Outdated or incorrect EHC fluid maintenance is a common problem in the power generation industry that is costing 100s of millions of dollars each year in unnecessary failures and lost production.

With the cost per megawatt hour (MWh) averaging $50/MWh, a single failure can cost $20,000 to $50,000/hour. At one nuclear power station, a severe EHC system failure attributed to fluid condition resulted in a 30-day shutdown of the 1100 MW steam turbine. At these average market rates, this failure resulted in a production loss totaling 40 million dollars.

CHALLENGES WITH EHC FLUID TESTING AND MAINTENANCE

Common issues that significantly impair asset reliability, and increase EHC fluid maintenance range from limitations in standard testing capability to conventional EHC fluid maintenance products and procedures

EHC fluid testing is missing key information

- ISO particle count testing (ISO 4406) only measures particles greater than 4 microns; however, our testing has shown that up to 90% of the total solids by weight can be below this range. For proper servo valve operation, particles <4 microns should be quantified. Membrane patch testing at 0.45 microns (Fig. 1) quantifies these particles by mass, with values exceeding 5 mg/50 ml suggesting unusual contamination levels.
- Metals in EHC fluids are not routinely tested, which is problematic for several reasons. Metals provide the fluid breakdown pathways that increase the rate of acid production by up to 10x. Metals are also involved in the formation of gels and other solid deposits. Conventional acid removal filters are often a primary source for metal contamination including sodium and calcium.
- Dissolved contaminants, including fluid break down products, accumulate over time and eventually come out of solution to form deposits on servo valve components (Fig. 2 and 3). Dissolved contamination is not normally measured, and when present, frequently impairs servo valve response time, presenting an elevated risk of malfunction or failure (Fig. 8).

“Dissolved contamination is not normally measured, and when present, frequently impairs servo valve response time, presenting an elevated risk of malfunction or failure.”

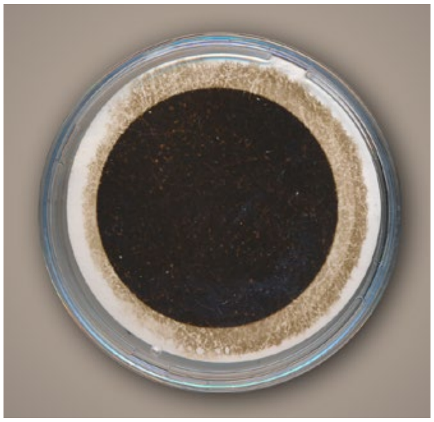
Fig.1—Membrane patch test at 0.45 microns

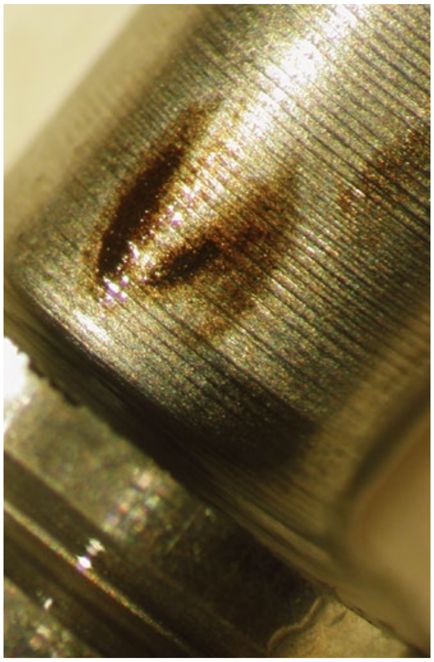
Fig.2—Deposit on servo valve

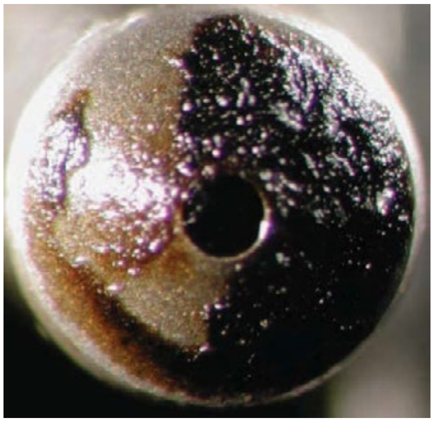
Fig.3—Deposit on nozzle

Traditional EHC fluid maintenance is not removing harmful types of contamination

Common approaches to EHC fluid maintenance such as Fuller's Earth or alumniosilicate (e.g. Selexsorb®), while somewhat effective at acid removal, do not remove the contamination that is the actual cause of servo valve problems.

- Harmful contaminants in EHC systems include metals, fine particulates and dissolved breakdown products. The latter is responsible for varnish and deposit formation. Not only do conventional filters not remove this contamination, they have been shown to be a major source of contamination – both metals and fine particulates (Fig. 4).
- Extensive analysis has proven that alumniosilicate acid filters artificially increase resistivity because of the fine particulates that are released into the fluid (Hobbs and Dufresne, 2014). These particles have dielectric properties that interfere with the test (ASTM D1169). Low resistivity is associated with electrokenetic wear (Fig. 5).
- The acids in EHC systems can break down high-pressure filters resulting in micro-glass fibers being released into the system. These fibers end up in servo valve strainers reducing flow to the servo valves (Fig 6).

Operating practices can increase the rate of fluid breakdown and fluid maintenance

Heat, water, air and metals determine the rate of oxidation and, therefore, the rate at which EHC fluid breakdown occurs. These factors are often not managed in EHC systems, resulting in higher than desired rates of EHC fluid breakdown.

- Flow rates and fluid operating levels (Fig. 7) need to be reviewed so excess fluid flow conditions do not exist.
- Excess flow rates increase air in the system leading to micro-deiseling, which causes fluid darkening, excess acid production and premature fluid failure.
- Fluid operating life is reduced by 50% for every 10°C increase in operating temperatures. Maintaining high operating temperatures to manage water levels or shutting off cooling water supply to save electricity costs is counterproductive.

SOLUTIONS FOR EHC FLUID MAINTENANCE

EHC fluid condition-related failures and their resulting production losses can be virtually eliminated through EPT's industry leading fluid maintenance and testing program – the result of 20 years of specialization in EHC fluid applications. EPT's 4-step approach is comprehensive in scope, targets common weaknesses, and removes the contamination responsible for servo valve deposit issues. Our program offers turbine owners and operators a clear path forward to protect their equipment from failure while reducing maintenance costs.

Step 1 – Improve fluid testing

EPT's phosphate ester maintenance and testing program measures the hidden contamination that accumulates in most EHC systems. While water,

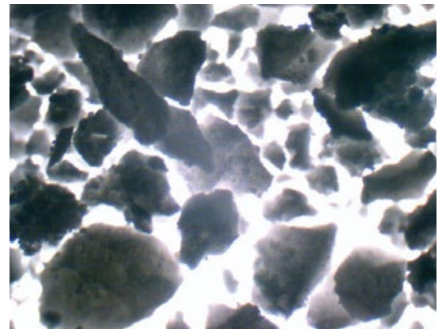

Fig.4—Acid filter material is abrasive contributing fine particulate and metals

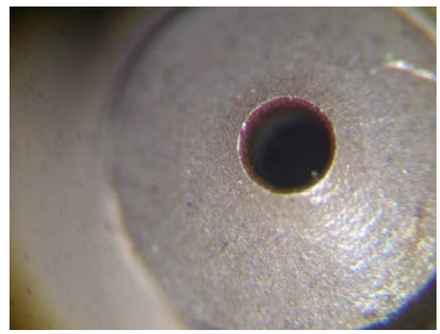

Fig.5—Evidence of electrokinetic wear from low resistivity

Fig.6—Servo valve strainer plugged with filter fibers from pump discharge filters

Fig. 7—Low operating fluid level in reservoir

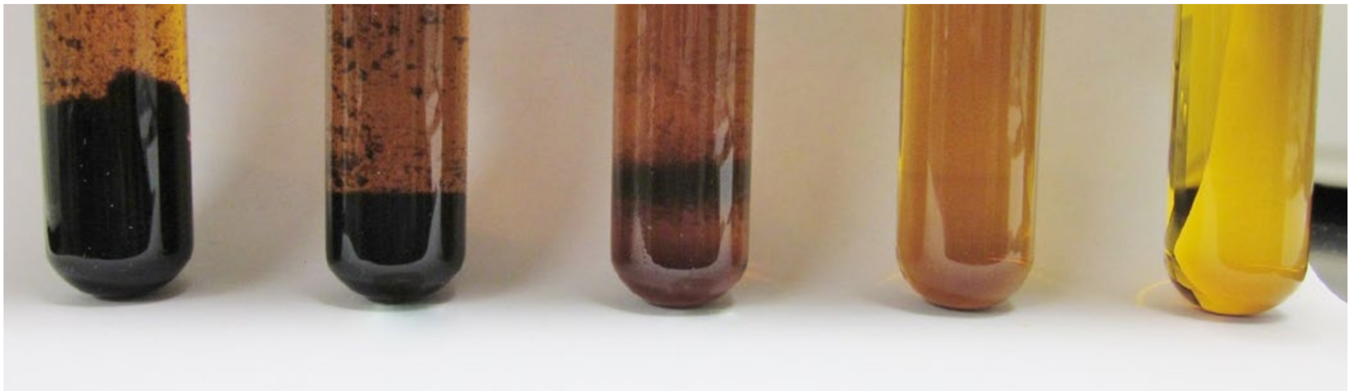

Fig.8—Deposition Tendency Test results – no visible deposits should form

acid and particulate testing is routinely performed, EPT also measures the dissolved breakdown products that are responsible for varnishing, servo valve sticking, low resistivity and high rates of fluid breakdown. Our EHC fluid testing program precisely measures contamination levels to identify problem areas and to track cleaning progress.

To have our expert team provide you with a complimentary fluid assessment, complete our Sample Submission Form.

Step 2 – Remove contamination responsible for mechanical issues

Acids and dissolved contamination

While Fuller's Earth and Selexsorb® filters have been widely used to remove acid in phosphate ester based EHC fluid applications, an entirely new level of EHC fluid purification is available through the use of Ion Charge Bonding (ICB™) filters. ICB™ is a specialized ion exchange product developed by EPT that not only removes acids, but more importantly removes the dissolved contamination responsible for servo valve sticking (Fig. 8).

Figure 8 shows results of a Deposition Tendency Test (EPRI EHC Fluid Maintenance Guide 2002, Page 4-39), in which EHC fluid is mixed with hexane forcing dissolved contamination out of solution. In the first 3 test tubes, EHC fluids cleaned with conventional filter treatment form visible solids. Servo valve performance and reliability would be significantly impaired using EHC fluid in this condition. Samples 4 and 5 cleaned with ICB™, show that this contamination has been eliminated. Servo valve response time and reliability would be maximized operating EHC fluid in this condition.

The ability to remove this contamination using ICB™ is a game changer for phosphate ester based EHC fluid maintenance. For the past 40 years, steam turbine EHC operators have worked to manage acid numbers and fluid resistivity values, without the ability to remove the contamination responsible for servo valve sticking. ICB™ removes this limitation, enabling significantly improved servo valve operation.

ICB™ filter for removing acids, metals, dissolved contaminants and restoring fluid resistivity

Solids contamination

There are two basic categories of solids contamination: >4 micron particulate measured by ISO 4406, and <4 micron particulate which is not measured.

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When looking at >4 micron particulate, we frequently observe levels 50 – 100x greater than the maximum allowed level permitted in servo valve applications. The "trouble-free" operating window of a servo valve above this specification is zero hours.

The reason many EHC systems are at such high levels is that the efficiency of the conventional filters used is often far below what is reported in the filter spec sheets. Standard filter efficiency (99.5%) is measured under ideal laboratory conditions. While a filter may perform well in the lab under static conditions, in real-life dynamic conditions, filter efficiencies are typically much lower. For this reason, EPT recommends specialized particulate filters rated at 99.5% under dynamic conditions.

Stainless fiber media elements, such as Dynafuzz, offer these efficiencies while eliminating the common issue of fiber shedding into the servo valve strainers. Upgrading your pump discharge filters while eliminating the risk of fiber shedding offers an extraordinary ROI opportunity of >10,000%.

Our investigations have shown that up to 90% of total solid contamination in EHC fluids is below 4 microns and, therefore, not reported in ISO 4406 particle code testing. To quantify this contamination to assess if there is an issue, a patch weight test can be used to measure the total mass of solid contamination above 0.45 microns (Fig. 1). This particulate contamination is responsible for fluid darkening and is generally produced from micro-dieseling, which is a type of high temperature fluid breakdown caused by air release issues. When patch weight values are high (≥5 mg/50 ml), EPT's Electrostatic Contamination Removal (ECR™) system is recommended.

Step 3 – Remove water and prevent atmospheric contamination

Water is the most damaging contaminant found in hydraulic and lubricating systems. The complication is that water comes in three forms: free, emulsified and dissolved. Conventional maintenance technologies often will remove one form, but not all, which frequently results in the wrong technology being applied. What is not understood is that in many applications, the primary mode of water ingression is atmosphere itself. When the moisture content of the atmosphere is higher than the moisture content in the lubricant, the atmosphere provides an unlimited source of water. EPT's TMR™ N_2 products are used to remove existing water and, more importantly, to prevent additional water and other atmospheric contamination from entering the system.

Step 4 – EHC system review and fluid monitoring

The air release properties of EHC fluid are very important to ensure that the fluid is not overly stressed. Excess fluid flows from improperly set relief valves or high pressure pumps decrease the available settling time the fluid has to release air in the reservoir. Low fluid operating levels or fluid return lines above the fluid level will increase air entrainment and the amount of settling time required. The consequence of air release issues or insufficient settling time is micro-deiseling, which causes fluid darkening and increases overall fluid maintenance requirements.

> "ICB™ is a specialized ion exchange product developed by EPT that not only removes acids, but more importantly removes the dissolved contamination responsible for servo valve sticking."

ECR™ system for removing fine particulate and restoring fluid color

TMR™ N_2 system for removing water

The mechanically available settling time (fluid operating volume ÷ total system flow rate) should be calculated for each reservoir and compared to the actual fluid air release value (minutes). When this value exceeds the available settling time, the system is providing insufficient time for the fluid to release entrained air.

EPT will work with you to review your operating practices to minimize these common issues. EPT's Fluid Testing Program is available at no charge to all customers until results have been documented. Ongoing fluid testing packages are recommended to verify steady state EHC fluid condition is maintained.

RETURN ON INVESTMENT (ROI)

Because of the high value of production in EHC applications, a single failure over 10 years could cost more than proper fluid maintenance and testing over the same time period. Our 20 years of experience suggest that failures are much more common than 1 every 10 years. In the three case studies below, cost savings greater than $1 million per turbine have been achieved using EPT's program.

Economic analysis is provided for a fleet of 100 turbines operating over a 37 year period ((Hobbs and Dufresne, 2014).

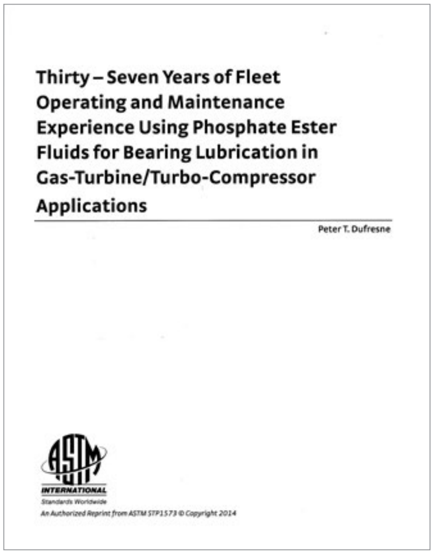
- Traditional lubricant and fluid maintenance was costing $5 million per year and mechanical failure costs from poor lubricant condition another $13 million per year.
- EPT's optimized fluid maintenance reduced maintenance costs by over 80% and no further lubricant-related mechanical failures were observed.
- Fluid and maintenance cost savings totaled $97 million for the fleet or on average $1 million per turbine.
- Mechanical and failure cost reductions totaled $243 million or on average $2.4 million per turbine.
- Ongoing ROI is >600% per year versus previous lubricant maintenance spending.

One of the largest power stations in the southeastern United States had to de-rate their 1300 MW steam turbine to 1000 MW because of serious EHC mechanical issues associated with fluid quality.

- Using EPT's program, which was installed on-line without replacing any mechanical components, the EHC problems were eliminated and the output was increased to 1300 MW within 30 days.
- With the cost per MWh averaging $50/MWh at an average capacity factor of 75%, the lost production and resulting cost savings were an estimated $11 million per month.

A large power station in Singapore prepared a comprehensive white paper on their EHC fluid maintenance costs using traditional lubricant and fluid maintenance, and the resulting cost savings using optimized maintenance provided by EPT.

- Total savings were estimated at $6.3 million or $1 million per turbine.


Thirty – Seven Years of Fleet Operating and Maintenance Experience Using Phosphate Ester Fluids for Bearing Lubrication in Gas-Turbine/Turbo-Compressor Applications

Peter T. Dufresne

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ASTM article outlining cost saving in excess of $90 million

"EPT's optimized fluid maintenance reduced maintenance costs by over 80% and no further lubricant-related mechanical failures were observed."

ADDITIONAL RESOURCES

1. Hobbs, M.G. and Dufresne, P.T. Jr., "Phosphate Ester-based Fluid Specific Resistance: Effects of Outside Contamination and Improvement Using Novel Media," Fire Resistant Fluids, STP 1573, John Sherman, Ed., pp.1-18, ASTM International, West Conshohocken, PA 2014.
2. ICB™ Filter Element Upgrades
3. TMR™ N_2 Total Moisture Removal
4. ECR™ for EHC Systems
5. EHC Case Studies using ICB™, ECR™, and TMR™ N_2

CONTACT INFORMATION

For additional information contact:

E sales@cleanoil.com
T +1. 403. 246. 3044

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