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Innovative Solutions to Address Lube Varnish in Hydrogen Seals

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INTRODUCTION

There is a plethora of varnish mitigation technologies available for mitigating varnish in large-volume lube oil sumps. These technologies are commonly installed on turbine oil reservoirs. However, there are so many other applications where varnish and deposits create reliability concerns, such as hydraulic units, gearboxes, and compressors. Even wind turbines can have performance problems due to deposit formations.

Many of these applications have too small of a reservoir to justify installing a varnish mitigation system. Some of these formulations also have additive components that can be removed by several of the varnish mitigation technologies. The presentation illustrates a novel approach to control deposits in these applications and presents several case studies illustrating the benefits of eliminating varnish in these applications such as compressor, pulverizer, wind turbines, and tube drawing applications.

Hydrogen is the medium of choice for cooling about 70% of electric power generators over 60MW. It is more efficient for dissipating the heat load in generators compared to water, air or oil. Most large frame gas turbine models use hydrogen as cooling medium for their generators. Oil, often the same turbine oil used for bearing lubrication, is used as an occlusive seal to keep the small molecules of hydrogen gas from leaking down the shaft and out of the generator.

Seal oils face extreme conditions, and upon degradation may cause significant problems to seal systems leading to mechanical failure of the seals, loss of coolant, and possible safety concerns.

This paper addresses some of the factors that lead to hydrogen seal failures and presents some solutions to address this problem.

Fig. 1 - Controls for a hydrogen seal system in a large frame gas turbine.

GROWING PROBLEM WITH HYDROGEN SEAL VARNISH

All aspects of a turbine and generator design are continually evaluated by operators and OEMs alike to optimize for greater energy and cost efficiency. Hydrogen seal effectiveness, with significant cost implications, are no different. This has led to a shift in some seal designs from spring held seals with higher leakage rates, to a more rigid bolted seal design to maintain tighter clearances. Bolting the hydrogen seals prevents the seal from expanding with shaft oscillation or under thermal stress, resulting in better control of hydrogen leakage. However, the tightly maintained clearances of bolted seal designs are highly susceptible problems relating to varnish deposits.

Lube deposits in the hydrogen seals lower clearances even further, compounding the problem and producing new degradation regimes. Though other mechanical factors may often play a contributing role, there are two primary factors to hydrogen seal failures. First is improper installation or establishing too low of a clearance. Second is reduced lube oil quality allowing degradation and varnish formation on the seal surface. Many gas turbines share the same reservoir for their seal and bearing lube oils. It is common to see oil degradation occurring in other parts of the system, with problems manifesting in the hydrogen seal areas as well. Regardless of the initial cause of the problem, lube oil varnish will accelerate the problem, increasing the chances of seal failures.

EFFECTS OF HYDROGEN SEAL DEPOSITS

Hydrogen seal issues are primary initiated by reduced clearances. This may be due to installation or deposit formation. The impact of reduced clearances and signs of impending seal failures are:

- **Low seal oil flow.** The typical flow rate in a large frame gas turbine may be 6-8gpm with total system flow capacity around 20gpm. Problematic seals may have flow rates between 1-4gpm.
- **Increased seal oil temperature.** Normal temperature of the seal oil is between 135-145oF. If the flow paths have been restricted, the residence time in the seals is longer resulting in higher temperatures. Problematic seals may expose the oil to temperatures well in excess of 200oF.
- **Reduced hydrogen consumption,** due to lower flow rates.

Hydrogen seal deposits range in severity. Below are several examples of problematic hydrogen seals. Hydrogen seal varnish can be classified as:

1. **Incipient Varnish** – beginning of varnish formation
2. **Propagating Varnish** – spreading widely of the varnish
3. **Critical Varnish** – varnish is in danger of equipment reliability

INCIPIENT VARNISH

Incipient Varnish is a thin layer of deposits that are usually yellow to light brown in color. Typical clearances in the hydrogen seals is between 0.07"-0.12". Even though these deposits appear to be a very thin layer, the depth of the varnish is sufficient to impact the dynamic clearances in the seals. Deposits may not be uniform around the entire seal surface, leading to areas of higher and lower flow and exacerbating problems.

Varnish deposits have been shown to have a wide range of chemistries and the typical chemistry of the Incipient Varnish in hydrogen seals can also be determined to have differences.

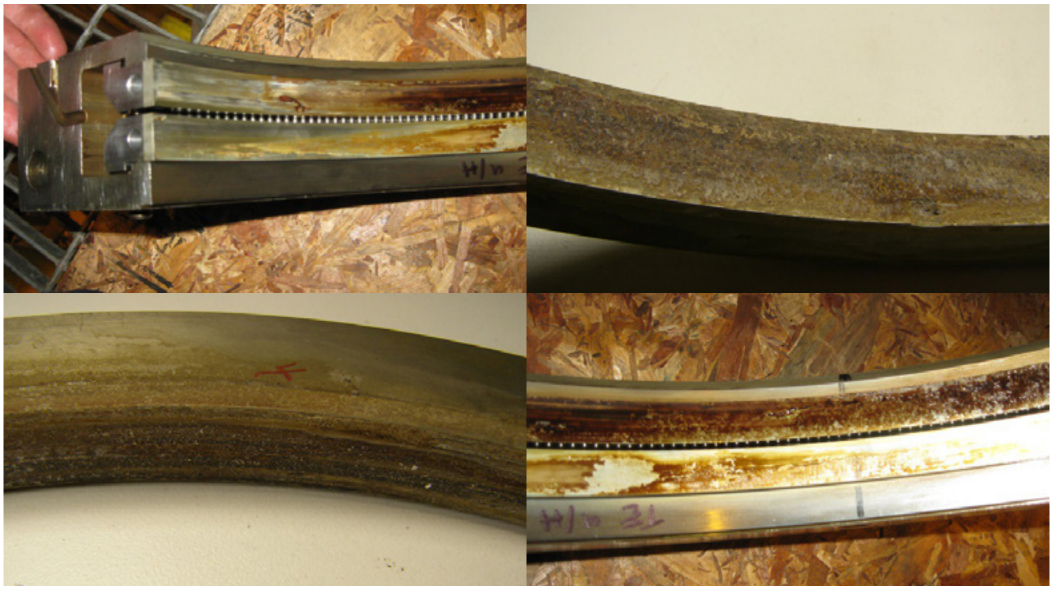

Fig. 2 - Hydrogen Seals coated with Incipient Varnish. These seals are coated with a thin layer of varnish deposits. The varnish is in the initial formation stage since it shows no extensive decomposition and the bearing is still functions.

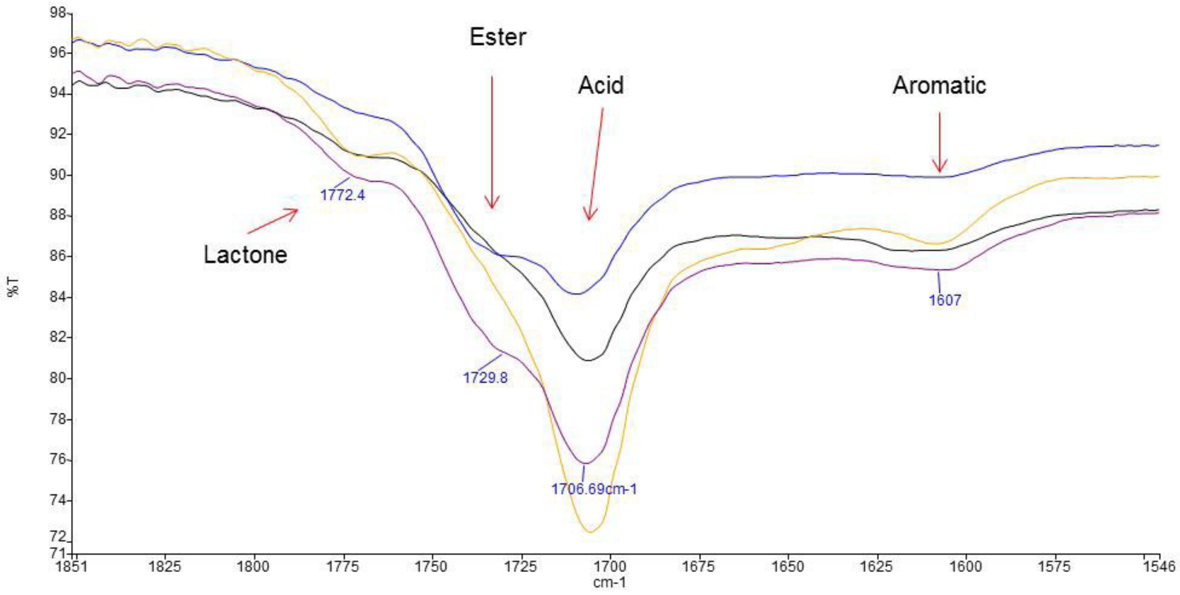

Fig. 3 - This Fourier Transform Infrared (FTIR) spectral analysis is of four isolated varnish deposits from hydrogen seals that are in the Incipient Varnish stage. This is a close up of the carbonyl and aromatic hydrocarbon region showing a molecular fingerprint of the degradation products found in the deposits. These degradation products are largely the result of oxidation mechanisms of the oil due to the formation of acids, esters and lactones.

PROPAGATING VARNISH

Propagating Varnish deposits in hydrogen seals are usually darker in color and in a thicker layer which further disrupts oil flow. These deposits often include both organic and inorganic deposits because the temperature of the fluid, deposit and seal are higher causing additional decomposition chemical reactions to occur. In addition, the seal itself with the lubricant may now create new modes of degradation for the lubricant, such as cavitation. With Propagating Varnish, often the surface of the hydrogen seal has seen mechanical damage and if not corrected, will lead to seal failure.

The operation of the seal is where oil is pressurized in-between two seals (C/E= Collector End toward the generator and T/E = Turbine End toward the turbine). The oil is drawn into the seal by the spinning action of the rotor shaft with the aid of this oil pressure. This action pulls oil into the seals and out toward each shaft end to prevent hydrogen from migrating through the seal.

If there is varnish on the seal there may be insufficient gap to allow the oil to be drawn into the seal. This can create a cavitation event which further heats the oil as well as mechanically destroying the seal.

Since a major purpose of the oil is also to help in the cooling process and the oil flow through the seal has been reduced by the varnish, the seal area experiences increased temperature and slower oil flow to further "cooking" the oil to help in the Propagating Varnish formation.

Fig. 4 - Hydrogen Seals coated with Propagating Varnish. Notice that the varnishes are varying in thickness in the different seals. The upper and lower right has just started reaching the propagation level, while the upper right is thick enough to observe rubbing with the shaft and the lower left has started cavitation.

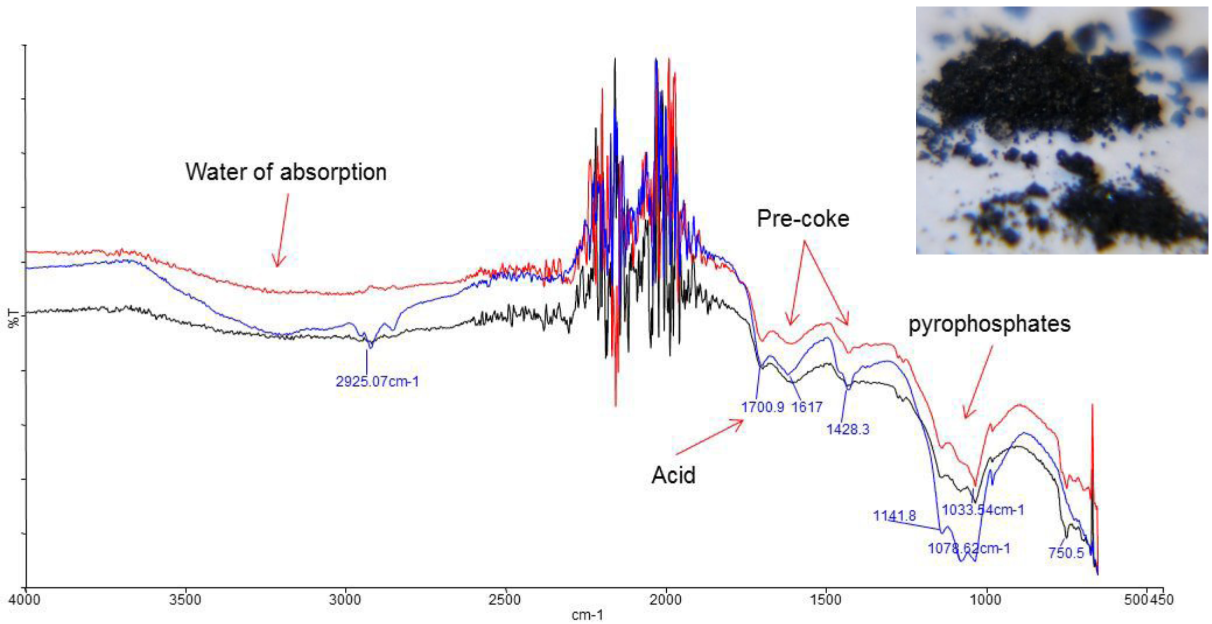

Fig. 5 –Varnishes are isolated into organic and inorganic fractions for proper characterization. This FTIR Analysis is of the inorganic fractions of Propagating Varnish. Often, Propagating Varnish started off as Incipient Varnish deposits composed primarily of oxidation products. Over time, and with excessive heat, these deposits further oxidize, dehydrate and transition to a dark colored pre-coke or black coke-like product as the temperature causes thermal-cracking of the varnish.

CRITICAL VARNISH

Deposits that can be classified as Critical Varnish often are categorized by extensive mechanical damage to the seal and the strong presence of thermally degraded components. Critical Varnish is usually found in failed hydrogen seals or in those with impending failures. The thickness, hardness and structure of Critical Varnish are a root cause in the destruction of the seals themselves through flow restriction and resulting erosion and wear mechanisms.

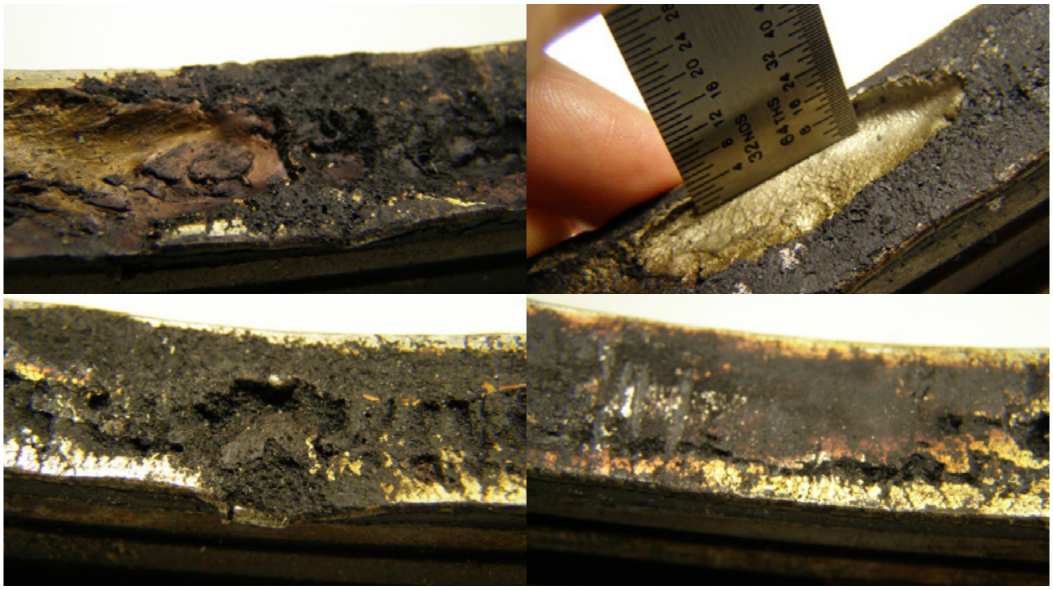

Fig. 6 - Hydrogen Seals coated with Critical Varnish. These seals are all experiencing critical varnish. The shaft has been in contact with the varnish and cavitation destruction is evident. The seal destruction by this varnish deposit formation can be severe enough to migrate completely through the babbitt surface of the seal.

SOLVING HYDROGEN SEAL VARNISH ISSUES

If there are operational signs of hydrogen seal deposits, there are two strategies that have successfully been employed to solve these issues. In most cases, it is recommended to consider both solutions as they are complimentary

MECHANICAL SOLUTION

Increasing clearances in the hydrogen seals can make them less susceptible to varnish formation through increased oil flow and reduced temperatures. In some cases, plants have elected to go back to a less efficient spring seal design. Unfortunately, the drain capacity on many hydrogen seal systems is of quite limited capacity and cannot accommodate significantly larger seal oil flows.

CHEMICAL SOLUTION

Treating the oil to eliminate the chance of deposits from forming in the hydrogen seal is preferred over moving to a less efficient seal technology. Appropriately treating the chemistry of the oil will also provide numerous other benefits in a gas turbine. The performance benefits include elimination of servo-valve sticking, reduction in journal and thrust bearing temperatures and removal of deposits in heat exchangers. Removing catalytic degradation products also results in longer lasting turbine oil.

There are two options for treating oil adequately to eliminate hydrogen seal varnish. Both options will slowly dissolve deposits back into the oil, restoring the hydrogen's seals designed clearances if mechanical damage has not already taken place.

Electrophysical Separation Process (ESP) – Fluitec's ESP is a kidney loop filtration system employing a unique chemical filtration technology that selectively removes oil degradation products without disturbing healthy additive components.

Fig. 7 – Fluitec ESP Varnish Mitigation System installed on a turbine.

Boost VR – Fluitec's Boost VR is a solubility enhancer that can be safely added to in-service turbine oil. This synthetic oil allows stubborn deposits to be dissolved by increasing the oil's inherent carrying capacity for degradation products - thus preventing further varnish from forming.

These two complementary technologies can also be used together in a synergistic improvement approach. In this scenario, the Boost VR allows the varnish to be dissolved back into the oil and then carried to the ESP system for removal. This is an advantageous approach as the removal of catalytic degradation products extends the life of the oil.

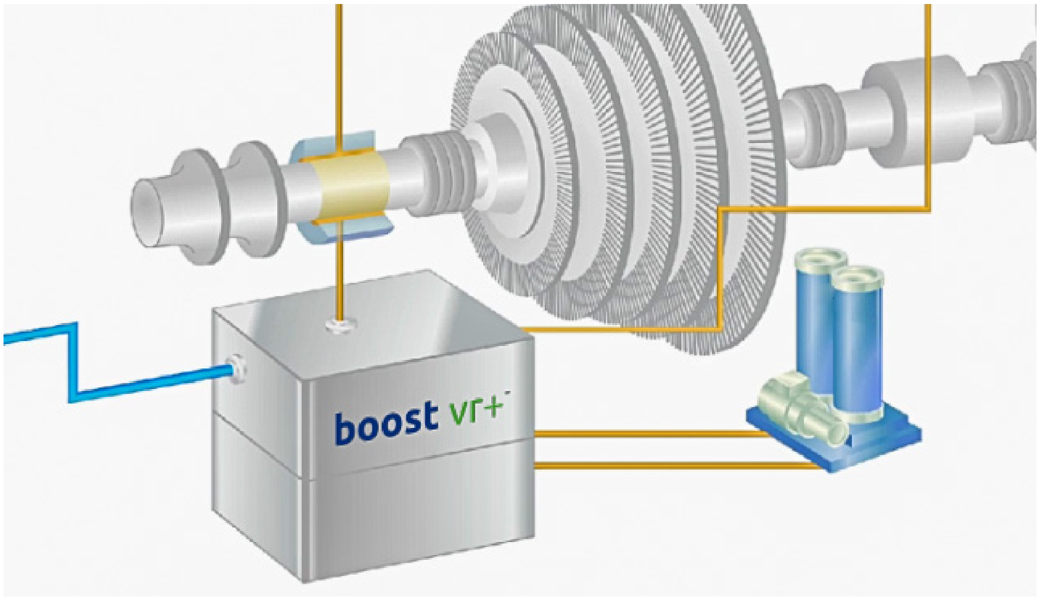

Fig. 9 – Fluitec ESP and Boost technologies are designed to work synergistically offering the safest way to quickly eradicate varnish in lube oil systems and hydrogen seal surfaces.

CASE STUDY 1 – INCREASING FLUID SOLUBILITY

THE PROBLEM

A large frame gas turbine had used spring hydrogen seals since 2000. In 2010, they installed bolted hydrogen seals in an effort to improve efficiencies. The plant first noticed problems 8 months later when their hydrogen seal oil had a much lower flow rate than expected. Instead of the normal 8-gpm flow, the oil was flowing at 1-gpm. Thermocouples added to seal drain lines measured outlet temperatures as high as 200oF indicating even higher oil temperatures in the seal area itself.

The plant performed multiple tests in an attempt to verify the problem, including a "bucket-test" to verify flow rates and installation of ultrasonic Doppler flow meters on feed lines. Several months after identifying the problem, the plant worked with their OEM to replace the seals. The new bolted hydrogen seals were carefully installed with the following clearances:

Turbine End Seal Clearances
Air Seal: .012”
Gas Seal: .009”

Collector End Seal Clearances
Air Seal: .012”
Gas Seal: .011”

Six months after the installation of the new seals, flow rates dropped and the same problem re-emerged. The plant inspected the seals and found Incipient Varnish covering the surfaces.

THE SOLUTION
Before switching back to the older spring seal design, the plant decided to increase the solubility of the oil to see if this could have a positive impact on the varnish deposits. One week after the introduction of the solubility enhancer, the flow rates improved. The plant had the ability to inspect the seals one month later and found the seals to be clean and the layer of varnish removed.

This solution allowed the plant to continue using the more efficient bolted hydrogen seal design.

The plant is continuing to carefully monitor seal oil flow rates and turbine oil analysis as a monitoring step.

CASE STUDY 2 – REMOVING OIL DEGRADATION PRODUCTS

A large frame gas turbine had an unexpected outage due to failed seals. This resulted in seal oil leaking both into the generator and out of the shaft of the turbine on the ground. The plant had to shut down the gas turbine for 10 days during peak season.

Inspection of the failed hydrogen seals showed significant mechanical damage as well as thick layers of Critical Varnish. Analysis of the oil also showed high varnish potential. The MPC values were 51.

THE SOLUTION
Along with the installation of new hydrogen seals, the plant also installed Fluitec’s ESP unit. The varnish potential of the oil was reduced from an MPC value of 59 to 8 in less than a month.

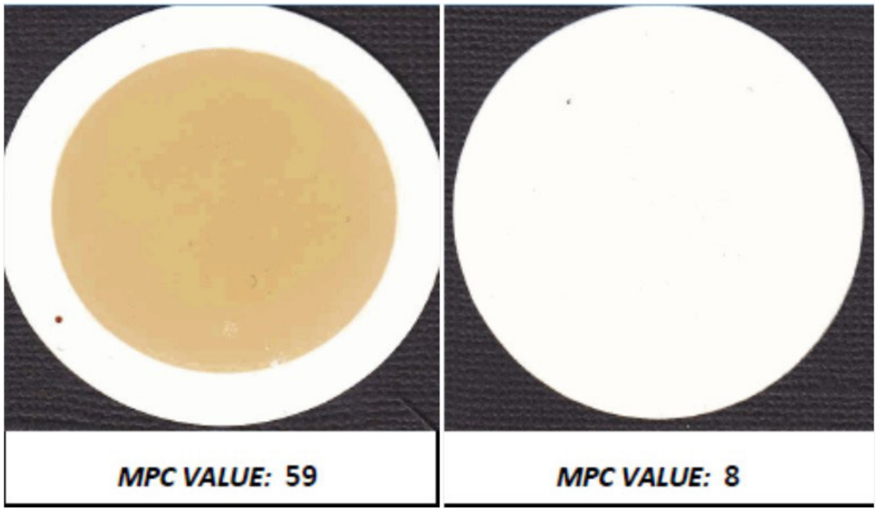

Fig. 10 - The Membrane Patch Colorimetry (MPC) test is run according to ASTM D7843. It measures the varnish potential of a turbine oil. Fluitec's ESP system was able to reduce the MPC value from 59 to 8, preventing another hydrogen seal failure due to varnish.

As a preventative measure, the plant installed ESP units on their second gas turbine and steam turbine, restoring the varnish potential to normal ranges.

REMOVING

Hydrogen seal failures can be very costly to large frame gas turbine users. The problem can either begin with the installation of bolted seals or the increase of varnish in the turbine oil, both of which will lower the dynamic clearances in the seals.

The best way to solve these problems is by taking both a mechanical and a chemical approach. Inspecting and correcting the seal clearances is an appropriate step to help mitigate this problem from a mechanical perspective. Treating the condition of the oil is an appropriate step to take from a chemical perspective.

Fluitec's ESP technology is a proven method of removing oil degradation products from turbine oil. Fluitec's Boost VR is a proven method of improving turbine oil's solubility, dissolving varnish from hydrogen seal surfaces. Combined, these two technologies provide the best method to ensure that the turbine oil is operating with a very low varnish potential and won't generate hydrogen seal deposits.

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