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Lubricants & Specialties

Gas Turbine Lubrication: Filter Plugging & Valve Sticking (Cause & Effect, and Prevention)

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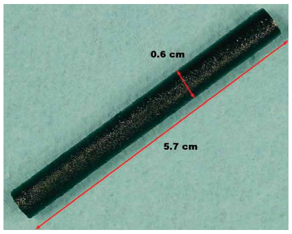
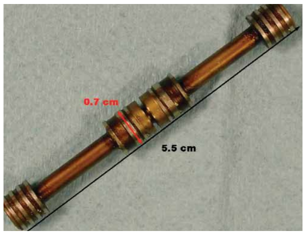
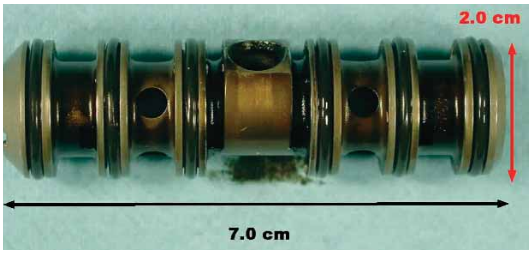
Varnish On In-Service Servo Components



Pencil Filter



Spool



Bushing (Sleeve)

Setting the Stage

The energy industry becomes more competitive every day, with more players entering the market, increasing capital costs, increasing fuel costs, and downward pressure on delivered prices, all squeezing profit margins to their lowest levels ever. These market conditions drive changes in equipment design, operation procedures, and maintenance products and procedures - including lubrication.

Gas turbines used as prime movers are becoming more thermally efficient, running hotter. Today's bearing temperatures will range as high as 302°F/150°C. Maintenance intervals are being extended, looking for the most efficient lifetime cost of operation per unit. Additionally, the cyclic demand for electricity requires that significant horsepower be kept in reserve to stream only during peak demand periods.

One of the benefits of gas turbines is their ability to respond quickly to dispatching requirements. Over the past few years much of the new power generation equipment has been large gas turbines. These turbines are predominantly being used for peaking or cycling duty. In fact in the year 2000, roughly 80 percent of these turbines were being operated as base load plants. Today that number is only 20 percent with the rest being peaking or cycling.

All of these changes put additional stress on the lubricant. Gas turbine oils today must withstand hotter bearing temperatures, provide good air release and foam control, and provide good deposit control to keep the bearings and hydraulic control circuitry clean. It must do all of these things while contributing to lower total cost of operation.

The Cause & Effect of Filter Plugging and Valve Sticking

One specific area of gas turbine operation provides an opportunity for improvement. The drive to hotter temperatures, longer oil life, and cyclic-temperature service has created conditions that lead to the plugging of the micro-fine filters, or cause component malfunctions in the hydraulic control circuits.

The same materials that plug filters can also plate out on servo-valve surfaces leading to sticking. Servo valves are typically used to control components such as gas or liquid fuel control valves, and variable inlet guide vanes. Today's combustion turbines have been designed to generate power while maintaining very low exhaust emissions. These high performance machines require very tight control limits on the fuel and air control valves. As a safeguard, most control systems are designed to remove a machine from service anytime the controlled component does not respond to command.

Filter plugging and sticking of servo valves can lead to a no-start condition upon start up, or trip a unit already running. Both of these phenomena can therefore remove large blocks of power from the grid, costing turbine operators thousands of dollars in lost revenue.

Our analysis of the materials causing these filter plugging and valve sticking deposits in several cases has shown them to be conglomerations of very fine particles created as oxidation by-products of whichever turbine oil was in service. These particles start to form polarized complex polymer chains, bound together by a light atomic attraction known as Van Der Waal's forces. These deposits seem to occur with all turbine oils on the market today. The severity and speed at which they form appears to depend on the formulation of the oil used, the severity of the turbine operation, and the level of filtration and maintenance applied.

Oil Formulation

Oxidation-type deposits have been seen to form in turbines running on all the major turbine oils, but the speed and amount of deposit formation appears to be related to the formulation of the oil. Oils with better oxidation resistance will tend to generate less of the oxidation by-product particulate. It is important to note, however, that typical oxidation tests (often called glassware tests) such as ASTM D943 Turbine Oil Stability Test (TOST), and D2272 Rotary Pressure Vessel Oxidation Test (RPVOT) do not correlate well with the amount of oxidation particulate created, nor the overall deposit control of the oil. Particulate generation and deposit control are functions of the overall balance of the turbine oil's formulation. The two components of any lubricant formulation are additives and basestocks, and they are discussed separately below.

Probably the most important additive class for gas turbine oils is antioxidants. The two main types of antioxidant used are phenols and amines. Other materials are used to either boost the activity of these antioxidants, or to prevent catalysis of the oxidation process by metals present in the turbine oil. Most high-performance turbine oils today use a combination of multiple antioxidants, boosters, and metal passivators to achieve long oxidation life. The drawback is that some of these additives tend to create more particulate than others as they perform their function, or get used up. This presents a formulation challenge to balance the oxidation life of the turbine oil with its ability to not generate significant particulate in service.

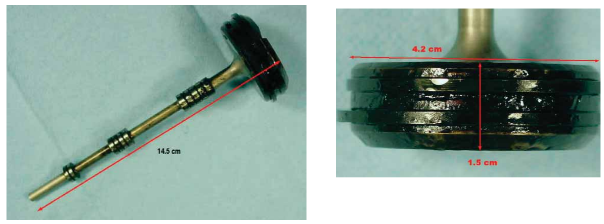
Basestocks also play a role in the creation of deposits. Basestocks classified as API Group II, tend to be more oxidatively stable than Group I stocks. The flip side of that coin is that Group II basestocks tend to have less natural solvency than Group I stocks. This means that while Group II basestocks may oxidize less readily than Group I in service, they also have less natural capacity to hold oxidation by-product particles (and other particles) in suspension. Again, this creates a challenge to balance the turbine formulation to provide long oxidation life while controlling deposit formation.

When presented with test data to select a gas turbine oil, remember that glassware tests do not provide a perfect comparison of how different turbine oils will perform in a specific machine. That's why it is critical to also weigh actual proof of performance in similar turbine applications when selecting your turbine oil. If a specific turbine oil has proven good performance in similar units, with similar operating and ambient conditions, one could reasonably expect the same level of performance in a like turbine. While individual units may experience particularly poor or outstanding performance, a basis for comparing actual performance of those oils can be developed if one evaluates several turbines running the candidate turbine oils.

Operation

In addition to oil formulation, operating conditions also affect deposit formation in gas turbine lubricating systems. The operating parameters that most affect creation of deposits that lead to filter plugging and valve sticking are outlined below:

Trip Relay Piston (Varnish Evident)



High Temperatures - Gas turbines today will run such that the oil sees temperatures as high as 302°F/150°C, especially in the bearings. The hydraulic control circuits around the combustion chamber will also see high temperatures, contributing to the oxidation of the oil. As the rate of oxidation increases, so does the rate of creation of oxidation by-product particles.

Aeration of Oil - When oil is aerated, it contains thousands of air bubbles entrained in the volume of the oil. This increases the oil surface area in contact with air, which also increases the opportunity for oxidation. As pointed out above, increased oxidation leads to more particulate formation.

Cyclic Operation - This is a very important operating parameter in terms of the speed with which filter plugging and valve sticking deposits form. There are two main issues with cyclic service that promote faster deposit formation:

- Cyclic service can lead to shutdown of circulating and hydraulic system flow while some components are still hot. This allows the oil to become static in the components (bearings, valves, filters, etc.) and absorb dissipating heat without the cooling benefits of circulation. This accelerates oxidation and creation of oxidation by-product particles.
- Most turbine oils are designed to settle contaminants out of static oil, such as while residing in a reservoir. This design leads to good air release and demulsibility, as well as allowing particulate to settle out when the oil is static. This "settling" phenomenon occurs more readily as the oil temperature drops. As the temperature of the static oil distributed

throughout the turbine circulating and hydraulic systems drops below about 104°F/40°C, the oxidation by-product particles begin to come out of solution. This occurs in the pencil filters and servo-valves the same way it does in the reservoir, just on a smaller scale. Because some of the hydraulic system components are located in areas that are relatively colder than other components in the system, they are more prone to developing deposits.

- During the down period in cyclic service the varnish present in the oil will tend to drop out of solution in the low flow/colder regions of the system. When not in operation, servo valves will have a small amount of leakage flow to drain. So for a turbine that is on turning gear, with the hydraulic or lift system in operation, the servo valves will be leaking a small amount of varnish-laden oil through the valve to drain. Because the turbine is down, the oil is cooler and the flow is slower, promoting varnish deposition and accelerating build up in these areas.

These deposits build up over time, more quickly in units seeing more cyclic service. The resulting problem is a start-up failure or trip. When trying to start up, the valves won't operate due to deposits in the valves themselves, or due to filter deposits decreasing oil flow to the point it won't actuate the valve. Either cause results in the actuators' response lagging the command signal by several seconds causing a trip. This build-up occurs over multiple cycles before creating any problems. It appears to take approximately 1 to 3 years to manifest, depending on system specifics.

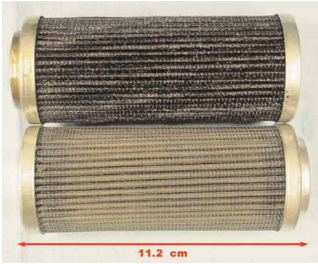
Filtration and Maintenance

Maintenance practices are the other major factor noted that affects the speed of deposit formation leading to filter plugging and valve sticking. One of the most important aspects of maintaining the turbine and its lubricant is filtration. The other main areas that seem to affect deposit formation are oil circulating and heating procedures, and cooling system maintenance.

Most valve sticking and filter plugging deposits in gas turbines appear to be caused by internally generated particulate caused by oxidation. It stands to reason that more effective filtration would help remove the particles before they can come out of suspension in the oil and create those deposits. Improvements in filtration have been seen to provide a drop in both particle count and in the ultra-fine particles seen in centrifugal separation of sediment from turbine oil samples.

In one case, the addition of a 3m absolute filter in a kidney loop configuration dropped both the particle count and ultra-fine particulate levels significantly. Not enough time has elapsed since the addition of extra filtration to determine if it extends servo-valve and filter life. However, the filtration added was inexpensive and may lengthen the life of the servo-valves and filters by slowing deposit formation.

External Servo Filters (Both Exhibit Varnish, Upper More Severe)



One note of caution when making filter design changes to your systems - there is a theory that says flow across ultra-fine synthetic (glass) media filters can lend a static charge to some particles. The theory states that those particles may then be more prone to deposit on metal surfaces, actually increasing the varnish tendency. There is not conclusive proof that this theory is correct, but there have reportedly been cases where moving to finer filtration apparently led to increase in deposit formation. Correctly sizing the filters and housings so that a minimum pressure drop is created will minimize this potential. A reputable filter company and the oil supplier can help with assessing this issue for the given application.

Investing in improved filtration will help extend the life of the components in the turbine, as well as the life of the turbine oil. It is important to work with a good filtration company to ensure the improvements will be cost effective. In some cases, just moving to the finest filter elements that fit in existing housings will provide significant improvement. In other cases, that move may actually cause more problems than it solves. A balanced approach to filtration, including looking at kidney loop, or side-stream filtration, will definitely contribute to lowering the overall cost of operating the turbine.

Another area of maintenance that affects deposit formation in gas turbines is oil circulating and heating procedures. Two factors accelerate deposit formation - soak-back heating of stagnant oil after shut down, and lowering oil temperatures leading to less natural solvency of oxidation by-products. The oil circulation system in conjunction with reservoir or in-line heaters can help reduce the impact of both factors.

Most gas turbines require continued oil circulation after shut down. Extending that interval will continue to remove heat from hot components. It will also prevent oil from stagnating in contact with the hot metal, slowing the oxidation process and retarding deposit formation.

It is also important to ensure that oil flow to the turbine bearings is correct. Insufficient flow can cause the oil to be in contact with the hot bearings for longer periods of time, again leading to increased oxidation and deposit formation. Ensuring the bearing oil flow is correct will allow the oil to carry heat away from the bearings without being unnecessarily cooked. If actual oil flow to the bearing can't be measured, as is often the case, it is important to ensure the oil temperatures both into and out of the bearing are running where they should be. As a general rule of thumb the delta T of the bearings should run approximately 25 - 50°F/14 - 28°C.

Finally, using a heater and continuously circulating the oil can greatly reduce the chance for deposit formation during shut down. If a properly sized heater is used to maintain the oil above roughly 104°F/40°C, it will help maintain the oil's natural solvency of oxidation by-products, and mitigate the "settling" effect previously discussed. Continuous circulation also helps by avoiding stagnant spots, reducing the tendency to form deposits. One alternative is a kidney loop filtration unit with or without a heater.

Some consideration has to be given to the hydraulic circuit design. Some minor modifications may enhance the effectiveness of this procedure. Also, it is critical that the heater used be sized properly, both in terms of watt-density and maximum surface temperature. Generally, lube oil heaters should be lower than 8 watts/in^2, and lower than 194°F/90°C skin temperature. This can be varied based on system design, but care should be taken not to allow the heater chosen to contribute to oxidation of the oil.

Another option for maintaining heat in the circuit is electric heat-tracing the lines. The first servo-valves to experience the "settling" of varnish deposit materials are typically the IGV (inlet guide vane) in cyclic-loaded units, and the GCV (gas control valve) in base-loaded units. Since these two circuits seem to be particularly vulnerable to varnish deposit formation, taking steps to maintain oil temperature (and flow if possible) through these parts of the system while down could reduce deposits and extend valve life, helping prevent trips.

Lubrication System Components (Very Clean – Demonstrates Effective Varnish Control)

The last main area of maintenance that affects deposit formation in gas turbines relates to the cooling system. This could also be argued to be part of the original machine design and installation, but is crucial either way. The cooling system designed for any turbine must be meticulously maintained, and regularly checked to ensure it is doing its job effectively. If the turbine is not getting sufficient cooling, it will run hotter and increase the thermal load on the oil. It is important to remember that for every 10°C increase in oil temperature the oxidation rate doubles. That increase in oxidation rate would have a corresponding affect on deposit formation, and on valve sticking and filter plugging.

Ion Exchange Oil Cleaning

One technique to remove the sub-micronic oxidation by-products is electrostatic oil cleaning. It has been used successfully in conjunction with other maintenance steps to solve servo-sticking problems due to varnish when it was not viable to shut down and thoroughly clean the oil systems.

In theory, electrostatic oil cleaners work by charging the particles in the oil, then alternately charging the filter element. This provides an attractive site for the sub-micronic, insoluble, polar contaminants to settle rather than inside the lube and hydraulic systems. As the saturation level of these particles is reduced in the oil, it regains capability to hold more particles, potentially removing some particles from newly formed varnish deposits. Subsequent passes through the electrostatic cleaner then remove these particles.

Another ion exchange technology available in the marketplace divides the flow of the lubricant into two paths. A current is introduced such that one path has positively charged particles and the other path has negatively charged particles. The paths are subsequently recombined and the oppositely charged particles attract each other forming larger particles that in theory can be more readily filtered and removed.

These approaches have been successful in extending the life of components, even in systems with oxidized oil and previous varnish failures on servo-valves. Other corrective measures taken in those systems at the same time may have contributed positively, so it can't be definitively stated that ion exchange oil cleaning was the predominant reason for improvement. Evaluation continues regarding the effectiveness and proper application of ion exchange oil cleaning.

Detecting Varnish Tendency

Standard used oil test methods have proven ineffective at predicting an oil's tendency to form varnish. Typical tests include Total Acid Number (TAN, ASTM D 974), Oxidation (FTIR), and Rotary Pressure Vessel Oxidation Test (ASTM D 2272) among others. Oil samples have returned acceptable results in all of these tests, and yet the turbine systems had sufficient varnish deposits to cause unplanned trips or control failures. Different test methods are required to effectively detect the tendency to varnish.

There are several test methods that appear to provide better indication of an oil's tendency to create varnish deposits due to the presence of oxidation by-products: particle count (ISO 4406), ultra-centrifuge, gravimetric testing, and colorimetric testing.

Particle count relates the numbers of particles in the oil larger than 4m, 6m, & 14m in size. While effective for gross contamination such as dirt ingestion, the micro-fine oxidation by-product particles that form varnish have not proven to correlate well with particle count results. If this test is used to evaluate varnish tendency, the more important value is the 4m rating. The trend in that range may provide some useful data.

Ultra-centrifuge is a test where a fixed amount of oil is centrifuged at high speed (10,000 to 20,000 rpm) separating particles to the bottom of the test tube. The amount of particulate separated is compared to a visual scale and given a relative value. This method has proven valuable in detecting the particles that lead to varnish, and the trend in this rating can provide useful information in detecting varnish tendency. However, the test requires specialized equipment and expertise.

In the gravimetric test, a fixed amount of oil is filtered through a very fine filter patch. The patch is then weighed and the filter weight subtracted to determine the amount of sediment captured. The trend upward or downward in sediment weight provides an indication of the oil's increasing or decreasing tendency to form varnish. This method is typically used in conjunction with the colorimetric method below.

Colorimetric testing has been developed to analyze turbine oils by analyzing the color spectra of the sediment captured in the same fashion as the gravimetric method above. The higher the colorimetric index, the more prone the oil is to forming varnish. This method in conjunction with gravimetric testing has been discussed in multiple publications by Clarus Technologies.

Work is ongoing to determine the correlation of all these test methods to varnish tendency in turbine oils. Regardless of which method used, it is important to supplement the typical used oil tests with one or more methods aimed at evaluating the ultra-fine particulate that leads to varnish formation. Traditional test methods indicate a number of things about oil life and machine operation, but they won't identify when the oil could be heading for deposit formation.

Preventing Filter Plugging and Valve Sticking

The main contributing factors leading to short pencil filter and servo-valve life in gas turbines are covered above. Also discussed were some of the tests that may help detect impending varnish deposit formation. The balance of this paper recommends steps to help extend the life of those components, and to lower total cost of ownership for gas turbines. The last two sections outline ideas for reducing deposit formation in gas turbine lubrication systems, and remediating the problem if it occurs.

References:

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2. *Swift, S.T., Butler, D.K., and DeWald, W. Turbine Oil Quality and Field Applications Requirements. ExxonMobil L&S, Fairfax, VA.*

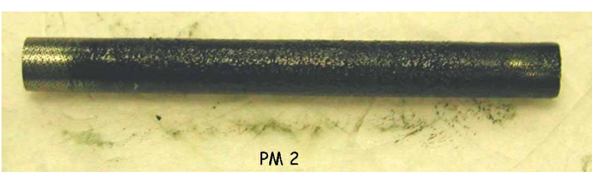
3. *ASTM D 4378-03. Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines. West Conshohocken, PA*

4. *Livingstone, Greg J., Solving Electrohydraulic Servo Valve Stiction Problems in Large-Frame Gas Turbines, Clarus Technologies*

Preventing Pencil Filter Plugging and Valve Sticking

- Be smart about choosing a gas turbine oil. Start the evaluation based on glassware tests and oxidation tests, but then ask the oil supplier what work they have done to determine whether their oil will lay down deposits in gas turbine service. Remember that just looking at the oxidation and other glassware tests can be misleading. Finally, ask for references, both from the oil supplier and other contacts in the energy business. If a turbine oils works well in similar units in similar service, it will likely work well in the turbine under consideration.
- Use ultra-fine filtration, full-flow down to 0.5m, b1000; a kidney-loop can be even finer. Be sure to work with a reputable filter company to evaluate options and choose the right solution for the specific operation, including sizing the elements and filter housing correctly so that there is minimum pressure drop. Installing a kidney loop filtration system independent of the turbine lube system is a good option. Improved filtration will help remove oxidation by-products, extend component life, prevent valve sticking, and improve uptime.

Pencil Filter Condition - Before/After Implementing Varnish Control Measures



- Ion exchange filtration has also been shown to remove sub-micron particles, including oxidation byproducts, which can help reduce varnish formation. The data on this technology is still being gathered, but there have been cases where ion exchange filtration in conjunction with other measures was effective at prolonging component and oil life.
- Use quarterly oil analysis. Watch all critical oil values, and include particle count (focus on 4m rating) and UC (ultracentrifuge) sediment ratings. Supplemental gravimetric and colorimetric testing may provide additional information helping to detect developing deposit tendency. These will help show when oxidation by-product debris is beginning to build in the system, and will help direct corrective action before unplanned outages occur.
- Keep the circulation system running and warm (~100°F/38°C to 120°F/49°C) when the unit is shut down. This will help eliminate the settling of debris from stagnant oil onto components by keeping it moving. A kidney loop auxiliary filtration system should be added if the system can not be readily modified. Make minor modifications to hydraulic circuitry to enhance flow through all components if possible. Use electric heat tracing on the IGV and GCV circuits to maintain the temperature in these critical loops.
- Heating elements (including any electric line tracing) must be carefully used. They should be sized to be no larger than 5-8 watts/in^2, and have maximum skin temperature of 200°F/93°C (static) to 350°F/177°C (full flow). If an immersive heater is sized for oil flow across element, the controls should be tied into the circulating pump to prevent a heat-on/pump-off condition. Improperly sized heating elements, or elements that are not operating properly can quickly oxidize the oil, and will lead to severe deposit formation in the circulating system.
- The heating elements should be inspected every year, or every other year to confirm proper operation, and to insure no deposits have formed on the element. This should be done as part of an overall bi-annual Oil System PM Service to inspect the reservoir condition and to purify the turbine oil.
- Ensure the turbine's cooling systems are operating properly and providing optimum cooling to the appropriate systems and components in the turbine. This will stress the oil less, leading to less oxidation and less deposit formation.
- Use the turbine manufacturer's recommendation as the base interval to change pencil filters and servo-valves. Inspect these components for varnish formation, or insist the re-builder inspect them and provide photographic docu mentation. The condition of these components can indicate the oil's tendency to create varnish and lead corrective efforts. Extend these OEM intervals only based on site-specific empirical evidence.

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- When the turbine is down, take the opportunity to cycle all control circuits fully through their range of motion. If possible, cycle them several times while the oil is warm. Remember that static, cold oil is the most likely to lay down deposits. Flowing warm oil through the control valves and pencil filters will tend to keep the oxidation by-product materials in suspension for removal by the filters.
- When commissioning a new unit or changing oil in the system, a full flush (preferably high velocity flush) of the reservoir must be made to ensure all rust preventative and all old oil are removed from the system. This will avoid immediate contamination of the new oil charge and extend its life. **Reuse of the flush oil as the initial-fill turbine oil is not recommended. If the flush oil must be reused as the initial-fill turbine oil, full testing by the turbine oil manufacturer should be done to determine suitability for continued use prior to start up.**

Remediating A Turbine System That Has Varnish Contamination

There are numerous turbine lube systems in use that already have some level of varnish formation. Understanding the extent of varnish formation, and its economic impact on the turbine in question, is critical to establishing a remediation plan. In many cases the varnish formation is causing significant operational issues that need to be addressed immediately. In those cases a Varnish Flush may be required, which involves adding a chemical to the turbine oil to help dissolve the varnish while running auxiliary heat and filtration.

As discussed above, typical used oil tests aren't effective at detecting varnish tendency in turbine oil. However, the four supplemental test methods reviewed - Particle Count (PC), Ultra-Centrifuge (UC), Gravimetry, and Colorimetry (CM) - show better correlations to the amount of varnish pre-cursors building up in the oil. Combining these four tests with standard used oil analysis, system inspection results (reservoir/servo valves/ pencil filters, etc) and factoring in the current operating performance into one, integrated analysis will provide a strong decision base.

Three examples of analysis indicators and possible remediation actions:

Example #1:

- Situation – High PC, Low to moderate UC, Flat gravimetric trend, Low CM (w/ no significant evidence of varnish and no current operational issues)
- Solution – Install kidney loop fine filtration unit, Consider upgrading full-flow filtration, Review preventive measures outlined above

Example #2:

- Situation – Low PC, Moderate UC, Moderate increase in gravimetric trend, Moderate to High CM (w/ minor varnish formation – no current production problems)
- Solution – Install kidney loop fine filtration unit, Upgrade full-flow filtration, Implement preventive measures above, Consider installing an electrostatic filtration unit

Example #3:

- Situation – Low to Moderate PC, High UC, Moderate to High gravimetric trend, High CM (w/moderate to significant varnish formation and with current operating problems)
- Solution – Perform a Varnish Flush, Replace the Turbine Oil, Install kidney loop fine filtration unit, Upgrade full-flow filtration, Implement preventive measures above, and Install an electrostatic filtration unit

Typical Costs:

- Install kidney loop - 4 micron absolute filtration - $8,000 to $15,000
  – Can be done with system operating
- Install electrostatic kidney loop filtration - $12,000 to $24,000
  – Can be done with system operating
- Integrated Varnish Flush – $18,000 to $40,000 (not including new charge of turbine oil)
  – Requires a 2 to 3 day shutdown