Let's talk about varnish

CAUSES VARY, BUT A CONSENSUS IS EVOLVING ON AVOIDING DEPOSITS AND TESTING

KALYAN KALYANARAMAN

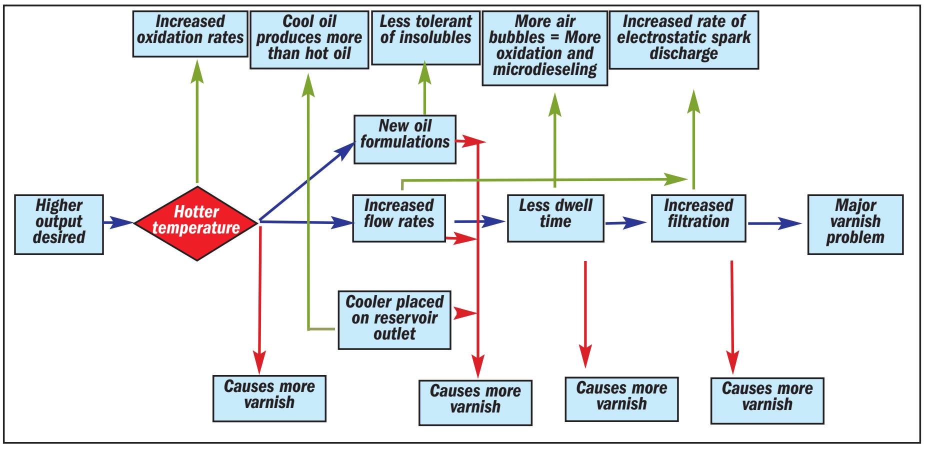

Figure 1: Varnish is an unexpected side effect of advanced gas turbine technologies and lube oils

Suddenly, varnish has become a hot topic in the gas turbine industry. It is the buzz word mentioned in connection with lube oil.

Turbine users have experienced significant varnish-related problems, which has been reflected in online user group discussions and user group meetings. Turbine OEMs are inundated with requests about how to measure their lubricant's varnish potential and what measures to take to prevent the problem. Lubricant manufacturers are also getting frequent queries as to why varnish has suddenly become such an epidemic.

Contaminating the pure

OEMs report that the most frequent performance problems with lubricant varnish in combustion turbines are start-up failures or unit trips. These are due to servo valve sticking in the control circuit of the lubricant system. Depending upon the duty cycle, either the Inlet Guide Vane actuator (Figure 2) or the fuel control valves are the first to exhibit performance problems, says Greg Livingstone of Analysts, Inc. (Torrance, CA), a leading oil analysis lab.

Experts say that varnish has the potential to form on all oil-wetted surfaces; however, the most common areas are valves, filters, strainers, heat exchangers, bearing surfaces and reservoir walls. Besides interfering in the control system, varnish build up on the bearing surface could cause the lubricant regime to transition from full-film (hydrodynamic) to boundary, causing metal-to-metal contact and catastrophic failure. Less dramatic performance problems are decreased cooling capacity of heat exchangers, component corrosion from the acidic nature of varnish, decreased filter life and plugging of oil orifices.

Turbine oils consist of a blend of complex additive chemistries and hydrocarbon base-stocks, resulting in lubricants with dozens of different kinds of molecules. A wide range of thermal and mechanical stresses impact oil in service and every stress point can react with the oil molecules differently, experts say. "This combination creates a limitless range of potential by-products, making it difficult to trace back the destructive pathway that created the varnish," says Livingstone.

Further, there is limited research on the causes of lubricant varnish in turbine engines. "This is still a dark area and we don't know everything about it yet," says Carlos Koeneke, technical service manager for Mitsubishi Power Systems (Orlando, FL).

However, several varnish-producing situations have been documented (Figure 1), which show why varnish is more common today in combustion turbines. The situations include higher turbine operating temperatures, higher lube oil flow rates, tighter filtration, and new turbine oil formulations using Group II base-stocks.

Lube oil suppliers started using Group II and higher-quality base oils that are obtained via hydrotreating or hydrocracking processes, says Vittoria Lopopolo, a researcher with Petro-Canada Lubricants (Mississauga, Ontario). These processes selectively remove or transform undesirable components, such as sulfur, nitrogen, oxygen and aromatic components and at the same time saturate the molecules. "This was done to improve the purity, thermal and oxidation resistance, volatility, as well as the temperature-viscosity properties of the finished lubricant lube oil."

An OEM notes that while some of the lube oils with Group-II base stocks prevent impurities, they also have less ability to maintain these impurities in solution once formed. Len Badal, global enterprise manager of Chevron Global Lubricants (San Ramon, CA), says that it would be a wrong conclusion to say that all oils formulated with Group II base stocks cause varnish. "Group II basestocks provide more robust oxidative stability, but without the correct additive formulation, the oils may be more prone to varnish formation."

New turbine oil products, such as the Chevron GST 2300, have advanced additive systems designed to retard fluid degradation, resisting varnish formation. "Significant progress is being made to manufacture more advanced additive chemistries to improve an oil's resistance to form varnish," adds John Taylor of Afton Chemical (Richmond, VA), a leading supplier of turbine oil additives to major oil companies.

In addition to having the right additives, the right formulation balance is equally important, adds Lopopolo. "A well balanced formulation, one containing optimal additive levels with synergistic effects, will help to reduce overall additive treat rates and alleviate some of the solubility concerns of Group II and higher-quality base stocks." Petro-Canada has introduced Turboflo XL and Turboflo EP turbine oil products that claim to resist varnish formation.

From various fronts

There are a multitude of forces that act to degrade a lubricant to form varnish. Oxidation — a chain reaction catalyzed by the presence of water, heat and certain metal components such as iron and copper — is the most important, says Analysts' Livingstone. Thermal degradation is a chemical reaction that occurs at high temperatures to "crack" the oil mol-

Figure 2: Varnish on the piston and rod of an IGV actuator (above) can affect turbine operation

ecule. "The primary mechanisms of thermal degradation in a gas turbine are from Electrostatic Spark Discharge (ESD) from lube oil filters, 'micro-dieseling,' and hot spots."

"Micro-dieseling," says Mitsubishi's Koeneke, "occurs when entrained air in the oil implodes when it passes through high-pressure pumps in the hydraulic circuit, which can create temperatures over 1,000°F."

In the Mitsubishi lube design, the hydraulic circuit and the lube oil circuit are separate. If these two systems share a common reservoir, then the varnish deposits that are created in the lubrication circuit — due to high flow rates and operating temperatures — could transfer to the hydraulic circuit. The relatively low flow rates in the hydraulic system gives these contaminants a higher chance of agglomerating to form varnish, says Akira Sasaki, a former managing director of Kleentek Industry Co., Ltd, (Tokyo, Japan), a supplier of an electrostatic varnish-removal system. The hydraulic system could have a flow rate of 8 gpm compared to over 1,000 gpm in the lube oil circuit.

According to Sasaki, filters in the lube and hydraulic oil system are a root cause of vanish formation. The high flow-rate on the lubrication side creates ESD through the grounded filter. A grounded filter accumulates positive charges and has more potential energy than an insulated filter, but due to the use of sensitive electronic equipment in the system, the filter needs to be grounded, he adds.

Sasaki goes on to say that a study he conducted found static electrical charges accumulated on the synthetic fiber (insulating material) of the filter, and large numbers of small spark discharges occurred between the charged synthetic fiber and the center core of the filter element (grounded metal). The high temperature of sparks vaporized the nylon material. The nylon vapor cooled down quickly to become fine spheres suspended in the oil. The spark discharges from static electricity crack the oil molecules and produce free radicals, which initiate oil oxidation. Sasaki concludes that low fluid velocities and even static oil in some circuits of the hydraulic system provide conditions for the chemical chain reactions that generate insoluble material depositing as varnish.

A strong relationship exists between deposit formation in the hydraulic circuits of a gas turbine and the oil's antioxidant levels, says Dave Wooton, a lubricant formulator and founder of Wooton-Consulting, who has been studying the problem identified by Sasaki. "In some situations, this problem can be overcome by careful on-site replenishment of additive components." But he warns, "This practice must only be performed by an experienced formulator after in-depth analysis."

Sasaki contends that over-filtering the lubricating oils in gas turbines with filter pore sizes in the 3 to 5 micron range causes these discharges. He believes that the spark discharge phenomena might be minimized if the filter pore size were raised to 20 to 25 microns and oil flow velocities were minimized.

Although Sasaki says he has based his findings on actual case studies and has pictures to prove his point, some experts say that there is limited proof that ESD is related to varnish production. "Sizing the filters and housings correctly so that a minimum pressure drop is created will minimize this effect," says Glen Sharkowicz, product technical advisor at ExxonMobil.

"Some of our filter elements are already made with components capable of carrying the charge away and do not exhibit ESD behavior," says Matthias Schwender, manager for fluid filter development, Hydac Filtertechnik GmbH (Sulzbach / Saar, Germany), a leading supplier of ultra- and micro-filters. In most cases, even the filter elements composed of purely synthetic materials, which can accumulate negative charges due to high flow rates, do not exhibit critical ESD behavior over a wide range of operating conditions (see chart in www.turbomachinerymag.com archives). "To avoid ESD at low temperature and high flow-rate conditions, we have embarked on an R&D program to develop synthetic, environmentally friendly filter elements with proprietary conductive media that retain the original metal-free construction."

Meanwhile, ExxonMobil says that varnish is more prevalent in cyclic operation. Stopping lube oil circulation while components are hot after shutdown promotes oxidation of the oil in contact with the hot component. "As the static oil cools, the solubility of varnish pre-cursors declines, especially in areas where the oil is stagnant such as in reservoirs, pencil filters and servo valves," says Sharkowicz. This could happen during the down period in cyclic service.

Testing for varnish

Varnish potential — a measure of the oil's propensity to drop varnish deposits — cannot be measured by standard used-oil test methods, experts say. They recommend ultra-centrifuge and Quantitative Spectrophotometric Analysis (QSA), also referred to as colorimetric testing. Particle count tests measure larger than 4 micron, 6 micron and 14 micron size, and are therefore considered inadequate for the under-1-micron contaminants of varnish

Ultra-centrifuge is a test where a fixed amount of oil is centrifuged at high speed (10,000 to 20,000 rpm) separating varnish-forming particles to the bottom of the test tube. The amount of these particulates is compared to a visual scale and given a relative value.

QSA removes all of the varnish-causing contaminants in a sample of oil and then uses a spectrophotometer to measure the color. The test is based on the principles of colorimetric analysis, but then ties the hue of the residue to a specific varnish potential in the lubricant represented on a 1 - 100 scale, says Brian Thompson, laboratory manager for Analysts Inc. and developer of the QSA test. He states, "We have seen a good correlation between the varnish potential rating in the QSA test

"The primary mechanisms of thermal degradation in a gas turbine lube oil system are from Electrostatic Spark Discharge (ESD) from lube oil filters, hot spots and micro-dieseling" — Greg Livingstone, general manager of a service division at Analysts, Inc.

A PROCEDURE THAT COULD PREVENT VARNISH

Figure 3: The CRV plate supplies a metered flow to the hydraulic valve block when it is not energized

Thomassen Turbine Systems BV (Rheden, The Netherlands) has engineered a procedure using a modified valve that reduces sludge, another product of oil degradation, and promises to reduce varnish, too. "Varnish is the deposit of polar molecules on a surface, while sludge is the polymerized manifestation of degradation products that fall out of solution when the temperature of the oil falls below a certain range and time allows the molecules to grow like snowflakes," explains Sjoerd Cats of the engineering and product support division of Thomassen Turbine Systems.

A modified flow valve (Figure 3), called the CRV plate and connected to the servo valve, keeps oil flowing through normally cold and low-flow hydraulic oil lines to and from servo valves. "It keeps the oil warm, and even when the oil cools down it does not allow the time to form polymerized molecules (sludge) that block filters." While the CRV plate has been proven to prevent sludge, the prevention or even removal of varnish formation is expected, but not yet observed, adds Cats.

and real-world varnish occurrences." Chevron Texaco's Badal recommends the QSA test to the company's customers.

American Society for Testing and Materials (ASTM) is currently developing a standard test method to determine the varnish potential of a turbine oil. Analysts' Livingstone, who chairs the section, says that the proposed test standard is based on Analysts' QSA test in addition to Sasaki's research on colorimetric testing. He adds that there is also some evidence suggesting that trending data from sub-micron particle counting (ASTM F312) can help to predict varnish potential.

Responding to varnish

The rate of varnish formation can be retarded by following some operating procedures. ExxonMobil recommends:

• Extending the circulation of oil after shut down to prevent it from stagnating with the contact of hot metal
• Ensuring correct oil flow to the turbine bearings, which will help to carry the heat away from the bearings. Typically the temperature difference of the lube oil at the bearings ranges from 14°C to 28°C
• Using a properly sized heater and continuously circulating the oil after shut down, maintaining a temperature above 40°C. This will help maintain the oil's natural solvency of oxidation by-products, and mitigate the settling effect previously discussed
• Electric heat-tracing the oil pipelines
• Maintaining the correct lube oil temperatures, which would retard oxidation rates and hence deposit formation
• Following a quarterly oil analysis program that includes varnish tests

Three electrostatic separation systems in the market place promise to remove varnish. These systems are operated in a low-flow, kidney-loop fashion off the main lube oil reservoir.

Explaining the electrostatic technologies, Analysts' Livingstone says, "In used oil, a constant balance is maintained between the insoluble and soluble oil degradation by-products." And any excess insoluble material falls out of suspension and forms deposits.

When a technology, such as electrostatic separation is employed, it only has the ability to remove the insoluble contaminants, says Jon Prescott, a leading lubricant varnish consultant. Insoluble contaminants can be compared to bad cholesterol while soluble contaminants are like good cholesterol. When the insoluble fractions are removed, it creates an imbalance in the oil. The fluid wants to maintain a balanced state and essentially seek insoluble material. "In this situation, varnish that has settled out in the system will now have a higher attraction to the oil then to the metal walls of the system and is re-adsorbed by the fluid."

The soluble contaminants — good cholesterol — are a critical component of varnish removal. "Simply dumping the oil and replacing with new oil has no impact on removing varnish. The deposits in the system remain largely insoluble in the oil until an artificial imbalance is created," adds Prescott.

By removing sub-micron oil degradation by-products — the principal components of varnish — deposits are removed and prevented from forming.

One electrostatic separation technology is referred to as Balanced Charge Agglomeration (BCA), offered by ISOPur Fluid Technologies, Inc. (Rocky Hill, CT). The technology splits the fluid into two streams and places a positive or negative charge on the insoluble material within the oil. When the particles are recombined, the opposite charges attract, allowing sub-micron particles to agglomerate to micron-size particles that eventually grow to multi-micron size. When the particles are large enough, they can be removed by traditional mechanical filters. Because the fluid is in dis-equilibrium, the agglomerated particulate does not generally adhere to metal surfaces, but is held in the mechanical filters of the BCA equipment and overall lube system.

Kleentek, Ltd of Tokyo, Japan developed the first successful electrostatic technology using the principles of electrophoresis and dielectrophoresis to remove varnish and other insoluble particulate. Within the cleaning chamber on both technologies, a collector cell is maintained within a high voltage electrostatic field. As oil is passed through the chamber, a processes of electrophoresis removes the particles with inherent positive and negative charges by attracting them to the oppositely charged electrode. At the same time, an effect known as dielectrophoresis creates gradient forces within the collector cell that forces neutral particles into the collector media. The amount of dielectric effect plays a large role in the removal speed of the sub-micron varnish.

This technology removes insoluble material down to 0.01 micron to produce a strong dis-equilibrium in the oil to lift existing deposits. Since the cleaning process takes place in a disposable collector cell, varnish and other insolubles are completely removed from the circulating oil system.

A third electrostatic separation technology has been introduced by Environmental Power Technologies of (Calgary, Canada) called the Electrostatic Contamination Control (ECR) technology. The ECR 8000 is designed to control severe varnish conditions in gas turbine applications.

A worst-case scenario

In the case of significant varnish build-up, a high-velocity flush and chemical cleaning of the lubrication lines and reservoir followed by a charge of new oil is recommended. However, even with a clean system and new turbine oil, a tank-side varnish removal unit should be installed to remove any varnish insolubles produced from future system operation, says Chevron's Len Badal. Flushing with fresh oil is always recommended for both new turbine systems, as well as in-between oil changeouts to remove traces of preservative oil and decomposition by-products, adds Petro-Canada's Lopopolo.