Discovering the Root Cause of Varnish Formation

The Hidden Issues Beyond Heat

BY BUDDY ATHERTON, UNITED AIR SPECIALISTS, INC./KLEENTEK

Oxidation results from the thermal stressing of lubricating oil, and the by-products of oxidation can lead to the formation of varnish in hydraulic control and lubricating oil systems.

Dr. Akira Sasaki, consultant and former managing director of Kleentek Corporation, conducted a groundbreaking study on the root causes of varnish formation in gas turbine oil. Specifically, he examined the hydraulic control and lubricating oil filters of a gas turbine to determine the role they played in the formation of varnish, as well as the reasons behind spark discharges that result from static charge buildup within the system. Research included the examination of a GE frame 9FA gas turbine that was experiencing severe varnish effects.

Although a gas turbine was reviewed in the study, the conclusions have relevance to both gas and steam turbine systems, as well as hydraulic control and lubricating systems.

Gas Turbine Applications

The severity of the operating environment for gas turbine oil has increased as turbines develop to improve efficiency and minimize capital cost. This can lead to elevated firing temperatures (hence higher operating oil temperatures) and the use of a common oil reservoir, often combining the turbine's bearing oil with the control oil. In some cases, the single oil reservoir may also supply the sealant for compressed gases (such as hydrogen) and provide hydrostatic lift oil while the turbine is on turning gear. These severe operating conditions, particularly the high cyclic nature of operation and high temperatures, cause varnish.

Although steam turbines and other hydraulic applications may have less severe operating conditions, varnish formation remains a problem.

Turbine Problems Caused by Varnish

After oxidation and the evolution of free radicals into a combined form of varnish, these sticky deposits adhere to the metal surfaces of the oil loop – piping, valves, heat exchangers, strainers, filters and other sensitive equipment. In turn, this growing film catches other fine particulates on the sticky surface, which continues to build up around the particulates, forming an abrasive, destructive surface. Research has shown that deposits of polymerized oil oxidation products contribute to the deterioration of gaskets and mechanical seals.

Other potential problems caused by varnish in turbine systems include:

- Restriction and sticking of moving mechanical parts, such as servo or directional valves
- Increased component wear due to varnish attracting dirt and solid particle contaminants

Figure 1a. Varnish on Shaft

Figure 1b. Varnished Pencil Filter

Figure 2. Spark Discharge within Oil Reservoir

- Loss of heat transfer in heat exchangers; increased friction, heat and energy due to varnish's thermal insulation effect
- Autocatalytic deterioration of the lubricant
- Plugging of small oil flow orifices and oil strainers
- Reduction in filter efficiency and potential filter plugging
- Journal bearing failure
- Increased maintenance costs due to cleanup and disposal of oil

Heat: The Root Cause of Varnish

Without an effective removal system for oil oxidation products, the varnish contamination level in the oil will inevitably grow until it exceeds the capability of the inhibitors, regardless of the robustness of the oil additive package for oxidative and thermal stability. Higher operating temperature or increased levels of harmful catalysts (such as water and wear metals) accelerate oil oxidation and challenge the effectiveness and durability of antioxidant additive packages.

For every 10°C (18°F) increase in operating oil temperature, the rate of oil oxidation doubles (Arrhenius rate rule). However, oxidation of oil, and therefore the formation of varnish, are not slowed as much as expected when the oil temperature is kept below 60°C (140°F). This is because other causes of localized intense heat, beyond the heat generated within the turbine bearings, exist within the oil circuit.

One cause of hot spots in the oil is microdieseling, which is the implosion of entrained air bubbles when the oil passes through a high-pressure pump in the hydraulic circuit. This creates a local oil temperature in excess of 1,000°C (more than 1,800°F), which releases more than enough heat to cause oil molecules to oxidize.

Another cause of hot spots is the generation of spark discharges. The power generation industry's shift to synthetic and glass filter media has created unexpected side effects caused by the combination of tighter filter pore sizes to remove fine sediment with high filter flux rates (flow rate per unit area) to reduce capital cost. The result is static charge buildup within the oil system.

These spontaneous discharges (lasting nanoseconds) can generate sparks with temperatures greater than 10,000°C (more than 18,000°F), which is hotter than the surface of the sun. This intense heat caused by static discharges literally cooks the oil, creating oil molecule fragments that deplete antioxidant additives. A video of the filter spark discharge test conducted by Dr. Sasaki can be found at www.kleentek.com/video.asp.

Although filter manufacturers are conducting research to mitigate the static charge effect of synthetic and glass media, additional research has shown that places in the oil circuit where metal-on-metal contact occurs can also generate a significant static charge that leads to spark discharges.

Even gas turbines that drive peaking units with low operating hours are still vulnerable to oil oxidation and varnish formation. Rolling the turbines with the turning gear two to four hours each week minimizes rotor bowing, and keeping the lube oil circulating at all times maintains reliability and availability. Unfortunately, with these benefits comes the undesirable side effect of furthering lube oil oxidation and varnishing.

Spark Discharge in Oil Filters

Dr. Sasaki examined the voltage potential generated by oil flow through various filter medias used in turbine oil filtration, with the most prevalent being a tight-pore glass media composite. An electrically

Continued on Page 24

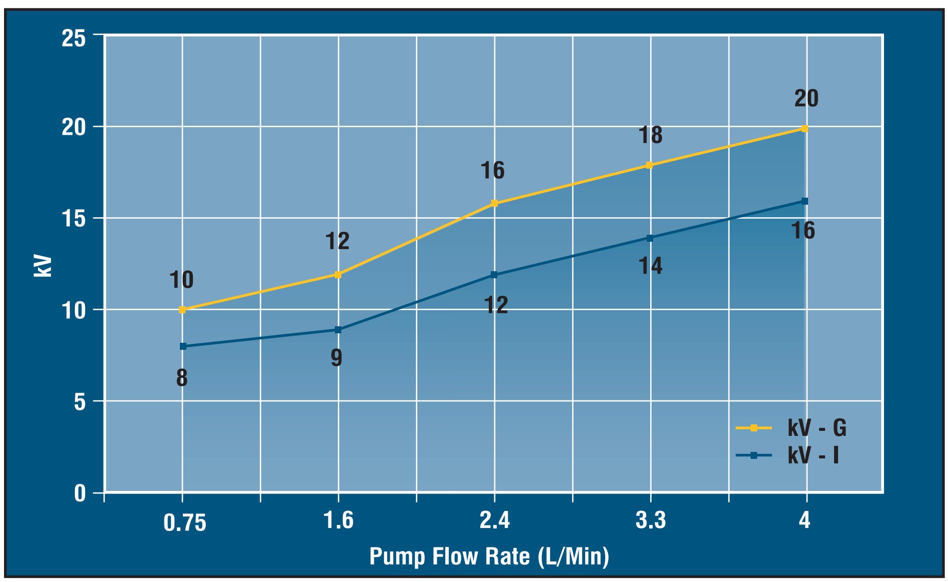

Figure 3. Measured Oil Potentials

Number of Spark Discharges	0	500	2,000	3,000
AN – Just after spark discharges	0.08	0.08	0.08	0.08
AN – After 6 months	0.08	0.09	0.36	0.59
AN – After 9 months	0.08	---	0.40	0.74

Table 1. Turbine Oil Acid Number, mg KOH/g

Sample No.	Catalysts	Water	Time (hours)	AN
1	none	none	3,500	0.17
2	none	Exist	3,500	0.90
3	Fe	none	3,500	0.65
4	Fe	Exist	400	8.10
5	Cu	none	3,000	0.89
6	Cu	Exist	100	11.20
Reference: Tribology Series - "Practical Performance of Lubricants," Saiwai Publisher				

Table 2. Effects of Metal Catalysts and Water on Oil Oxidation

Continued from Page 23

isolated test assembly configured to indicate if a charge is produced within the filter when grounded and ungrounded was used to measure the voltage potential created in the filter at different flow rates.

The two most startling observations from this experiment (Figure 3) were that the oil filter generates a greater voltage potential when it is grounded than when electrically isolated, and that the generation of these high voltages and resultant spark discharges can occur quickly and frequently. Dr. Sasaki consistently found voltage potentials exceeding 10 kilovolts, and that the magnitude of the voltage potential caused by static charge buildup is directly related to the flux rate through the filter media. A high flux rate creates high voltages resulting in more powerful and frequent spark discharges, while a low flux rate yields lower voltages.

In his analysis of the hydraulic and lubricating oil filters on a GE 9FA large-frame gas turbine, Dr. Sasaki observed that the oil flow through these two circuits is decidedly different in two key process parameters:

- The oil flux rate (flow per unit filter area) through the lubricating oil filter is dramatically higher than in the hydraulic control oil filter.
- The oil flow through the lubricating oil filter protecting the turbine bearings is continuous while the oil flow through the hydraulic control oil filter is infrequent (occurring only when a control device is adjusted), leading to cooler oil in the hydraulic lines.

The significance of these disparate conditions is that the high-flux lubricating oil filter contributes frequent spark discharges, creating oxidized oil by-products that form varnish. The hydraulic filter system then provides the cooler, more sedate environment where these varnish molecules can combine and become a substantial fouling problem for the critical hydraulic control devices.

The results of the study indicate that spark discharges in oil cause oxidation and the magnitude of this oxidation is affected by the frequency of spark discharges.

Dr. Sasaki's research also involved studying oil that was subjected to varying numbers of spark discharges, and then left for several months in isolation from light at room temperature. His findings revealed the presence of an autocatalytic process that continues the oxidation of the oil (and subsequent varnish formation), even when the conditions that directly cause oxidation (such as heat and oil wear) are removed (Table 1).

Table 2 demonstrates the relationship between the presence of metal catalysts and water versus oil oxidation as measured by the acid number (AN).

Note that the oil samples shown in Table 1, after spark discharges and being left for months in a controlled environment, did not have free or emulsified water or significant levels of wear metals present. However, the AN value increased for the 3,000 spark discharge/9-month sample. By combining the harmful effects shown by Dr. Sasaki that occur from spark discharges in oil filters and oil circulation systems with the addition of a continuing supply of wear metals and water, the rate of oil oxidation in lubrication and hydraulic systems can be challenging for antioxidant additives.

Ineffectiveness of Current Tests

Most oil analysis tests (such as the rotating pressure vessel oxidation test, RPVOT) do not reliably indicate an oil sample's varnish potential, and often will not identify this condition unless the oil already has a varnish level high enough to be detected. Research has proven that the application of traditional oil test methods as an early warning for the onset of oil varnish is either ineffective or provides limited information.

Tests such as Fourier Transform Infrared (FTIR) can detect oil oxidation by-products that are precursors to varnish formation but do not quantify the condition, which would express the degree of vulnerability.

Colorimetric methods appear to provide a relatively inexpensive means for both early detection of varnish and quantifying the condition across time to chart the system trend. This method (for example, the quantitative spectrophotometric analysis (QSA) test offered by Analysts, Inc.) provides a rating number that can be compared to a relative scale to determine the potential varnish problem and help evaluate equipment and methods to reduce varnish.

Preventing, Solving and Reversing the Varnish Problem Electrostatically

Conventional oil cleaning methods include strainers, centrifuges, vacuum dehydrators and mechanical media filtration. These methods are effective in removing water and

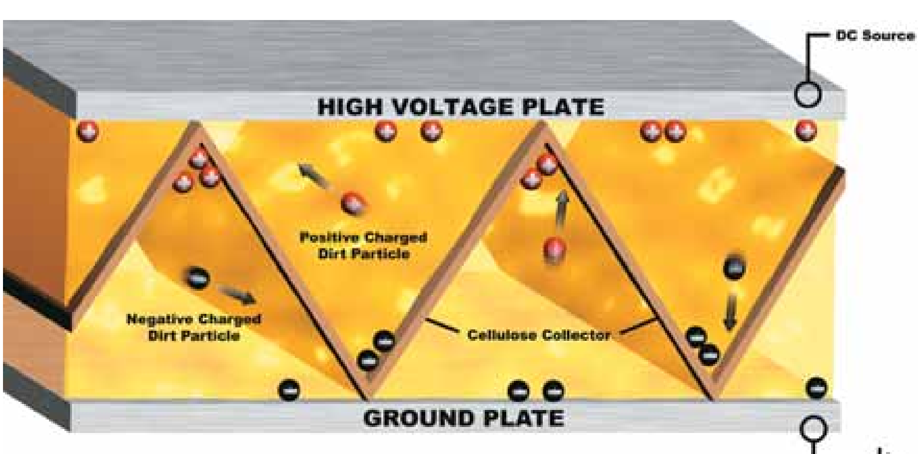

Figure 4. Electrostatic Collection

hard contaminants, along with some larger soft contaminants. But removing varnish and the by-products of oil oxidation that form varnish requires the removal of the insoluble submicron soft oxidation products. The most effective method is continuous electrostatic oil cleaning, which addresses contamination well beyond conventional means.

Using an electrostatic oil cleaning system reduces the oxidized oil by-products. This dissolves varnish on the surfaces of the oil circuit as the oil tries to reestablish the equilibrium between varnish and its precursor, the oxidized oil by-products. As the electrostatic oil conditioner continues to remove the oxidized oil by-products, the natural response of the fluid system to maintain the equilibrium continues to dissolve varnish until it is no longer present.

Figure 5. Varnished Servovalve Before and After 45 Days of Electrostatic Cleaning

The mechanism by which an electrostatic oil conditioner removes naturally charged contamination, such as submicron oxidized oil by-products, is shown in Figure 4. Varnish (the soft, sticky contaminant) is naturally polar (that is, possessing a zero net charge, but having charge distribution within the particle that creates positive and negative charged poles), but is still removed by the system by dielectrophoresis. A more detailed description of this process is provided in the "How It Works" section at www.Kleentek.com. Figure 5 shows a varnished servovalve before and after 45 days of continuous electrostatic cleaning, demonstrating that varnish dissolves and is removed by the system when a means for continual removal of the oxidized oil by-products is in place.

Continuous, on-line electrostatic oil cleaners offer the best means of preventing varnish from interfering with reliable equipment operation. **POA**

Dielectrophoresis (DEP) is a phenomenon in which a force is exerted on a dielectric particle when it is subjected to a nonuniform electric field. This force does not require the particle to be charged. All particles exhibit dielectrophoretic activity in the presence of electric fields. However, the strength of the force depends strongly on the medium and particles' electrical properties, on the particles' shape and size, as well as on the frequency of the electric field. Consequently, fields of a particular frequency can manipulate particles with great selectivity.
Source: www.wikipedia.org