White Paper

The Right Turbine Oil Provides Advantages that Result in Turbine Reliability for Power Plants

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Introduction

In recent years, increased demand for electricity has caused power producers to operate their power production turbines differently. In times of heavy need, commonly called peak demand times, they have to push their turbines harder to maximize production. Yet, the cost of fuel sources have continued to increase, so during non-peak times, they either dramatically slow down or completely shut down some of their turbines to reduce fuel consumption and emissions. This type of production is called peaking operating cycle. Within the past few years, many power producers using the peaking operating cycle have realized that they were having turbine operation reliability problems. Coincidentally, in the late 1990s, turbine oil producers began producing newer formula turbine oils. In the laboratory, these new turbine oils looked amazing, but in the field they were not performing as well. Many of the reliability problems seemed to be traced back to the turbine oil.

Since then, a significant amount of research has been conducted, and it has been determined that it is not just one factor; instead, it is a perfect storm of various factors causing these problems. Among the major concerns in gas turbines are oil consumption and the formation of varnish and sludge. Steam turbine operators have experienced increased problems related to foaming, oxidation, loss of water separation and sludge buildup. Subsequent studies have determined that the combination of the new operating conditions and the new turbine oils has resulted in these problems. Fortunately, continued research has begun to point out new ways to help mitigate these problems. One obvious suggestion is to evaluate the current condition of the oil in the unit, and – if the condition is problematic – change the oil.

Turbine Problems

The highest profile turbine oil-related problem experienced at power plants has been the formation of sludge and varnish, but various other problems also have been reported. These problems include:

- Lubricant consumption
- The formation of a gel-like material on the turbine chiller bundles
- Electrostatic spark discharge in the turbine filtration systems
- Corrosive wear on the turbine thrust plate bearings
- Reduced life from the turbine oil

For obvious reasons, turbine owners and manufacturers have become frustrated with the performance of many turbine lubricants. General Electric, one of the major turbine manufacturers, issued a service bulletin regarding varnishing (10). These types of problems did not occur in the past, which leads to the question: why are they occurring now?

At the 2007 Lubrication Excellence Conference in Louisville, Ky., one of the presentations was based on a paper by William Moehle and his associates titled “Practical Approaches to Controlling Sludge and Varnish in Turbine Oils” (11). Moehle’s paper provides an accurate, concise description of the mechanism for the varnish and sludge formation in turbines. Figure 2 in his paper is a flowchart that illustrates the complex mechanism that results in the formation of turbine sludge and varnish. Moehle pointed out that turbine oils were not the sole cause of the problems. He summarized this by using an illustration of a chain, shown in Figure 3 in his paper.

The problems identified by Moehle and his associates were the result of a chain reaction from various combinations of inferior lubricant formulation, thermal degradation, additive depletion and poor fluid maintenance.

With its properly formulated lubricants and its reliability partner products and services, such as filtration systems, sight glasses, oil analysis and training, Lubrication Engineers, Inc. can provide a comprehensive solution for all of these problems. This paper, however, will focus primarily on the lubricant formulation link of the chain.

Lubricant Formulation

Compared to some of the other types of lubricant formulations, turbine oil formulations are quite simple. They are a mixture of the following ingredients:

- Base oil
- Corrosion inhibitors
- Oxidation inhibitors
- Defoamants
- Demulsifiers

The base oil is usually 97 percent or more of the turbine oil formula. Additives are blended into the base oil at low levels to protect both the oil and the turbine parts. Additives should be chosen so that they provide optimized performance in the turbine, per OEM requirements.

Recently, however, many turbine lubricants have been formulated with base oils that were refined with newer techniques. Most laboratory bench test data indicated that the use of these new base fluids should provide longer lubricant life in field applications. Unfortunately, this has not been found to be true. In addition to the newer base fluids, studies have linked certain antioxidant combinations to the formation of sludge and varnish (11). Lubrication Engineers has found that its Monolec® Turbine Oils eliminate the problems mentioned above, as demonstrated by field performance. How?

LE's Monolec Turbine Oils are formulated using a specially optimized mix of base oils and additives, including Monolec, LE's exclusive wear-reducing additive. Field experience has shown that this formulation provides the proper synergy between the turbine and the turbine lubricant. The LE technical staff has conducted many hours of literature research to understand why this would be the case. Prior to three to four years ago, the oil analysis industry did not have much in the way of tests that would reliably predict a lubricant's tendency to form sludge or varnish. New tests have been developed and are being used to evaluate varnish-forming tendencies. One of these is the Quantitative Spectrophotometric Analysis, QSA℠, a test developed by Analysts, Inc. from which is produced a varnish potential rating, VPR (7, 8). The LE technical staff continually monitors the industry for developments and evaluates new test methods as they become available. Although the main evidence of Monolec Turbine Oil success thus far has been field performance, it is also possible to use good science to explain this success.

Literature Research Findings

Literature research can be used to describe the various causes of turbine oil sludge and varnish as noted by Moehle and his associates. Literature also can be used to answer "How?" LE's Monolec Turbine Oils eliminate these problems.

Oxidative Degradation

As previously noted, the largest part of any given turbine oil formulation is its base oil. While in service, turbine oil will eventually begin to break down through a mechanism known as oxidative degradation. Varnish and sludge in turbines are attributed generally to oxidation and degradation of the lubricant. Most lubricant base fluids are produced from crude oil through a process known as refining. During the refining process, crude oil is heated and treated in such a fashion as to separate it into certain viscosity cuts that can be blended with additives to formulate industrial and automotive lubricants. Through the late 1980s or early 1990s, the majority of lubricant base stocks were finished through a process known as solvent refining. Solvent-refined oils were finished through complex mixing and distilling cycles with various solvents.

In the late 1980s, many refiners began to finish lubricants using a process called hydrotreating. Hydrotreating involves subjecting crude oil fractions to hydrogen gas under high temperatures and pressures. Hydrotreating removes many of the impurities that naturally occur in the oil fractions, such as sulfur compounds, aromatic compounds and nitrogen compounds. Solvent refining techniques were not as effective in removing these, so they were still present in the finished lubricant base fluids. In general, hydrotreating causes the complex mixture of crude oil to become a much tighter cut of single types of hydrocarbon molecules as compared to that processed through solvent refining.

Use of hydrotreated base fluids began to increase dramatically during the late 1990s and early 2000s. Turbine owners began to install these newer lubricants, anticipating longer life for the oil and increased turbine reliability. Instead, varnishing problems began to appear in many turbines. Some of these turbines had run flawlessly for years, without varnish, using what was considered inferior lubricating oils. Researchers are discovering that some of the naturally occurring compounds that were removed by hydrotreating might provide performance benefits in turbines. The two major ones are sulfur-containing compounds and polyaromatic hydrocarbons. This is referenced by Moehle and his group as well as other researchers. The following paragraph points out the findings of several research groups that specifically support this premise.

Scientists at the Institute of Chemical Technology in Prague, Czech Republic, conducted research in which they tested nine hydrocracked base oils, as well as a polyalphaolefin (PAO) base oil, for oxidative stability (1). They found that the oxidative stability of the hydrocracked oils was affected largely by their sulfur and aromatic hydrocarbon content. The natural sulfur was shown to act as an inhibitor in these oils. In another study, researchers at Ethyl Petroleum Additives (now Afton Chemical) conducted research on 15 different base stocks, including hydrocracked oils and PAO oils (3). Like the previous researchers, they characterized these products for paraffinics, aromatics and napthenics content. What they determined was that low levels of multi-ring napthenics and polyaromatics affected volatility and oxidative stability of the base oils more dramatically than they expected. Careful selection of antioxidant type was determined to be critical.

Another study was completed by scientists at the Institut Francais du Petole in Rueil-Malmaison, France (4). Like the two preceding studies, these researchers evaluated the composition of various lubricating base fluids, including solvent-refined mineral oil, hydroisomerized (hydrocracked) mineral oil and 6-cSt PAO oil. They found that the normal solvent-refined mineral oils performed the best because they contained compounds that act as natural oxidation inhibitors. To make the study even more interesting, they extracted these naturally occurring ingredients from the mineral oils and added them to the hydroisomerized and PAO oils, which resulted in increased oxidation resistance with both of these fluids.

Aside from the base fluids, antioxidants are added to oil to defend it from oxidative degradation. However, some antioxidants have been found to contribute to varnish and sludge. Moehle and his associates note that it is best to use a combination of phenolic and aminic antioxidants. The aminics alone contribute to varnish. The phenolics alone do not sufficiently protect the oil. The proper combination provides a synergy that protects the oils, and minimizes sludge and varnish formation.

Oxidative Degradation & Monolec Turbine Oil

How does the above-mentioned research describe why LE's Monolec Turbine Oil performs better than other turbine oils? In any turbine oil, the highest concentration ingredient is the base fluid. The base fluid used in Monolec Turbine Oil might best be described as an API Group I+ base fluid. While technically API does not have a Group I+ category, a brief explanation of how it is refined might clarify the use of this LE-defined description. While industry experience and lab testing seemed to prove the increased value of hydrotreated oils, field performance proved the value of the solvent-refined oils. The base fluid chosen by LE takes advantage of both technologies. It is first solvent-refined and then hydrofinished. This means that it is not hydrocracked, but it is hydrofinished.

By comparison, most of the API Group II and Group III oils are two-stage hydrotreated, meaning they are first hydrocracked and then hydrofinished. The two-stage process removes nearly all of the aromatics, branched paraffinics, napthenics and sulfur. The almost complete removal of aromatics, branched paraffins and napthenics also results in base oil with lower solvency properties. The importance of this will be pointed out in subsequent discussions.

The Institute of Chemical Technology researchers found that low levels of sulfur provide natural antioxidant properties to the lubricant base oil. They and the Ethyl researchers found that base fluids with higher levels of aromatics or napthenics possessed less oxidative and thermal stability properties. The Ethyl researchers noted that the structural deficiencies were overcome easily by proper additization of the base fluid. Because the base fluid used in Monolec Turbine Oil is both solvent-refined and hydrotreated, it contains a low level of sulfur that provides some natural oxidation resistance. Because it is hydrofinished, it does not contain very high levels of aromatics, so it resists thermal degradation, yet it has enough to provide improved solubility for additives and oxidation byproducts. As noted by the Institute of Chemical Technology researchers, lubricants with less than 20 ppm of natural sulfur and no aromatics actually had worse oxidation properties.

The base fluid in Monolec Turbine Oil gives the user the best of both refining technologies. The additive technology blended with the base stock provides a synergistic blend that provides maximum turbine oxidation and thermal stability properties, thus minimizing the formation of carbon, varnish and sludge.

Thermal Breakdown

Thermal breakdown is similar to oxidation and likely increases the rate of oxidation. Like oxidation, it can result in varnish and sludge. Many assume that the temperatures and pressures experienced by the lubricant in turbine bearings are minimal, but recent field experiences indicate that these assumptions may be incorrect. Phenomena known as cavitation and microdieseling are partially to blame for thermal breakdown. Cavitation occurs when entrained air is passed from the compression side of the turbine bearing to the discharge side. There is a dramatic increase in pressure applied to the gas bubbles. According to gas laws, the gas temperature increases dramatically in the range of 100° to 1,800°F (38° to 982°C) (2). At these temperatures, a phenomenon called microdieseling can occur that causes increased oxidation and possible formation of carbon particles similar to the soot that forms in a diesel engine during combustion.

So, how does this relate to turbine applications? Turbines contain journal bearings that operate in the hydrodynamic wear regime (full film lubrication – no metal-to-metal contact). In some turbines, the ends of the turbine shaft come near or make contact with a thrust plate because of front-to-back, or axial, movement of the turbine shaft. As the shaft contacts the thrust plate, the contact pressures are high enough to cause dramatic changes in pressure and temperature. The spot temperatures noted above are high enough to result in thermal breakdown of the lubricant.

Researchers at the National Institute of Standards and Technology (NIST) and Cummins Engine Co. conducted a study on the oxidative stability and volatility properties of lubricants at elevated temperatures (5, 6). They found that although the sump temperatures in engines averaged around 170°C (388°F), the crown land temperatures averaged around 370°C (698°F). Their goal was to create a bench test that would evaluate a lubricant's thermo-oxidative properties, such as volatility, deposit forming tendency and hot metal surface catalytic effect. They described a phenomenon called oxidative volatility. At the high temperatures noted in the crown land and ring zones of the engine, not only would oxidation reactions cause the polymerization of the lubricant, they would cause the lubricant molecules to degrade into lower molecular weight, more volatile products. When this sort of volatility occurs in the engine, it results in a decrease of actual oil in the sump and an increased concentration of oxidation byproducts in the bulk oil due to a reduction in total oil. This results in accelerated oxidative polymerization (formation of sludge and varnish) of the oil. Moehle and his associates also referred to thermal degradation of the lubricant in Table 2 of their paper.

It is also possible that cavitation and microdieseling result in oxidative volatilization of the lubricant, coupled with spontaneous releases of water vapor and entrained air on the low-pressure side of the turbine bearing. As described above, the temperatures caused by microdieseling are high enough to cause oxidative volatilization of the lubricant, vaporization of water and cavitation of entrained air. The cumulative result is an increase in the amount of oxidative free radicals and carboxylic acids that form because of oxidation of the oil and form what have come to be known as precursors of sludge and varnish. When the concentration of the precursors gets too high for the base fluid to keep solubilized, they are deposited on turbine parts. As described earlier, the solvency properties of Group I base oils are superior to that of Group II base oils. Therefore, the Group I oils have been found to be more forgiving as varnish precursors form in the oil. By forgiving, this means that they can suspend more contamination than Group II oils.

Thermal Breakdown & Monolec Turbine Oil

As mentioned previously, most modern turbine oils are formulated with API Group II base oils and rust and oxidation (R & O) additives. The API Group I base fluid in Monolec Turbine Oil, however, contains a low level of naturally occurring sulfur, which is a wear-reducing agent. Together with Monolec, LE's proprietary wear-reducing additive, the LE formula minimizes the effects of cavitation and microdieseling that result in thermal degradation in the newer turbine oils. The Group I base oil also provides increased solubility for additives and varnish precursors. When the oil becomes oversaturated with varnish precursors, these precursors will lead to actual varnish on the turbine parts. Over time, even Monolec Turbine Oils might begin to degrade due to oxidation and thermal degradation. However, because of the improved solvency of the base fluid, Monolec Turbine Oils can better manage varnish precursors.

Oil Consumption

Oil consumption in turbines is another interesting phenomenon that has been observed recently. Most turbines contain a large oil sump. As such, the bulk oil temperature is never very high. Based upon this, one would not expect oil volatility. However, microdieseling and cavitation (as mentioned previously in this paper) might explain what is occurring to accelerate lubricant evaporation in turbines. In his paper, Moehle refers to the evolution of gas bubbles, or foam generation, in turbines. Most likely, these bubbles result from a mixture of entrained air, moisture and volatilized oil vapor that result from increased demands placed upon the turbines during peaking service. This leads to microdieseling and cavitation.

Many turbine oil sumps are blanketed with a flow of air in order to facilitate cooling, to keep the oil dry and to prevent external contaminants from entering the turbine reservoir. As the bubbles come to the surface and are released, the vaporized oil is carried out of the turbine, and then deposited in the area surrounding the turbine. This is why some turbine owners have complained about the amount of oil film on the catwalks, walls and floors around their turbines.

Oil Consumption & Monolec Turbine Oil

It was described previously that Monolec Turbine Oil is affected less by cavitation, microdieseling, and thermal and oxidative degradation. Less oxidative volatility means less oil vapor is released into the headspace of the turbine's oil sump to be carried out of the sump by the positive flow of air through the sump. In addition, Monolec Turbine Oil contains very efficient foam removal additives that are better at facilitating the release of entrained air. Less entrained air results in reduced cavitation and microdieseling. All of this means that using Monolec Turbine Oil will result in less oil consumption.

Electrostatic Spark Discharge

Figure 2 in Moehle's paper notes an increase in filter-related clogging due to electrostatic discharge. Lubricating oils are considered to be insulating materials. This means that they cannot conduct electricity. However, a static charge can build up in oil (2, 7, 8). This mainly occurs as the oil is passed through a filtration system. As equipment clearances and tolerances have become much tighter, the use of filtration to remove particles smaller than 10 microns has proliferated. When the lubricant is forced through these small particulate filters, friction is built up between the lubricating oil molecules. This friction strips electrons from the oil molecules. As the electrons accumulate in the filter, they accumulate energy that must eventually dissipate. The energy dissipates as electrostatic sparks, which have been described as molecular scale lightning strikes that can generate temperatures as high as 12,000°C (21,632°F). High temperatures such as these far surpass what is needed to cause lubricant oxidation and enter the realm of thermal degradation. Fortunately, there are electrostatic filters that can be used to minimize the effects of electrostatic discharge.

A study was conducted in which fully formulated turbine oil in a drum was zapped 500 times with an electric spark (2). The acid number of the oil was measured before and after the sparking, and it remained more or less unchanged. The drum was sealed and stored. Over time, the acid number was monitored continually. The acid number began to increase dramatically in a relatively short amount of time. The only explanation was that thermal breakdown from the sparks catalyzed oxidation reactions, which resulted in the formation of oxidation byproducts such as carboxylic acids that are measured by the acid number test.

Interestingly, it has been determined that low amounts of contamination, such as water and wear metals, can help to minimize the effects of electrostatic discharge, because they help the lubricant to conduct electricity and dissipate the static buildup. Unfortunately, these contaminants also help to catalyze oxidation effects, so they are not necessarily desirable.

Electrostatic Spark Discharge & Monolec Turbine Oil

LE is unaware of any static discharge events occurring at customer locations while using Monolec Turbine Oils. It is believed that this is a fringe benefit of the presence of Monolec in the product. Monolec, a wear-reducing additive, uses electrostatic properties to interact with metal surfaces. As such, it functions similarly to the contaminants mentioned above to help dissipate static buildup and reduce molecular friction as the lubricant travels through the filters. While there is no static discharge test at this time, field use has confirmed that Monolec Turbine Oil can help with this problem. In one example, a power plant that had been experiencing significant static discharge converted to Monolec Turbine Oil, and the problem was eliminated completely.

Chiller Bundle Gel Formation

Some turbine owners have complained about the formation of a gel material, almost like grease, on the chiller bundles within the turbine. The LE laboratory staff has had the opportunity to conduct analysis on this material from several turbines. Surprisingly, it was found that the gel was heavily laden with water and calcium. The reason this was a surprise was that the lubricant being employed did not contain high levels of water or calcium. There are calcium additives that can be used in certain lubricants as detergents, dispersants and corrosion-inhibiting additives, but none of these was present in the lubricants. Where did they come from?

The most reasonable suggestion is that the air that is used to blanket the lubricant sump contains low levels of water vapor. Water cooling towers at many power generation stations send a mist of cooling water to the environment near the turbine. Often, this water is taken from a nearby source of surface water or groundwater. Most of these water sources contain hard water, which contains calcium carbonate. When turbine oil becomes slightly oxidized, one of the common places for oxidation residues to form is on the metal surfaces of the turbine oil sump interior. The cooling bundles themselves are usually made out of steel. Lubricant oxidation residues are often composed of carboxylic acids formed when the oil degrades. As cool water passes through the cooling bundle, water condenses on the exterior of it. The condensation droplets provide a medium where an acid base reaction can occur between the carboxylic acid lubricant degradation byproducts in the lubricant and the calcium carbonate contamination from the hard water. This reaction forms soap on the chiller condenser lines.

Chiller Bundle Gel Formation & Monolec Turbine Oil

Monolec Turbine Oil minimizes the gel formation from occurring in two ways. First, the oil has excellent water separation properties, so any water contamination ends up lying on the bottom of the sump instead of circulating past the chiller bundles. Next, it has excellent oxidation stability, thus the amount of oxidation byproducts and varnish present in the oil and on the oil sump surfaces will be minimized. Therefore, the likelihood of the saponification reaction described above happening on the chiller bundles is minimized.

Conclusion

Turbine owners, like anyone with production equipment, desire reliability. Many turbine operators are experiencing a variety of problems while using newer turbine oils formulated with Group II or Group III base fluids. LE's Monolec Turbine Oils can be used eliminate these problems and ensure reliability, as proven by field performance and supported by scientific literature research. As illustrated in Figure 3 of Moehle's paper, a turbine reliability program should include the proper selection of lubricant, but true reliability is an entire program. Turbine oil varnish must be controlled not only by choosing the proper lubricant, but also by implementing proper fluid maintenance practices, such as filtration, installation of breathers and sight glasses, and education. In addition, it is critical to minimize lubricant mixing and to employ a turbine oil analysis program that evaluates thermal degradation and additive depletion.

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