Pearl GTL Plant located in Qatar manufactures GTL base oils. Source: Shell

TURBINE OILS: A Key Factor in System Reliability

BY ROB PROFILET, PH.D.

In a recent Shell global survey, turbine oil end users indicated that their biggest concern was unplanned downtime during turbine operation. The cost of downtime can be significant if a power company is unable to provide power. Today's turbine systems are operating under increasingly severe conditions including wider temperature variances due to stop/start cyclic operation, which has resulted in some instances in varnish formation on critical turbine component surfaces. Temperature fluctuation in the turbine oil can result in oxidation and thermal degradation initially caused by elevated temperatures of the oil, followed by the deposition of varnish on critical valves as the oil cools to lower temperatures. Resulting stuck valves can in turn cause unplanned downtime, added maintenance costs, and lower productivity.

The survey also indicated that end users are interested in extended oil drainage service intervals to reduce maintenance. In addition, the oil must provide adequate rust and corrosion inhibition, separate water quickly, be compatible with seals, not foam, and be readily filterable. These challenging operating requirements and the desire to extend the lifetime of the turbine oil require robust turbine oil technology in combination with a good oil maintenance program.

Turbine oil formulations must possess very specific properties if the oil is to provide adequate protection for the turbine. To prevent metal-to-metal contact, oils need to have the correct viscosity for

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a given application in order to provide a good oil film for bearings. Oils must release air rapidly to help prevent cavitation, but must also not cause excessive foaming. Rust and corrosion inhibition is a necessity to ensure all key components of a system are protected. In steam turbines, or in other systems where water contamination can be a concern, the turbine oil must separate water very rapidly. If water cannot separate from the oil, an oil-in-water emulsion can form which will interfere with the oil film needed to support loads carried by the bearings. The oil must also act to some degree as a coolant. The internal surfaces inside a turbine become very hot, and the oil must absorb this heat without thermally degrading or oxidizing prematurely.

FORMULATION OF TURBINE OILS

So how is turbine oil formulated? Unlike motor oils, which may contain 20 to 30 percent additives, typical turbine oil formulations contain approximately 99 percent base fluid and only one percent additive. Both the base oil and additive play very critical roles in the performance of the lubricant. The additive itself is a delicate balance of antioxidants, rust and corrosion inhibitors, demulsifiers, defoamants, and pour point depressant. In the case of turbine systems with gears, an anti-wear additive is often present as well. The right combination of additives and base oil is critical to minimize the impact of oxidation and thermal degradation which can lead to the formation of sludge and varnish.

The most common lubricants used in gas, steam, and combined-cycle turbines today are based on formulations utilizing mineral oils in combination with an additive system. The mineral base oils utilized are API Group I, II, or III. The base oil can have a significant impact on the performance of the turbine oil. When combined with appropriate additive technology, Group II and III base oils exhibit extended oxidation life compared to turbine oils formulated with Group I base oils. Turbine oils formulated with Group III base oils have an advantage over those formulated with Group II base oils because they have a naturally higher viscosity index. This higher viscosity index helps maintain the thickness of the oil film at the bearing during times of elevated temperatures. Group III oils also help provide enhanced surface properties in the finished lubricant.

GAS TO LIQUID BASE OILS

Base oil technology has evolved recently to help improve turbine oil performance. Shell recently introduced Gas to Liquid (GTL) base oil which is considered an API Group III base oil. The use of Shell GTL technology represents an exciting step change in technology for turbine oils. Shell GTL technology involves the conversion of natural gas into high-quality products including transport fuels, waxes, chemicals, and lubricants. Research into GTL for Shell began in Amsterdam in 1973, and now after many patents, is produced in Qatar. Shell GTL base oil has been shown to enhance motor oil formulations with better volatility control, better low temperature performance, and enhanced oxidation stability.

The benefits of GTL technology are a natural fit for turbine oil formulations. Enhanced oxidation protection helps the turbine oil last longer and resist the formation of oxidation byproducts which ultimately lead to the formation of varnish. Rapid air release properties of GTL base oils also enable the turbine oil to operate more efficiently by minimizing the chance for the oil film to be broken, which is critical in the lubrication of the bearings. GTL base oils also have a higher viscosity index, which helps maintain the optimum viscosity and film thickness required for the bearings in a turbine across a wider range of temperatures. Maintaining film thickness and reducing the formation of varnish can help reduce bearing temperatures.

OIL ADDITIVES

Although small in quantity, the additive used in turbine oils has a big job to do. Turbine oil additive systems are designed to minimize foam, provide rust and corrosion protection, and help separate water very quickly so it can be removed. Because turbine oils are expected to last a long time (7+ years for gas turbines and up to 20+ years for steam turbines) the additive must contain a robust antioxidant system.

THE PERILS OF VARNISH

Due to the high operating temperatures found in turbine systems, improperly formulated oils can thermally degrade, oxidize, and form varnish. Varnish is found on critical turbine surfaces and starts as a soft film, gradually hardening into a lacquer which is not easily removed. The lacquer can act as an insulating film that interferes with heat transfer. It can also trap particulates such as wear metals. In addition, the varnish can cause valves to stick, causing the turbine not to start. The varnish layer which forms on bearings takes up critical clearance space for the oil film, which can result in higher temperatures and the formation of more varnish.

Varnish precursors form when polar long chain acids, aldehydes, and ketones form in the oil from oxidation and thermal degradation of the lubricant. These precursors eventually combine or react with each other and form longer chain polymeric species. The oil will hold this material in solution until a saturation point is reached and the resulting "sludge" drops out on cooler parts of the system (often during shutdown). Overtime, the sludge turns into varnish and eventually a lacquer as temperatures increase.

IN THE LAB

Once a fluid has been developed, several tests are conducted in the laboratory to assess the performance of a product. Common physical property tests such as viscosity, flash point, pour point, and density are measured along with performance tests. Performance tests include water separation properties, resistance to rust and corrosion, air release, filtration performance, foaming tendencies, and thermal and oxidation stability tests.

A common method used to measure resistance to oxidation is the ASTM D943 Turbine Oxidation Stability Test. This test is commonly listed on supplier Technical Data Sheets. In this test, a mixture of oil and water is heated to 95°C in the presence of a catalyst and bubbling oxygen to expedite the oxidation process. The oil is monitored by total acid number, and the test is stopped when oils reach 2.0 mg KOH/g. The more hours in this test the better; long life turbine oils will have a value of >10,000 reported hours.

There are other oxidation tests which can also assess turbine oil performance. These include ASTM D4310 (1000 hour TOST) which measures sludge formation, ASTM D2272 Rotating Pressure Vessel Oxidation Test (RPVOT), and the Dry TOST Test (ASTM D7873).

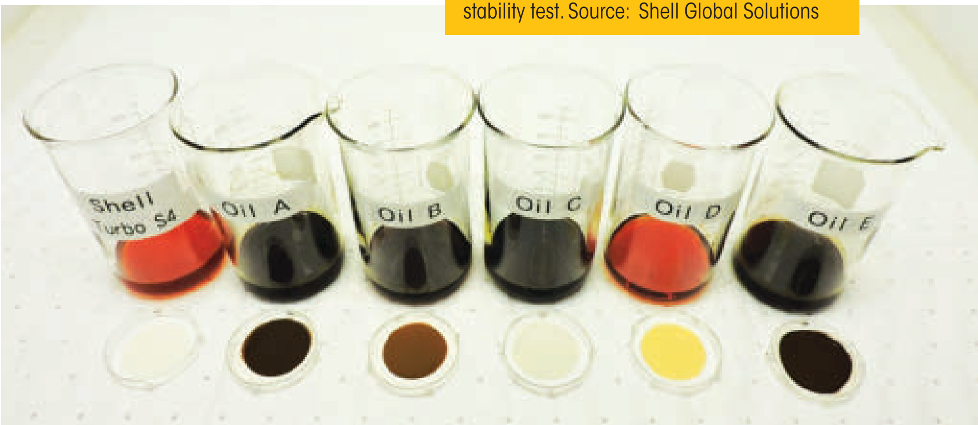
The Dry TOST Test (ASTM D7873) promotes the oxidation of the turbine oil in the presence of heat (120°C), metals (steel and copper coils), but no water. The test is conducted for a period of 1008 hours, and is designed to measure the sludging tendency of the fluid by measuring the RPVOT retention and insoluble oxidation products. The test is a useful method to predict turbine oil performance in the field.

A severe method to measure thermal stability is the MAN Thermal Stability Test. The test is conducted by heating the test oil in a static oven at 180°C for a period of two days. The amount of sludge formed is then measured, which helps to assess the thermal stability and short-term deposit resistance when the oil is exposed to very high temperatures.

IN THE FIELD

After laboratory testing is completed, turbine oil suppliers will often conduct field demonstrations of their product. Field demonstrations allow for careful monitoring of the fluid in real-world applications. The fluid is introduced and monitoring is conducted on a scheduled basis that is agreed upon with the end user.

Thermal stability in turbine oils can vary based on results of the MAN LTAT thermal stability test. Source: Shell Global Solutions



All turbine oils should be subjected to a proactive oil analysis monitoring system. There are many published turbine oil condition monitoring guidelines available from industry bodies such as ASTM and ISO. Original equipment manufacturers (OEM) also publish guidelines to help the end user monitor the turbine oil and get the most efficient performance. Lubricant suppliers will also provide guidance to help suggest a schedule for testing.

Test schedules will often include viscosity, total acid number (TAN), water

Typical Testing Schedule for Turbine Oils 1

Test	Steam Turbine	Gas Turbine	Suggested Limits
Viscosity	Quarterly/Bi-annual	Quarterly	+/- 5% of fresh oil value
Total Acid Number (mg KOH/g)	Quarterly/Bi-annual	Quarterly	Caution: 0.1-0.2 over new oil value; Warning 0.3-0.4 over new oil value
Water Content (KF, ppm)	Quarterly	Quarterly	<0.1% for steam; <0.05% for gas
Elemental Analysis (ICP)	Quarterly	Quarterly	Check contamination
Oil Cleanliness (ISO 4406)	Quarterly/Bi-annual	Quarterly	Follow OEM Limits
RPVOT (min)	Annual	Quarterly	<25% of fresh oil
Demulsibility (ASTM D1401)	Annual	---	>40-37-3 (40 minutes)
MPC or QSA (varnish formation)	---	Quarterly	<40 MPC; <60 QSA
Foaming (mL-mL)	Annual	Annual	450/10 max

Turbine oils should be tested on a regular basis to help extend the life of the fluid and the system.

Source: Shell Global Solutions

Predicting the Onset of Varnish 2

Turbine oils can be tested using the MPC test to help predict the onset of varnish. Increasing varnish potential results in a darker filter patch.

Source: Shell Global Solutions

content, elemental analysis by ICP, oil cleanliness (particle count), RPVOT, demulsibility, foam performance, RULER Test, and either MPC (membrane patch colorimetry) or QSA (quantitative spectrophotometric analysis) to assess varnish potential in the fluid.

Varnish potential screening methods have been successful in identifying a system with a high potential to varnish by isolating insoluble oxidation products and measuring their concentration in the system. By assigning a rating system, an end user can take different courses of action to help protect their system.

If a high rating is observed, there are many systems available which can be used to help remove varnish precursors from turbine oils or other lubricating oils. Popular methods include the use of electrostatic filters, balanced charge agglomeration systems, electro-physical separation processes (ESP), depth filtration, and filters which minimize electrostatic discharge.

The best route to minimize varnish formation involves a two-pronged strategy. First, a high-quality turbine oil should be selected. The oil should not only have excellent oxidation resistance, but should also be resistant to deposit formation. Second, a proactive oil monitoring program can go a long way in minimizing problems resulting from oil degradation, extending the life of the oil, and providing a higher level of protection for the system. Downtime and unplanned maintenance can be reduced or eliminated.

CONCLUSION

Shell recently introduced a new line of turbine oils which provide a very high level of performance for steam, gas, and combined-cycle turbines. The technology is based on the use of Shell GTL Group III base oils in combination with a specially developed additive system. Testing in the laboratory and in the field has shown that these products have a very high resistance to oxidation and thermal breakdown, minimizing the formation of sludges and varnish on critical turbine surfaces. These products have very rapid air release and are low foaming, helping to improve the overall efficiency of the turbine operation. The use of Shell Turbo S4 X or Shell Turbo S4 GX (for turbines requiring protection of gears) in combination with a suitable oil-monitoring program can help to extend the life of critical turbine components and help extend the life of the turbine oil. This can result in lower costs, less unplanned downtime, and higher efficiency. pe