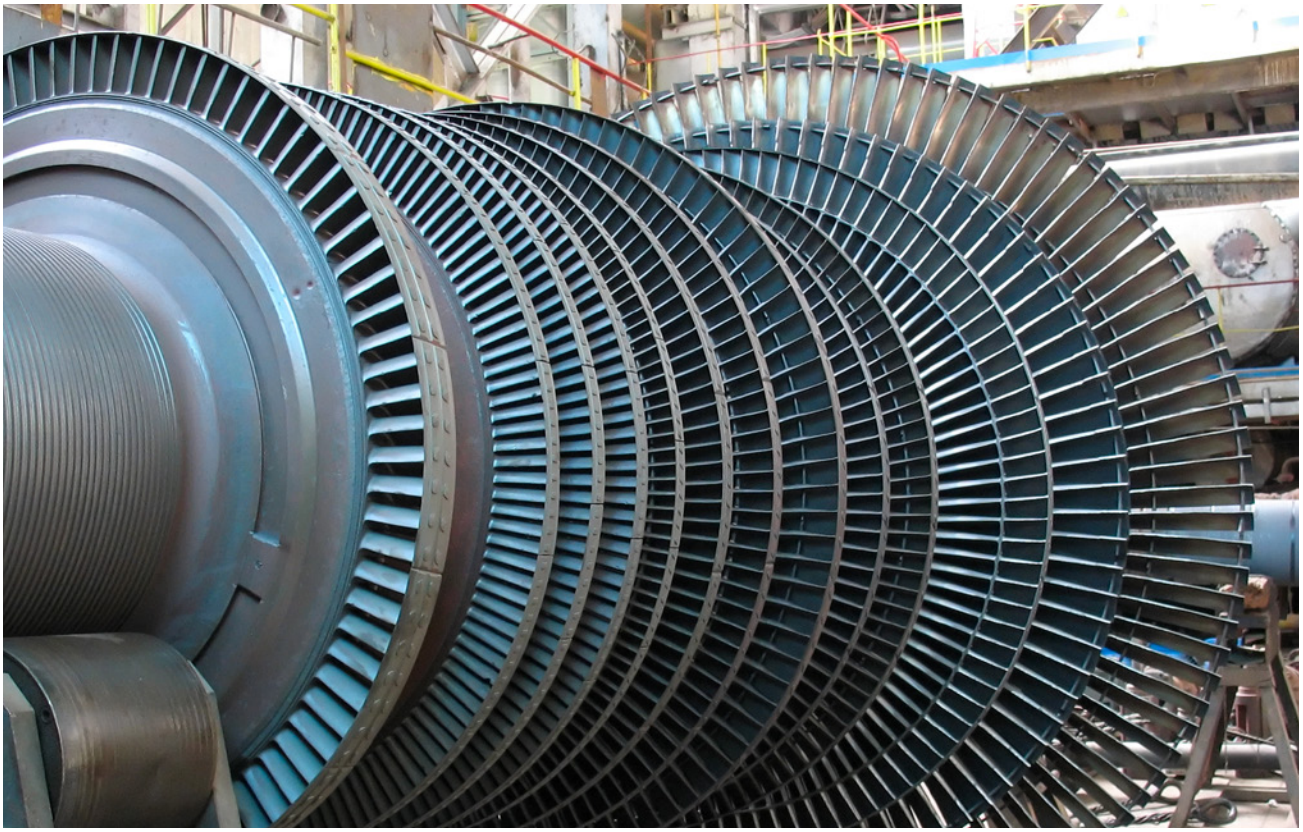

WHITE PAPER

CHOOSING THE RIGHT TURBINE FLUID

START WITH THE BEST TESTING METHODS
FOR THE OVERALL PICTURE

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ABSTRACT

By changing to Group II base oils, gas turbine fluid formulations have improved their oxidative and thermal stability. With that switch, however, came reduced solubility and the costly side effect of increased varnish formation.

More than ever, operators need to choose the right turbine fluid that will combat varnish accumulation. To do that, the industry needs to update its fluid test methods, because relying on the rotating pressure vessel oxidation test (RPVOT) alone has proven ineffective for comparing turbine fluids. As a result, misinformation could lead operators to choose a less effective fluid for their gas turbines.

This white paper aims to provide education on how turbine fluids have changed, why some test methods are not effective in isolation as performance-predicting tools and which tests do yield more accurate results for measuring varnish potential.

The Challenges of Varnish Formation

For natural gas turbine operators and maintenance managers, varnish formation is an issue that continues to interfere with operational efficiencies and mechanical performance, contributing to:

- lost circulation
- increased wear and corrosion
- equipment failure and, by extension, downtime

Peaking units in particular are challenged by varnish, due to cyclical warming and cooling.

Varnish formation has a long history in machinery, but only recently has it become a bigger issue to manage.

A principal reason for the noticeable increase in varnish formation is that, unlike traditional products that used Group I base oils, the majority of modern turbine fluids are made with more highly refined Group II base oils. The switch has uncovered several advantages for manufacturers, including the ability to add more complex and effective antioxidant chemistries that demonstrate better oxidative and thermal stability than when used in Group I oils.

The new added-performance capabilities are a necessity for gas turbines, which are the most demanding application for turbine oils. They also represent the fastest-growing market in North America for power generation, which underscores the importance of focusing on this formulation category.

Despite their natural resistance to oxidation, an unfortunate side effect of using Group II base oils is reduced solubility. In hydrocracking, the process used to manufacture these base oils (which contributes to improved oxidation properties), the compounds that would otherwise help the oil solubilize are removed. As such, additive companies have been tasked with adapting their chemistries to keep the compounds in solution.

Another reason for the increasing prevalence of varnish is because natural gas turbine fluids are required to perform more functions in increasingly harsh environments.

As more advanced metallurgies are developed, the efficiency and firing temperatures of gas turbines continue to increase. There are some industrial turbines in use in which the same reservoir of fluid simultaneously provides lubrication to the turbine bearings, generator bearings, atomizing air compressors, lift oil system, trip oil system, generator hydrogen seal system, load gears and a multitude of servo valves within the hydraulic circuit.

While power generators benefit from more efficient turbines and the output they deliver, the demands and stress on the turbine oil tend to rise. Manufacturers have no choice but to specify more performance from turbine fluids, as higher temperatures accelerate oxidation, which is responsible for numerous lubricant problems such as viscosity increase, varnish formation, sludge formation, additive depletion, base oil breakdown, filter plugging, loss in foam control, acid number increase, rust formation and corrosion.

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Get the Right Fluid by Changing How You Evaluate Performance

The importance of careful fluid selection cannot be overstated. There are no indications that the original equipment manufacturer (OEM) plans to revert back to Group I oils; in fact, as time progresses, the likelihood of moving to even more refined oils such as Group III and IV increases. Likewise, the demands placed on turbines and the operating conditions required to meet them are here to stay.

As such, varnish management will no doubt continue to be a priority for natural gas turbine operators when selecting a fluid. With that in mind, it is worth examining how operators make their fluid selections to ensure their methods are in line with the latest formulations available on the market.

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As it stands, operators look to testing and performance ratings—often specified by the OEM—to choose a turbine fluid that protects against oxidation and resists varnish formation. By all accounts, a data-based judgment is the most logical approach to making a decision, along with a field trial. Operators and maintenance managers require assurance that the investment they make will be able to mitigate the risk of failure.

The problem lies not only in the decision-making approach itself, but in what the industry still accepts as the baseline test for measuring how the fluid will perform. One particular method (RPVOT) for measuring fluid performance—while still extremely valuable as a benchmarking tool—is not as useful for predicting the actual, in-use performance of today's gas turbine fluid formulations, but it is a great resource to use when comparing particular system results over time.

Re-examining the RPVOT for Natural Gas Turbines

The rotating pressure vessel oxidation test (RPVOT) is an accelerated aging test designed to evaluate the oxidation stability of new and in-service lubricants having the same composition. This test was established as an ASTM standard in the 1960s and has now become the de facto measurement for helping end users determine the remaining useful life of turbine fluids.

The RPVOT is conducted by placing the lubricant, water and a copper catalyst in a pressure vessel fitted with a pressure gauge. The vessel is then pressurized with oxygen to 620 kPa (90 psi), placed in an oil bath at 150°C or dry block taken to 150°C, and rotated axially at 100 revolutions per minute (rpm). The result reported is the time taken for a pressure drop of 175 kPa (25.4 psi) below the maximum pressure. The drop in pressure indicates that oxygen has been consumed by reacting with the lubricant's components. The number of minutes required to meet the required pressure drop is used to infer the oxidation stability of the lubricant.

For older technology, Group I based turbine fluids, this testing method proved useful in predicting oil performance. New-generation turbine fluids, however, degrade at non-linear and unpredictable rates — which can be attributed to the specific antioxidant(s), as well as the natural oxidation-resistant characteristics of Group II base oils. As a result, the RPVOT provides little to no warning as to when the lubricant will start to degrade and generate system deposits. Thus, various tests are performed over time and trending is used to show the bigger picture. This is evident for several reasons. Here are two:

1. Some of the antioxidants that generate very high RPVOT values could also produce high levels of insolubles upon depletion, showing a direct correlation to varnish formation within the lubricating system. Thus, in some cases, these chemistries that showcase very high RPVOT values have contributed to increasing varnish potential in gas turbines.
2. RPVOT values can be strongly influenced by the addition of some corrosion inhibitors and metal passivators. These additive species can negate the effects of the primary catalyst in the RPVOT test, a copper wire coil, improving the test results and giving a false indication of the fluid's oxidation properties. This is why other oxidation tests are run as well. Corrosion inhibitors typically deplete out of turbine fluids fairly quickly, once put in service, as they are polar and designed to provide a protective film to metal surfaces. It is not unusual in some turbine fluid formulations to see a sharp drop in RPVOT values during the first year of service as a result of corrosion inhibitor depletion. RPVOT retention is a much stronger indicator of turbine oil performance than initial RPVOT results[1].

[1]Livingstone, G., Ameye, J., & Thompson, B. (2010). "Rethinking Condition Monitoring Strategies for Today's Turbine Oils". *Machinery Lubrication*.

To be clear, the RPVOT need not be discarded. Its results give a quality comparison of batches of the same composition. Operators can (and should) use this test to measure base-level fluid properties at the beginning of oil use and, over time, track oxidation effects on those properties. Furthermore, if you have a reservoir with mixed brands or formulations of turbine fluids, performing RPVOT testing is recommended as part of a complete test slate to help evaluate the condition of the fluid. RPVOT results can also be used as part of an overall analysis program for in-service oils of the same composition.

However, beyond a certain point, the RPVOT is no longer helpful for assessing the relative longevity of different gas turbine oil formulations. As such, the RPVOT should not be used in "isolation" as a measurement to compare competing lubricants.

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As a side note, the RPVOT test was never intended for the comparison of the performance between different oil formulations. In fact, the method specifically advises against the use of this test to compare oils of different compositions. According to ASTM D2272 – Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel:

"The estimate of oxidation stability [from this test] is useful in controlling the continuity of this property for batch acceptance of production lots of the same operation. It is not intended that this test method be a substitute for Test method ASTM D943, or be used to compare the service life of new oils from different compositions. This test method is also used to assess the remaining oxidation test life of in-service oils."

The desire to have a formula with a high RPVOT is fine, but not if that same formulation produces varnish, which tends to be far more detrimental to a turbine system. Today, experts agree it is of more value to choose a formulation with very low varnish and sludge tendencies.

Better Tests for Predicting Group II-based Fluid Performance

After determining that RPVOT ratings are not ideal for choosing a natural gas turbine fluid, alternative ratings are needed to fill the gap. Over the years, several tests have surfaced as valuable, and experts recommend using a combination of both new and well-established tests when determining the right turbine fluid.

ASTM D7843 Test – Measurement of Lubricant Generated Insoluble Colour Bodies in In-service Turbine Oils using Membrane Patch Colorimetry (MPC)

Measures the level of insoluble degradation products present in the oil

This is a relatively new lab method of extracting the insoluble contaminants from an in-service turbine oil sample onto a membrane patch. The colour of the patch is analyzed by a spectrophotometer.

This test can be used as a guide on the formation of lubricant-generated insoluble deposits. This test is considered highly sensitive and reliable for detecting subtle changes in insoluble levels and offers the ability to predict varnish formation. The results are intended to be used as a condition monitoring trending tool.

ASTM D6971 – Measurement of Hindered Phenolic and Aromatic Amine Antioxidant Content in Non-Zinc Turbine Oils by Linear Sweep Voltammetry (LSV) or RULER®

Measures hindered phenol and aromatic amine antioxidants in lubricants

Voltammetry is often the technique of choice for measuring antioxidants, as it is indicative of field testing, not lab testing. Antioxidants are one of the first components of the turbine oil formulation to be impacted by thermal, oxidative and mechanical stress and provide early warning for incipient lubricant failure. When calibrated against the new oil, the remaining antioxidant concentration can be determined to estimate the lubricant's remaining oxidative life.

Tests have been designed to measure oxidation reserve (the amount of protection remaining) and oxidation progress (the amount of oxidation that has occurred). Both testing methods have their advantages and the effectiveness of these tests depends on the operation of the in-service fluid. Understanding how the fluid is handling the oxidation problem can enhance the attempt in correcting the root cause of fluid oxidation. The lubricant specialist should be aware of the measuring tools available and what they may indicate. Therefore, one can address and potentially reduce this source of fluid oxidation.

Ultra-Centrifuge Test

Excellent indicator of varnish potential

The ultra-centrifuge (UC) test subjects a lubricant sample to G-forces that yield oil-degraded insoluble contaminants typically associated with varnish potential. Insoluble contaminants tend to have a higher density and will drop out during testing. This agglomerated material is compared to a rating scale to obtain a UC value (Rating 1 – 8).

ASTM D445 Test – Kinematic Viscosity of Transparent and Opaque Liquids

Measures the oil's internal resistance to flow at a specified temperature (often cSt at 40°C)

This tried and true test is still invaluable. Viscosity is one of the most important oil properties because the oil film thickness under hydrodynamic lubrication conditions is critically dependent on the oil's viscosity characteristics.

ISO 4406 – Method for Coding the Level of Contamination by Solid Particles (Cleanliness)

Quantifies particulate contamination levels per milliliter of fluid

This is an important test to perform and trend for all turbine fluids. It determines the overall cleanliness of the fluid.

ASTM D943 – Oxidation Characteristics of Inhibited Mineral Oils (Turbine Oil Stability Test – TOST)

Evaluates oxidation stability of the lubricant, testing "new" turbine oil properties

The TOST attempts to determine the expected turbine oil life and performance by subjecting the test oil to oxidative stress using oxygen, high temperatures, water and metal catalysts, all of which could increase sludge and acid formation. Because it is impossible to simulate actual in-service conditions in a lab, correlation between test results and actual field performance is difficult. As such, most turbine OEMs use TOST in their specifications to screen out high-risk turbine fluids. Also, this test does not account for other signs of deterioration such as sludge formation or catalyst coil corrosion. The use of ASTM D4310 is used for sludge measurements.

FTM-791-3462 Coking Tendencies of Lubrication Oils

Evaluates thermal oxidative stability of fresh turbine oil on hot surfaces

This test is run at a specified temperature and time, and at a consistent flow rate. The lubricant sample is dripped over the hot panel throughout the test period. Sludge and varnish will build on the plates and a visual comparison can be completed at the end of the test, as well as determining the weight of the varnish/deposit.

ASTM D3427 – Air Release Properties of Hydrocarbon Based Oils

Evaluates the ability of turbine fluids to separate entrained air

Some gas turbine OEMs specify air release limits in their new oil specification requirements. These limits are defined as the time for the entrained air in the fluid to reduce in volume to 0.2 percent under the conditions of the test and at the specified temperature. In turbines with small sumps and minimal residence time, entrained air mixtures could be sent to bearings and critical hydraulic control elements, causing film strength failure problems, loss of system control and an increased rate of oxidation.

In addition to looking at the above test results in comparing and selecting a new turbine fluid, it is also recommended that operators implement some of these tests in routine oil inspections. While traditional methodologies for monitoring the oxidative health of used turbine fluids — viscosity, acid number and RPVOT — are still beneficial, tests such as the MPC and LSV are more likely to reveal turbine oil degradation at earlier stages, as well as identify a fluid's deposit tendencies.

CONCLUSION

Varnish is an industry-wide concern, and natural gas turbine operators need to be armed with the right information to select the right turbine fluid that addresses varnish formation effectively. To ensure operators are well informed, the industry must re-evaluate the old test methods to welcome newer, more accurate performance tests, such as ASTM D7843 Test – Membrane Patch Colorimetry (MPC) and ASTM D6971 – Linear Sweep Voltammetry (LSV).

The RPVOT need not disappear, as it is still very useful for comparing batches or trends of the same product. It is not, however, effective for predicting oil life performance or for comparing one fluid to the next.