NEXT-GENERATION TURBINE OILS COMBAT OXIDATION, THERMAL DEGRADATION AND VARNISH

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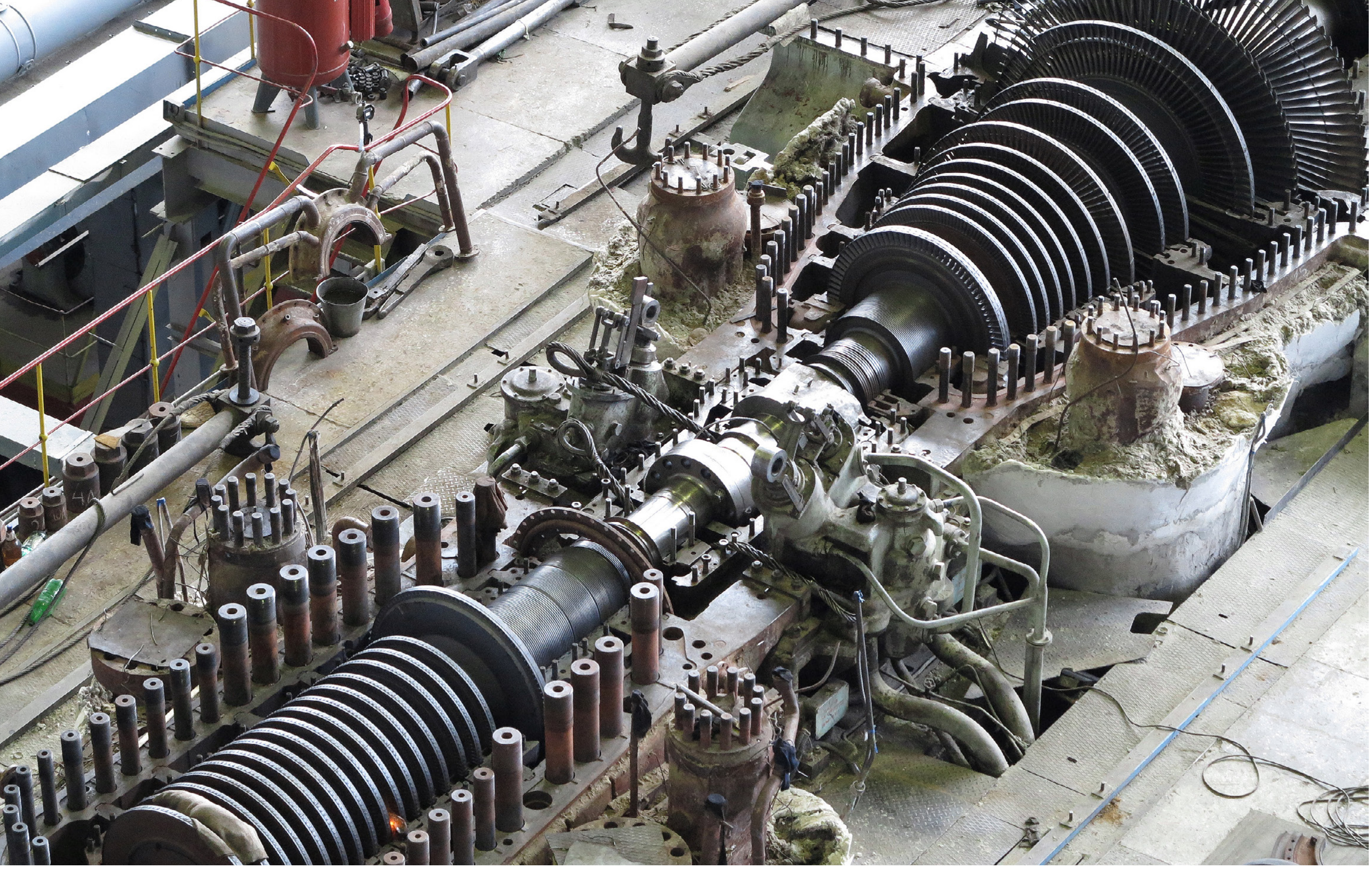


This steam turbine undergoing repair provides a view of the internal components of this complex machinery.
Source: alexrow /Adobe Stock

POWER GENERATION INDUSTRY TRENDS

Turbines are a critical technology in power generation, pipeline transmission, marine, chemical and other industries with intensive power requirements. Gas, steam and combined cycle turbine systems represent the most demanding turbine oil service conditions in power plants. Power generation can be for electrical energy production to the grid or site power and steam generation for manufacturing plants, refineries, chemical plants, off-shore oil platforms, primary metal plants, hospitals and other large or remote facilities.

Evolving plant operations and turbine design, with a focus on efficiency, require modern power turbines to operate under severe conditions. A push toward increasing efficiencies and higher levels of energy extraction have caused higher turbine operating temperatures inducing more thermal stress on the lubricant, demanding increased performance against oxidation, sludge and varnish formation.

Turbine oil sumps are also smaller to reduce capital costs of new turbines. Turbine oil is circulated at higher flow rates to compensate for higher turbine temperatures and smaller sump sizes.

The demand for continuous operation with minimized downtime for maintenance or turbine oil replacement further complicates the situation.

New high-efficiency turbine designs, such as this General Electric 7HA.02 (formerly frame 7) gas turbine, expose turbine oils to higher temperatures and flows compared to older turbines. Source: Oak Ridge National Laboratory

The result of new turbine design and extended uptime is higher turbine oil temperatures and thermal stress on the turbine oil, which is well documented. According to Turbomachinery International magazine, "…bearing oil temperatures may approach 100° C in typical steam turbines or industrial heavy-duty gas turbines and exceed 200° C in aero-derivative gas turbines." The 2013 article, In-service Condition Monitoring of Turbine Oil, from Texas A&M's Turbomachinery Laboratory, "…lube oil in aero-derivative turbines is in direct contact with metal surfaces ranging from 204° C to 316° C. Sump lube oil temperatures can range from 71° C to 121° C."

Pipeline transmission facilities use gas turbines to provide power and pressure for the transmission of liquids and gases. Medium-sized remote packages boost oil and gas pressure to facilitate long-distance transmission of products to market. In these applications turbine fluids often serve a dual purpose, lubricating both the turbine and compressor in remote facilities. Large commercial marine vessels and military ships employ turbine engines for both propulsion and power generation. Such remote applications require high reliability lubricants with long service lives because downtime is not an option in harsh environments and conditions, including cyclic loading, saltwater exposure and temperature extremes.

TURBINE OPERATION COMPARISON

Turbine Type	Sump Oil Temperature	Circulating Oil Tempurature	Speed (rpm)
Aeroderivative Turbine	70 to 120°C	204°C - 316°C	2400 to 6400
Gas Turbine	50 to 100°C	Up to 280°C	Up to 7000
Steam Turbine	40 to 70°C	Up to 150°C	Up to 3000
Hydro-Turbines	40 to 60°C	70 to 90°C	50 to 600
Wind Turbines	Up to 55°C	<-40°C to >50°C	10 to 20

TURBINE OIL FUNCTIONS AND PROPERTIES

The main function of turbine oil or turbine lubricants is to provide:

- Friction reduction for turbine bearings
- Corrosion and rust prevention
- Bearing and turbine component cooling
- Wear reduction
- Debris removal

When turbine oil is contaminated with water, the resulting acid and varnish formation can prevent the turbine oil from functioning properly, resulting in varnish, laden sludge, corrosion, increased friction, higher wear and elevated temperatures. Turbine components rust or corrode when water, free oxygen and electrolytes are present in a fluid system. The surfaces of turbine bearings and raceways are susceptible to attack through a water etching type of corrosion.

Several types of corrosion are found in turbine bearings and components:

- Steel corrosion or rust or steel oxidation
- Copper alloy corrosion
- Galvanic corrosion

Galvanic corrosion can arise in systems where dissimilar metals are in contact in the presence of water, acids or electrolytes. Turbines are susceptible because they contain a variety of dissimilar metals such as steel, copper and babbitt (Sn-Pb-Cu-Sb). Galvanic corrosion can be prevented by removing water, electrolytes and by electrically isolating the dissimilar metals.

Moisture and water enter the turbine oil by leakage past seals from steam, humid air or water coolant systems. Low grade fuels, biofuels and other alternative fuels can be sources of corrosive chemical species. Carboxylic acids (naphthenic acids) are typically the chemical species or corrosive elements in turbine oils. These acids are generated from water-induced lubricant degradation. The degradation is driven by thermal breakdown and hydrolysis, which causes hydroperoxides or carboxylic acids to form from the base oil. These acids contribute to corrosion and varnish formation and for these reasons the turbine oil must have effective water separation and acid inhibiting properties to delay acid formation.

Advanced turbine oils use ashless anti-wear additives as well as chemical agents to prevent or reduce acid formation, rust, oxidation and corrosion. Water separation is another important factor in reducing corrosion and oil breakdown in modern turbine oil systems. Turbine oils require sufficient levels of demulsifying or water separating properties so water traps in the circulating system can remove moisture. Good demulsifying properties and water removal practices reduce hydrolysis, which is a precursor for acid, sludge and varnish formation.

OXIDATION RESISTANCE AND VARNISH PREVENTION

Eventually, all lubricant and oil operating at high temperature will oxidize and hydrolyze resulting in the formation of varnish and sludge. In fact, 40% of facilities reported varnish problems within six years of oil service life. Degradation of turbine oil through oxidation and varnish formation on bearing surfaces, cooling systems and hydraulic control systems; and sludge in piping and sumps obstruct lubrication functions, resulting in shortened turbine oil life, increased wear and corrosion. Varnish and sludge also reduce circulation due to viscosity increases and filter plugging, reduce heat transfer from bearing surfaces, increase fail to start events, equipment failure incidents and extend downtime.

Varnish is caused by oxidation and polymerization of the base oil. The chemical reactions resulting in varnish formation occurs through several steps. As oxidation and varnish formation accelerates, deposits occur on cool surfaces, and accelerate sludge formation in the sump. Contaminants such as water and metals (copper and iron from steel) act as catalysts accelerating varnish formation reactions. Hydrolysis forms insoluble and radical precursors or building blocks leading to varnish formation, which can be measured with varnish potential (MPC) or ultracentrifuge tests. Nonpolar molecules are converted to polar molecules, which can act as precursors to varnishes and enable corrosion.

VARNISH PRODUCING TURBINE OIL CHEMICAL REACTIONS

R = Hydrocarbon (Oil or Lubricant)
O = Oxygen Molecule
H = Hydrogen

Thermal Breakdown

RH → R· (Hydrocarbon free radical)

Oxidation & Precursor Formation

R· ♦ O_2 → RO_2H (hydroperoxides/carboxylic acid)
RO_2H ♦ RH → RO_2H (alkylperoxy radical)
RO_2H ♦ RH → RO· ♦ ·OH

Polymer or Varnish Formation

R· ♦ R· → R·R (Polymer)
R· ♦RO_2 → RO_2R

Chemical reactions that produce varnish in turbine oils.

The additives and base oil stocks utilized in the lubricant formulation impact oxidation resistance and varnish formation. API group I base oils are refined using solvents. API group II base oils are made using a hydroprocessing or hydrotreating process. API group II base oils are inherently more resistant to oxidation compared to group I base oils. However, varnish and varnish precursors have less solubility in group II base oils.

Additives to prevent deposits such as detergents, dispersants and solvency enhancers are commonly employed to reduce varnish formation in formulations using group II base stocks. However, solvency modifiers can impact a turbine oil's demulsibility or water separability. Advanced formulations with improved anti-oxidant additives or oxidation inhibitors can prevent or delay the thermal oxidative chemical degradation and therefore varnish formation.

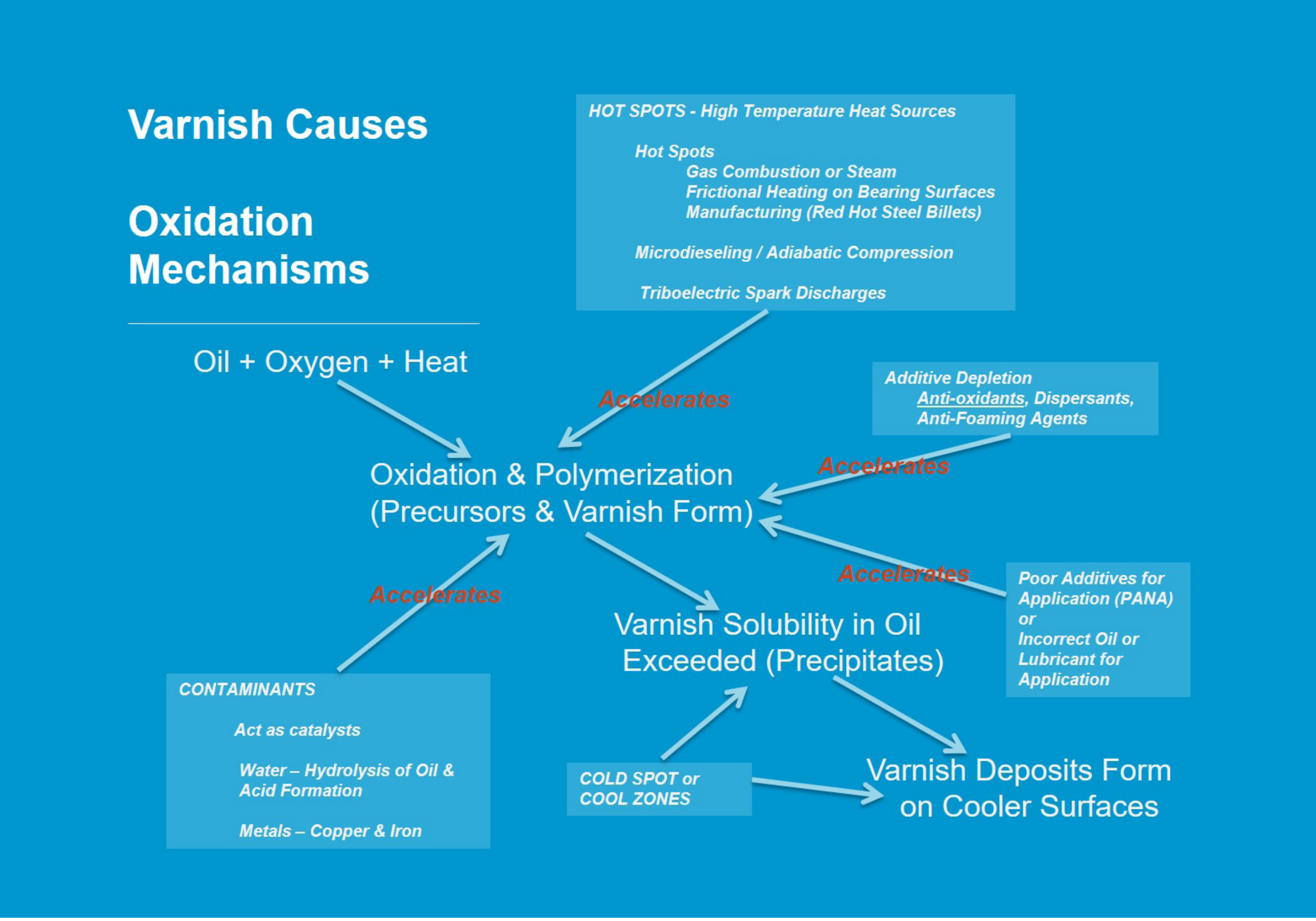
API BASE OIL STOCKS GROUP CLASSIFICATIONS

API group	Production process	Saturate Level	Sulfur Level	Viscosity index (VI)
API group I	Solvent refining	<90%	>0.03%	80 to 120
API group II	Hydroproessing or hydrotreating (partial hydrocracking)	≥90%	≤0.03%	80 to 120
API group III	Severe hydrocracking (catalytic dewaxing)	≥90%	≤0.03%	≥120
API group IV	Chemical synthesis (e.g., polyaplhaolefin)	Can obtain high VI, low pour point and high oxidative stability for specific applications.		
API group V	Varies with specific oil chemistry	Base oils not included in Groups I through IV.		

API base oil group classifications.

High performance turbine oils also exhibit excellent anti-foaming and air release properties. Foaming of the turbine oil and entrapment of air can degrade the oil's ability to efficiently lubricate, reduce wear, transfer heat and protect against rust and corrosion. Since air is significantly more compressible compared to the turbine oil, entrained air can cause sluggish operation of hydraulic control systems as well. In addition, air is a source for increased oxygen, which further exacerbates oxidation, corrosion and varnish formation.

Turbine oil conductivity is another property carefully controlled in advanced oils. Higher lubricating oil flow rates in modern turbine lubrication systems have the potential to increase triboelectric charging and static discharges or sparks within the filter elements. Low conductivity or highly dielectric turbine oils increases the potential for electrostatic discharge or sparking in filtration systems. Static discharges can damage filter elements, deplete protective additives and degrade the oil because the high temperature sparks promote oxidation and varnish formation. Turbine oil conductivity is controlled with the proper selection of additives.

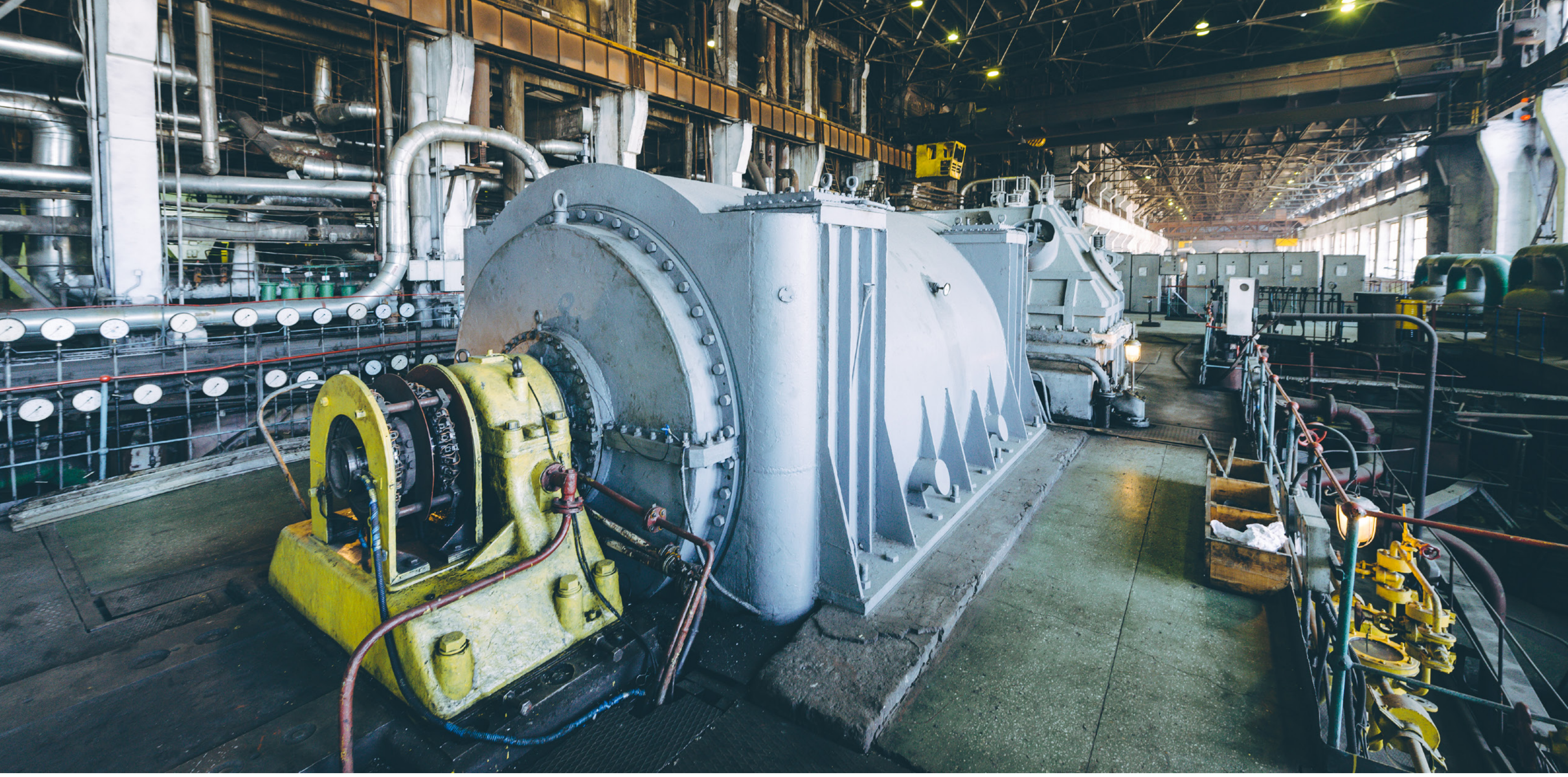


A thermal oxidative process breaks down turbine oil producing free radicals and varnish precursors and then dissolves varnish. When varnish concentration increases past solubility limits, varnish films deposit on cool surfaces. Source: IEEE GlobalSpec

Modern turbine oils can contain a wide variety of additives such as rust and oxidation inhibitors, foam inhibitors, pour point depressants, dispersants, foam inhibitors, conductivity modifiers and demulsibility additives. Interaction between the additives can occur and a thorough knowledge of lubricating oil chemistry and the chemical reactions possible during a turbine oil's life cycle is required to produce high performance turbine oil formulations.

COST OF TURBINE OIL DEGRATION

Turbine oil degradation can result in costly component repair costs and downtime for an operation. Replacement of a valve might be around $3,000 depending on the specific size, type and location of the valve. Varnish removal and repair of a valve might run around $2,000. Capital equipment damage from component failure could result in thermal or mechanical damage to expensive power or manufacturing capital equipment requiring costly repairs or replacement. The shutdown and lost productivity costs can be very large depending on the type of operation. Nearly 20% of unplanned shutdowns and associated lost production come from varnish build-up.



Turbine oil degradation due to poor turbine oil selection or insufficient oil analysis and maintenance programs can be extremely costly to a manufacturing or power generation plant. Source: agnormark / Adobe Stock

Other costs can be significant as well. In electrical power generation plants supplying the grid, a failure to start or trip out can cost more than $100,000 per incident due to the cost of buying power from other plants to meet obligations. Turbine oil replacement costs can range from $25,000 to $100,000 for large capacity turbine oil reservoirs with thousands of gallons. Costs can run as high as $50,000 to $150,000 for varnish flushing and cleaning a large turbine oil lubrication system.

Water entrapment and absorption can promote corrosion, acid formation and varnish. Turbine oils require good demulsibility or water separability. Source: Dipali S / Adobe Stock

MONITORING AND MAINTENANCE TO EXTEND OIL LIFE

Properly monitoring turbine oil using condition-based monitoring (CBM), oil condition monitoring (OCM) and predictive maintenance (PdM) methods can extend the lubricant's useful life. Oil analysis programs (OAP) are an essential element in keeping track of turbine oil health and turbine operating efficiency.

The first step in an oil analysis program is establishing good oil sampling best practices. Once the samples are taken, a chain of custody should be maintained, which includes proper labeling, documentation and safeguarding the oil sample from contamination.

Routine oil sampling should occur at frequent intervals. Different tests to check for unusual color, cloudiness, sediment, water or odor should occur at annual, monthly and weekly intervals and even daily if necessary. Viscosity index (VI) tests, ICP metals, water and ISO particle count tests should be run at least monthly. Monitoring quarterly to annually with the more time-consuming analytical laboratory tests is acceptable in most cases.

The specific battery of laboratory tests will depend on the type of turbine, turbine OEM and oil analysis laboratory.

Ferrography tests provide an indication of the amount of metal wear particles in terms of % sediment, or a particle count. ISO 4406 determines and specifies the ISO cleanliness code to be used in defining the quantity and size of solid particles or particulate contamination in a fluid on a per milliliter basis. ISO cleanliness should be routinely performed on turbine oils with the results trended over time. Several chemical and elemental analysis methods are used to identify contamination from cooling or other water sources.

Recommended tests and test frequency in a turbine fluid oil analysis program. Source: Phillips 66

RECOMMENDED TURBINE FLUID OIL ANALYSIS PROGRAM

Monthly

- Viscosity
  - 40°C, 100°C & VI
- ICP Metals
- Water
- Particle Count with ISO Rating

Quarterly - Annually

- RPVOT
- MPC
- RULER
- Water Separation
- Acid Number
- Foam
- Color

The “ICP metals test” is based on inductively coupled plasma-atomic emission spectrometry (ICP-AES) as per ASTM D5185-18. ICP metals test measures metallic element levels to determine changes in additive levels, contamination from leaks and metallic wear particles. For instance, increases in boron, sodium or potassium levels may indicate a coolant leak. ASTM D6595 uses rotating disc electrode (RDE) atomic emission spectrometry (AES) to detect and quantify metals from wear particles and contaminants.

Spectrometric methods such as FT-IR and GC-MS are used to a lesser extent but valuable in the detection and identification of contaminants or degradation. They can help in analyzing organic breakdown and oxidation retention of phenol or amine additives. ASTM D7889 – 13 Standard Test Method for Field Determination of In-Service Fluid Properties Using IR Spectroscopy provides a guide on using FTIR for the assessment of in-service fluids.

Remaining Useful Life Evaluation Routine (RULER®) uses linear sweep voltammetry (LSV) to estimate the remaining antioxidant additives in the fluid. Once these antioxidant additives are consumed, a more rapid increase in thermal degradation of the base oil can be expected. While the RULER® test is popular in the industry, the method and its repeatability are still evolving.

OXIDATION, TURBINE AND SLUDGE TURBINE OIL TESTS

Standard	Test method	Details
RULER® Remaining Useful Life Evaluation Routine	Linear sweep voltammetry	Increasing voltages are applied to the oil sample and the meter graphs results as remaining antioxidants accept electrons. The value is compared to a control sample to estimate remaining service life.
ASTM D2272 Standard Test Method for Oxidation Stability of Steam Turbine Oils by Rotating Pressure Vessel	Rotating pressure vessel oxidation test (RPVOT)	RPVOT test compares retained stability of test oil against that of an untested control oil.
ASTM D7843 Standard Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils Using Membrane Patch Colorimetry	Membrane patch colorimetry (MPC)	Insoluble contaminants from an in-service sample are extracted from a membrane patch. The color is measured by a spectrophotometer as a ∆E on the CIE LAB scale.
ASTM D7414 Standard Test Method for Condition Monitoring of Oxidation in In-Service Petroleum and Hydrocarbon Based Lubricants by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometry	Fournier transform infrared (FTIR) spectrometry	Measures the byproducts of oxidation with a common FTIP spectral feature between 1,800 and 1,670 cm-1.

Standard	Test method	Details
ASTM D7873 Standard Test Method for Determination of Oxidation Stability and Insolubles Formation of Inhibited Turbine Oils at 120° C Without the Inclusion of Water	Dry turbine oil stability test (TOST)	Samples are heated in the presence of oxygen and iron and copper catalysts. Samples are heated over intervals and insolubles are measured by RPVOT.
ASTM D943 Standard Test Method for Oxidation Characteristics of Inhibited Mineral Oils	Wet turbine oil stability test (TOST)	This test is typically run with water (17%) at 95° C in the presence of oxygen, and copper and iron catalysts, to simulate the conditions of a steam turbine. Oxidation is determined by increased acidity of the oil.
ASTM D4310 Standard Test Method for Determination of Sludging and Corrosion Tendencies of Inhibited Mineral Oils	Wet turbine oil stability test (TOST)	The test is that same as for D943, although testing is stopped after 1,000 hours and insolubles are measured.

Common ASTM oxidation, varnish and sludge turbine oil test methods.

Various test methods help engineers determine remaining turbine oil life to ensure maximum service life.
Source: photosoup/Adobe

Aeration or air entrapment can occur through leaks, refilling or return of turbine oil to the sump. Good air release and anti-foaming properties in a turbine oil are important because foam reduces lubricity and air is a source of oxygen, an ingredient for varnish formation. Source: Love the wind / Adobe Stock

Water and corrosion detection is another major goal of oil analysis efforts. Turbine oil chemistry changes indicating water and corrosive species in fluid include conductivity, acid number and water content. Important methods for the detection of water and corrosive species include Water Separation (ASTM D1401), Vapor Pro® and Karl Fischer methods, the Crackle visual test and total acid number (TAN).

Foam levels can be measured with ASTM D892, which empirically rates both the foaming tendency and the foam stability. Foam reduces the lubricating and heat transfer ability of turbine oils. Pour point, cloud point, flash point and other specific fluid properties can affect machine performance or equipment operation. These can be measured in laboratory tests. Thermal breakdown of a lubricant also reduces the flash point, which represents a safety hazard. Aeration levels can be measured by ASTM-D3427. Entrained air can affect the performance of turbine oil, including heat transfer, oxidation and varnishing.

A shutdown will far exceed the cost of an oil analysis program. By monitoring test results, defects can be detected, and preventive maintenance scheduled as needed. Phillips 66 provides testing and prediction expertise for the most demanding turbine oil monitoring situations.

Early detection of varnish and varnish precursors is of critical importance because steps can be taken to prevent further degradation of the turbine oil or damage to the equipment. Membrane patch colorimetry (MPC) and ultracentrifuge tests are key methods in the early discovery of varnish potential or varnish precursor formation. Varnish potential analysis typically employs several methods such as ultracentrifuge tests, MPC and rotating pressure vessel oxidation tests (RPVOTs). In particular, the RPVOT value of a new turbine oil is compared against that of the used turbine oil, offering what is known as RPVOT retention, an overall better indicator of oil quality.

While operators may note the color of turbine oil during oil monitoring and analysis, oil color does not indicate varnish potential. Very dark oils can have low varnish potential and surprisingly light oils can have a high varnish potential. Varnish precursors are sub-micron sized and not visible to the naked eye.

Visual examination of the lubrication system can be used to detect varnish films on components and sludge formation in sump. Initially, varnish can be detected by looking for a varnish “bathtub” ring inside the oil sump. The first varnish deposit will form on cool, low flow areas within the lubrication system, so inspection of valves for varnish deposits during a shutdown is another good practice. Visual inspections should also be made to detect signs of corrosion.

TURBINE OIL CONTAMINANTS

Contaminant	Ingress Source
Water or Moisture	Leaks in steam turbine seals, leaking heat exchangers or chillers, condensation of humid air on cool metal surfaces, wet fuel in gas or alternative fuel turbines
Hard Inorganic Particulates	Leaks past air filtration system of air laden with coal dust, ash, sand, dirt and other hard abrasive particles
Metal Particulates	Particles produced internally from wear of bearings, raceways and other components
Microbes	Water, tramp oil and air ingress can carry along microbial or bacterial contamination
Corrosive Chemical Contaminants	LNG, sour gas wells, alternative fuels, geothermal steam, & offshore (saltwater) facilities can introduce high chlorides, sulfides and other corrosive contaminants

Turbine oil contaminants.

Failure to properly maintain your turbine oil will result in reduced productivity, equipment reliability and life as well as decreased operational efficiency. When it comes to operating a turbine system reliably and efficiently, superior oil is only the beginning. An effective maintenance program that includes in-service oil monitoring is also required to ensure reliable and efficient operation for many years.

A good turbine oil and lubrication system maintenance program will include:

- Eliminating contamination sources such as coal dust, sand, water and air
- Checking seals for leaks and other contaminant sources
- Maintaining turbine oil to prescribed ISO cleanliness ratings
- Inspecting surfaces for signs of corrosion and varnish films
- Examining last-chance filters for varnish

Cooling and chiller equipment upkeep is an important part of the lubrication system maintenance because heat is an enemy of turbine oils. The chillers should be checked and optimized to maintain and improve cooling ability. Cooling systems are often a source of water ingress and they should be checked frequently for water leaks, unexpected coolant loss and other contaminants. Filters and filter media should be maintained and replaced regularly, and separators, water absorption filters, vacuum dehydrators and desiccant air breathers can help aid in moisture removal.

Cleaning and flushing of turbine oil lubrication systems is an important step to take before recharging a system with new turbine oil. Several different cleaning processes are available. Mechanical flushing uses heated oil and high flow rates to remove sludge and wear debris. Mechanical flushing is not typically effective in removing varnish. In solubility enhanced system cleaning, the turbine oil is loaded with additional cleaning agents during the last few days or weeks of operation or before flushing. The American Society of Testing and Materials (ASTM) provides a Standard Guide for Cleaning, Flushing, and Purification of Steam, Gas, and Hydroelectric Turbine Lubrication Systems (ASTM D6439).

For severe cases, chemical flushing uses water- or oil-based chemical detergent cleaners to dissolve and suspend varnish and sludge from internal surfaces. Chemical cleaning is not recommended for systems on steam turbines sensitive to water contamination. Insoluble soaps from the flushing oil can deposit in the lubrication system during cleaning. Because of the risks of chemical residue or water, chemical flushing should only be completed by highly qualified technicians and suppliers.

Soldier inspecting a CH-47 Chinook helicopter gas turbine for corrosion. Source: U.S. Army/Charles Rosemond

NEXT-GENERATION TURBINE OILS FROM P66

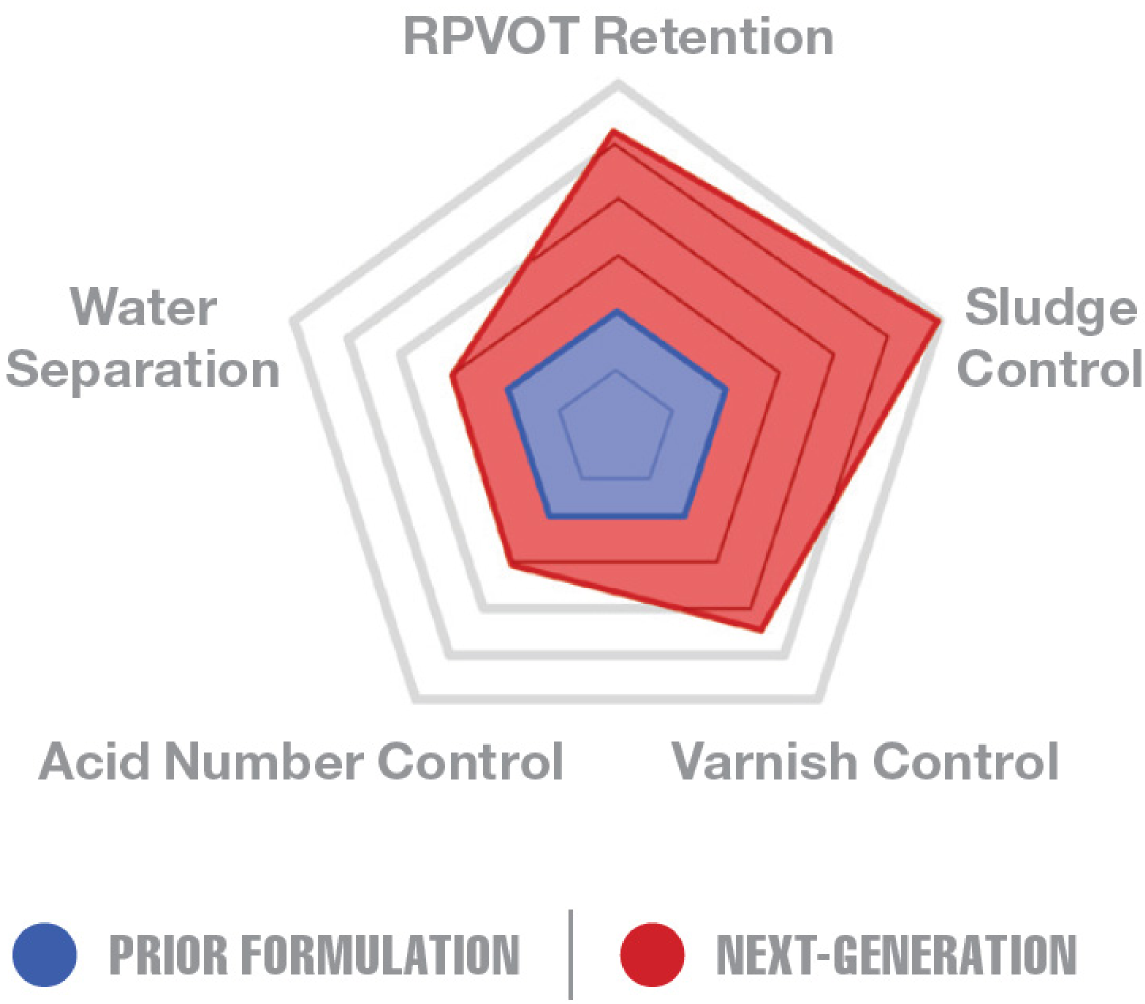
INDUSTRY SPECIFICATIONS

	Turbine Oil	Diamond Class® Turbine Oil	Diamond Class AW Turbine Oil
ABB G12106	♦	♦	♦
Alstom Power HTGD 90 117, Geared			♦
Alstom Power HTGD 90 117, Non-Geared	♦	♦	♦
ASTM D4304-06a, Type I	♦	♦	♦
ASTM D4304-06a, Type II			♦
ASTM D4304-06a, Type III	♦	♦	♦
British Standard 489	♦	♦	♦
Cincinnati Machine P-38 (HL-32)	♦	♦	♦
Cincinnati Machine P-54 (HL-68)	♦	♦	♦
Cincinnati Machine P-55 (HL-46)	♦	♦	♦
DIN 51515 Part 1, Type L-TD	♦	♦	♦
DIN 51515 Part 2, Type L-TG	♦	♦	♦
Elliott YR Turbines	♦	♦	♦
General Electric GEK 101941a			♦
General Electric GEK 107395a	♦	♦	♦
General Electric GEK 27070	♦	♦	♦
General Electric GEK 28143a	♦	♦	♦
General Electric GEK 32586h	♦	♦	♦
General Electric GEK 46506e	♦	♦	♦
ISO 8068, Type L-TGB		♦	
ISO 8068, Type L-TGSB		♦	
MHI MS04-MA-CL001	♦	♦	♦
MHI MS04-MA-CL002	♦	♦	♦
MHI MS04-MA-CL005	♦	♦	♦
Siemens TLV 9013 04	♦	♦	♦
Siemens TLV 9013 05	♦	♦	♦
Siemens Westinghouse 21T0591		♦	♦
Siemens Westinghouse 55125Z3	♦	♦	♦
Solar Turbines Es9-224, Rev. W, Class II			♦ (1)
U.S. MIL-PRF-176, Symbol 2075 T-H	♦	♦	♦
U.S. MIL-PRF-176, Symbol 2110 T-H	♦	♦	♦
U.S. MIL-PRF-176, Symbol 2135 T-H	♦	♦	♦
U.S. Steel 120	♦	♦	♦
U.S. Steel 125	♦	♦	♦
U.S. Steel 126	♦	♦	♦

Phillips 66 oils meet many industry standards.

Selection of a high-performance, long-life turbine oil can alleviate future problems in a turbine lubrication system. Phillips 66 has recently developed and released advanced next-generation turbine oil formulations. The next-generation turbine oils provide superior protection against sludge and varnish formation. Their excellent water-separating and inhibition properties provide outstanding protection against rust and corrosion while enabling easy removal of water from the system, a key catalyst in many negative chemical reactions that effect a turbine oil throughout its life cycle.

The good foam resistance and air release properties of Phillips 66 turbine oils help maintain lubricity of the oil and reduce air entrainment. Reduced air entrainment reduces the oil's exposure to oxygen and reduces the potential for thermal break down and varnish formation. Since Phillips 66 turbine oils have low carbon-forming tendencies, they also perform effectively in air compressors such as the atomizing air compressors used in gas turbines to increase the combustion efficiency.

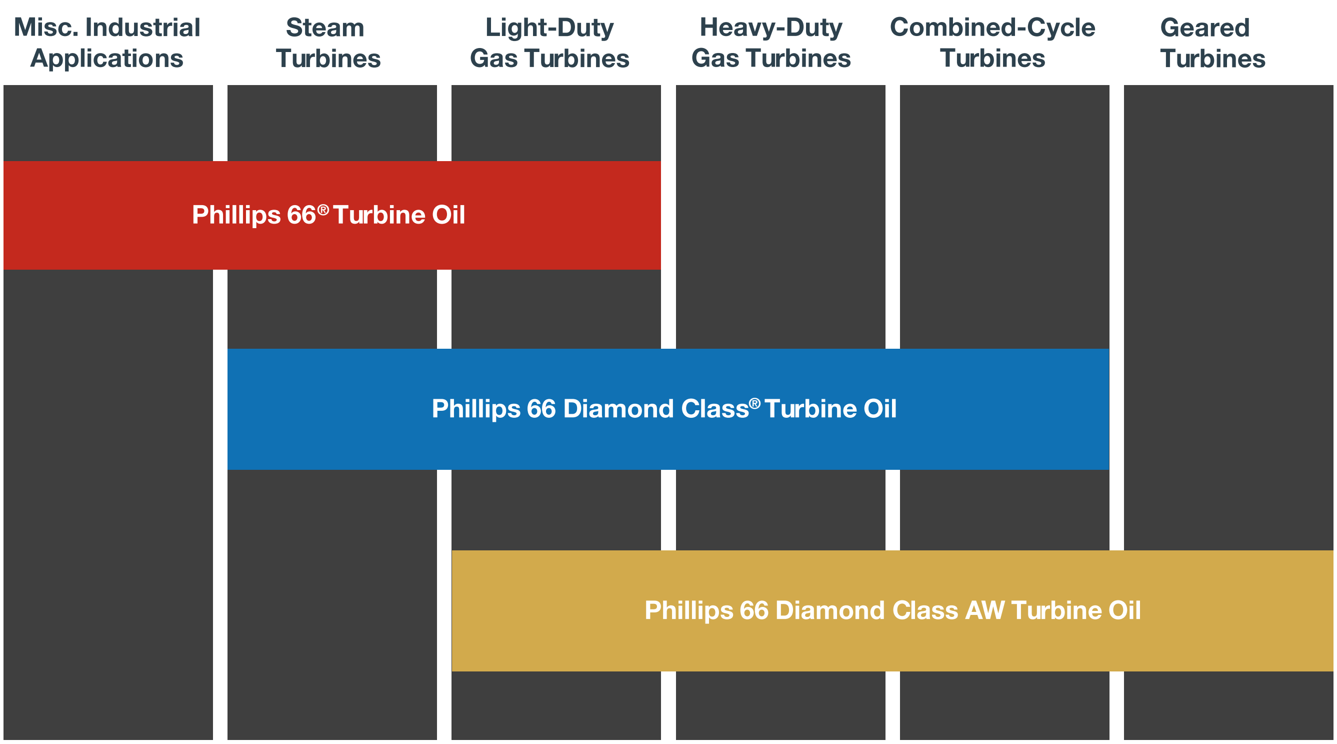


Next-generation turbine oils provide superior performance and life through advanced lubricant formulation including the use of excellent base stock and careful balanced mixture of additives. Source: Phillips 66

Phillips 66 turbine oils are available in ISO Grades 32, 46, 68 and 100. Phillips 66 provides several variations of turbine oils with formulations tailored to enhance certain properties required to improve performance in specific applications:

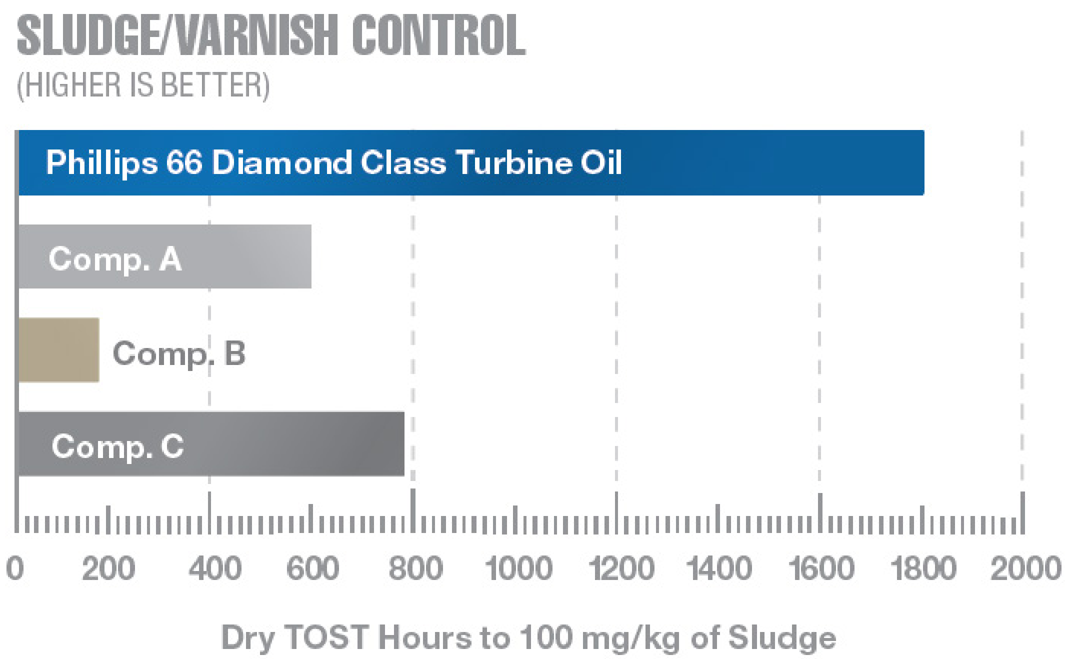
- Phillips 66 Turbine Oil
- Phillips 66 Diamond Class® Turbine Oil
- Phillips 66 Diamond Class® AW Turbine Oil
- Phillips 66 Ultra-Clean Turbine Oil
- Phillips 66 Syncon Turbine Oil
- Phillips 66 Syndustrial Turbine Oil

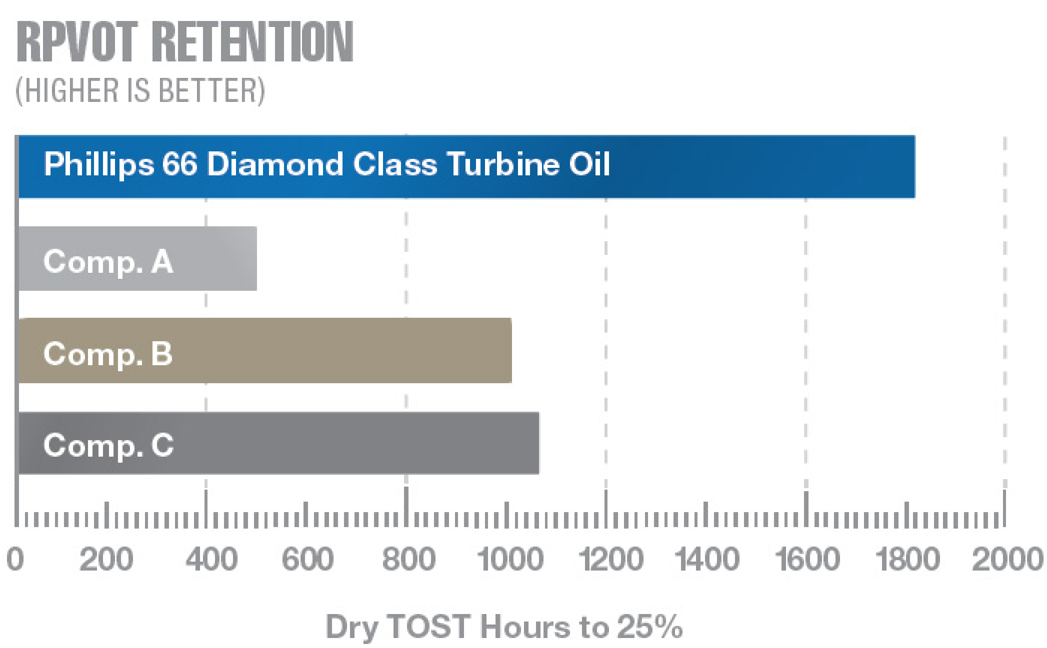
Phillips 66 Diamond Class® turbine oils significantly improved RPVOT retention and sludge and varnish control compared to standard Phillips 66 turbine oils. Diamond Class® turbine oils are filtered at the plant to ensure particle cleanliness levels to an ISO Cleanliness Code of 18/16/13. The Diamond Class® turbine oil formulation utilizes premium hydrocracked base oils combined with state-of-the-art proprietary additive systems. The combination provides outstanding oxidation resistance and deposit control, which assure long service life and significant cost savings to power generation customers by minimizing the formation of harmful sludge and varnish deposits. Diamond Class® turbine oils are especially useful in preventing varnish buildup in servo valves and IGV valves where oil flow rates are low and frequent heating and cooling cycles promote varnish film deposition in peaking gas turbines. Phillips 66 Diamond Class® AW turbine oils have enhanced anti-wear properties for use in geared and direct-drive gas turbines and steam turbines in severe service.



Applications suitable for various Phillip 66 turbine oil formulations. Source: Phillips 66

Phillips 66 Syncon turbine oil uses synthetic base oil to provide outstanding oxidation resistance and thermal stability at high temperatures experienced in land-based gas turbines. A polyalphaolefin (PAO)-based turbine oil also provides excellent low-temperature fluidity, low pour point and a high viscosity index, which permits use over a wider temperature range. Phillips 66 Syndustrial turbine oils are based on synthetic polyol ester base oil to provide oxidation resistance and thermal stability at extreme temperatures experienced in aero-derivative gas turbines. Phillips 66 Syndustrial turbine oil also has excellent low-temperature fluidity, high load-carrying capacity and a natural detergent ability. The high flash point of Phillips 66 Syndustrial turbine oil can reduce explosion hazards compared to conventional oils. Phillips 66 synthetic turbine oils also provide superior protection against rust and oxidation.

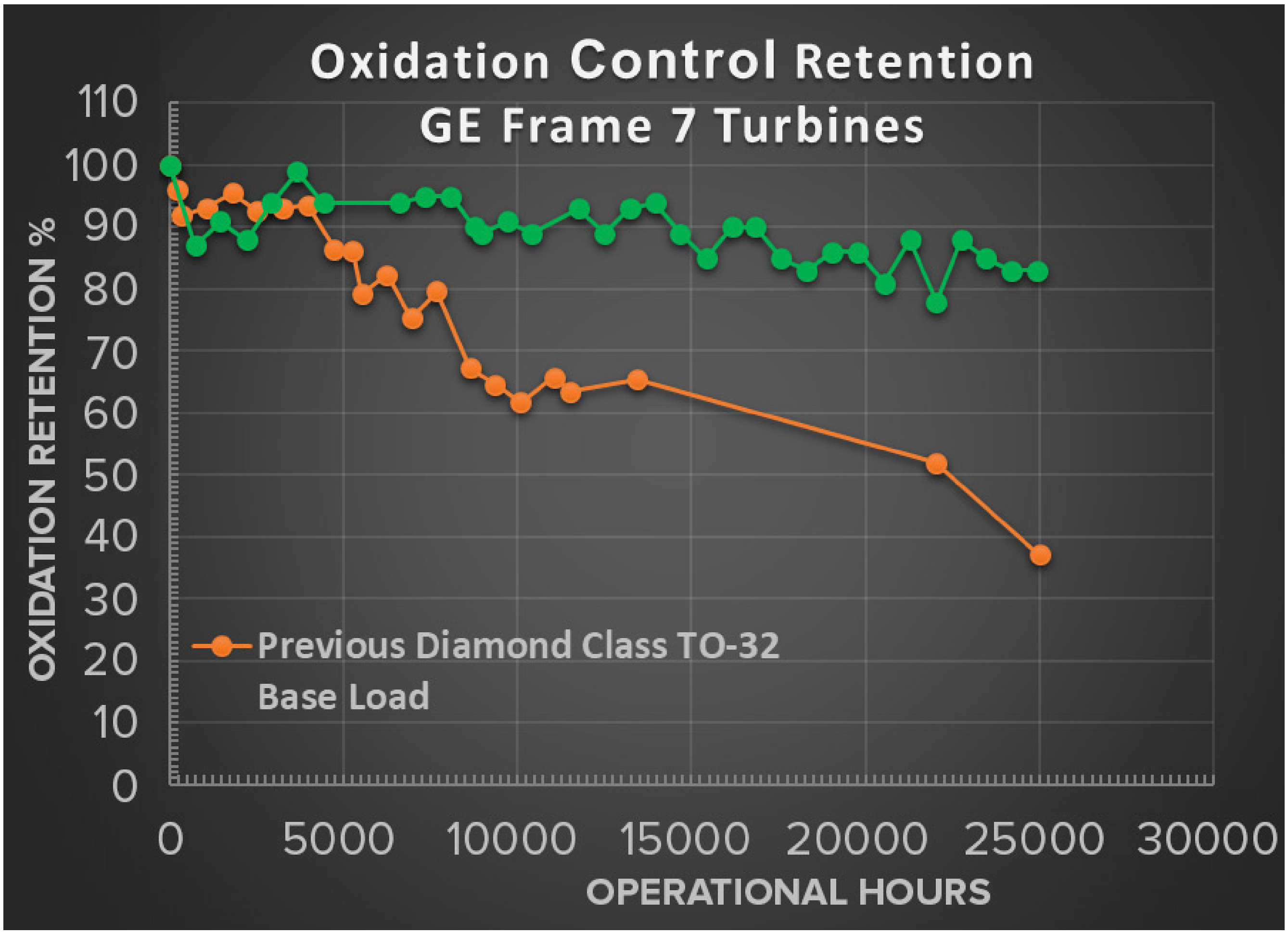




P66 turbine outperforms leading competitors in RPVOT retention and sludge and varnish control. Source: Phillips 66

Phillips 66 has released next-generation versions of their standard and Diamond Class® turbine oils, which provide further improvements in sludge and varnish control, RPVOT retention, water separability and acid number control. Phillips 66 next-gen turbine oils outperform competitor turbine lubricants in several laboratory tests.

The field testing, in a GE Frame 7 gas turbine, of next-gen Phillips 66 Diamond Class® turbine oil have been phenomenal. RPVOT results continue to trend flat through the first several years of this ongoing field trial. Phillips 66's advanced turbine oil formulation maintained very favorable varnish potential levels based on MPC tests of used oil samples.



Field tests results for the GS Frame 7 turbine. Source: Phillips 66

NEXT STEPS FOR IMPROVING TURBINE OPERATION

Turbine oils in today's advanced turbines operate under the most severe conditions. Turbine oils must be resistant to oxidation, thermal degradation, varnish formation and additive depletion to provide extended life and lubrication performance. In addition, proper system maintenance, condition monitoring, oil analysis and contaminant exclusion are required to fully realize the benefits of these advanced oil formulations and maximize turbine oil operating life.

Turbine technologies are facing increasing demands and challenging conditions, and the Phillips 66 Turbine Oils homepage provides key information on P66's turbine oil products and advancements.

Phillips 66 next-generation turbine oils address industry-wide challenges with superior RPVOT retention and unmatched varnish and sludge control. Give turbines what they need with Phillips 66's premier power generation turbine oils. Get in touch with one of Phillips 66's technical experts to find out how to evaluate Phillips 66 turbine oils in any application to optimize turbine efficiency and power generation reliability.