Turbine Oil: Care and Selection Criteria

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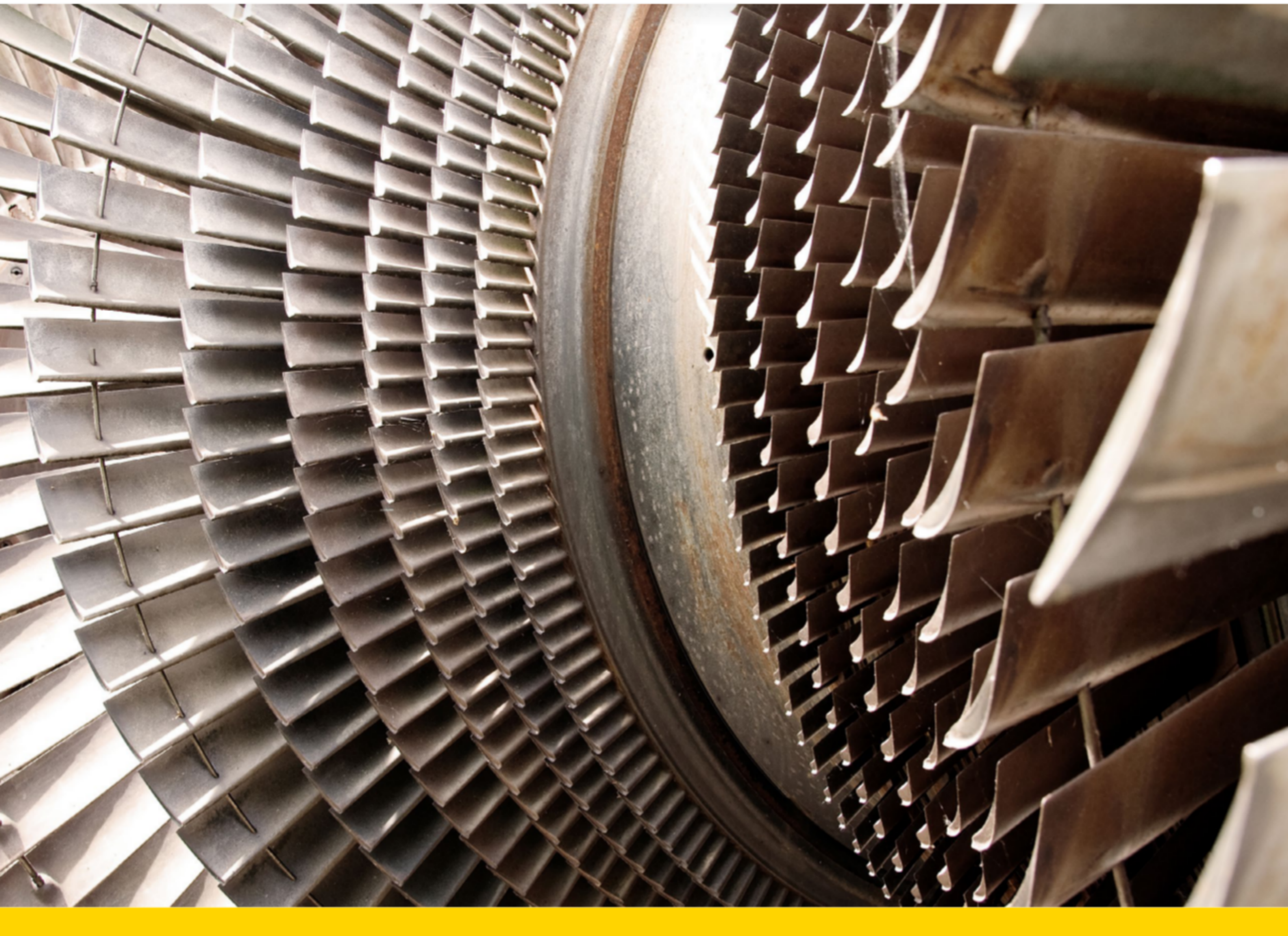


The reliability of turbines is pivotal to the success of power generation facilities — a problem with the main turbine can cause outages and production delays. A study performed by General Electric revealed that about 20 percent of forced outages in power plants could be attributed to turbines, and 19 percent of these issues were connected to the lubricating oil system.

Because the continued operation of turbines relies on the performance of turbine oil, it is important to select the right turbine oils and monitor them closely for signs of degradation.

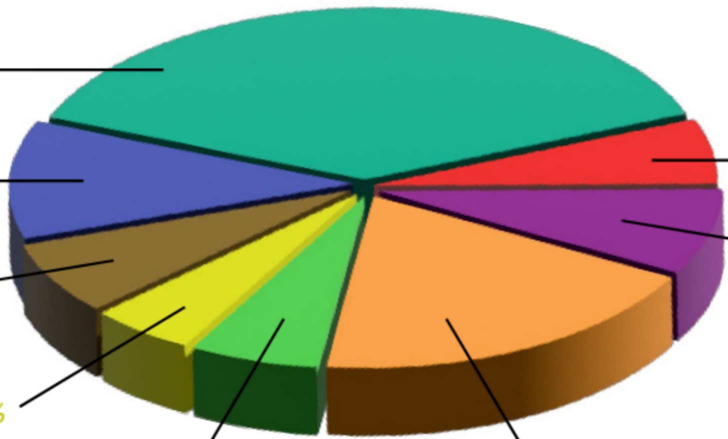


Figure 1. Contributors to Costly Forced Outage

Turbine Oils

Turbine lubricants are formulated for specific purposes, and different turbines oils have different properties, making them suited for specific applications (gas combustion turbines, steam turbines, combined cycle turbines, etc.).

Turbine oils are comprised of a base oil and an additive package, but the chemical and physical characteristics are different than other lubricating oils. Specifically, turbine oils are considered Rust & Oxidation inhibiting (R&O) oils, and high-quality turbine oils, like the Shell Turbo line of lubricants, are designed to limit machine downtime during continuous operation.

Sludge and Varnish

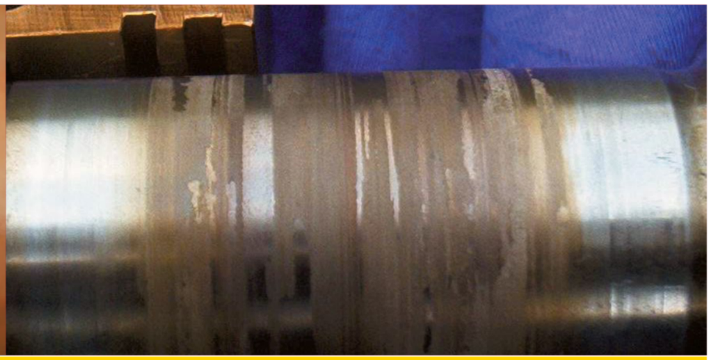
Sludge and varnish are products of oil degradation. When initially formed, these products exist in the oil in a dissolved state. The oil can only hold so much of the dissolved sludge and varnish; once the oil's holding capacity (saturation point) has been reached, the excess contaminants become insoluble degradation products. These products then begin to build up on machine surfaces, either in the location the degradation occurred or somewhere else in the machine, carried by lubricant.

These contaminant deposits will take different forms, depending on where the deposit build-up occurs; deposits in cooler areas may possess a soft or gummy structure while deposits in hotter areas can thermally cure, forming an enamel-like coating on the machine surface.

These deposits become a problem when they form on sensitive machine surfaces and restrict mechanical movement or the flowing of oil.

Common examples of sludge and varnish formation in turbine oil systems:

Traits	Location
Black, crusty deposits	Mechanical seals
Gooey-brown accumulations	Oil filters
Gold, adherent films	Valves
Carbonaceous residue	Mechanical surfaces
Charcoal-like deposits	Babbitt sleeve bearings
Black, scabby deposits	Mechanical seal surfaces; Thrust-bearing pads



Common examples of sludge and varnish-induced failures:

- ✓ Plugged orifices
- ✓ Plugged discharge ports
- ✓ Prematurely plugged oil filters
- ✓ Jour-bearing wear
- ✓ Silt-locked valves
- ✓ Impared oil cooler performance
- ✓ Damage to mechanical seals

Turbine Oil Degradation Methods

Bulk Oil Oxidation

Oxidation degrades oil over time and ultimately cannot be stopped; it can be delayed, however, by using lubricants with the right additive package. Other factors also influence the rate of oxidation, including:

- **Elevated temperatures**
  The Arrhenius Rate rule states that, for every 10 C (18 F) increase in operating temperature, the rate of oxidation doubles.

- **Oxygen**
  When air is allowed to enter an oil, separated oxygen atoms can bond with unsaturated hydrocarbon, producing acids that lead to oxidation.

- **Water**
  While water contains oxygen, the real danger lies in water's ability to degrade oxidation-fighting additives.

- **Wear Metals**
  Reactions of the ions in metals like copper and cobalt can accelerate the oxidation process. This process can then spiral: wear metals cause oxidation, which in turn generates more wear metal particles.

Thermal and Compressive Degradation

Adiabatic compressions, a catalyst of thermal degradation, can be caused by air bubbles entrained in the oil, or when the oil contacts a hot surface, typically 200 C (400 F) or hotter (such temperatures can be reached due to steam, gas combustion, highly loaded frictional surfaces, etc.).

Electrostatic Discharge

In oil systems, electrostatic discharge is caused by internal molecular friction and electric potential between the lubricating fluid and the machine's surfaces. These electrical charges build up in areas such as reservoirs and then discharge, leading to localized thermal-oxidative degradation.

Essential Turbine Oil Properties

There are some properties that every high-quality turbine oil should possess, regardless of the environment in which the oil will be used. As discussed, many of the problems associated with turbine oil degradation can be traced to oxidation. Oxidative stability, then, is one of the primary properties to look for in a turbine oil.

It is also essential to use a turbine oil made with a quality base stock — a base stock with low levels of sulfur, nitrogen, and aromatics and a high level of saturates. A good base stock provides longevity, both to the machine and the lubricating oil, and when combined with extensively tested and properly blended additives, will optimize machine operations.

It is also essential for turbine oil to have excellent property retention. A good additive package and a quality base oil mean nothing if the oil fails prematurely. A high-quality turbine oil will retain its properties throughout its operational life.

Shell Turbo S4 Oils

The designers of Shell Turbo S4 Oils started with a GTO-based oil and built a proprietary additive package into it. Shell Turbo S4 Oils minimizes deposit formation in real-world applications, while lower quality oils present problems like increased deposits, foaming, less air release, and reduced reliability.

In a newly developed ASTM Turbine-oil Oxidation Stability Test (TOST), designed to quickly produce varnish and deposits like those that would be experienced in a turbine, the Shell Turbo SF Oils outperformed the competitors, showing very little varnish and deposit formation over the course of the test.

Evaluating Turbine Oil Performance

Turbine oils are expected to last a long time. For this to happen, though, the physical and chemical properties of the oil must be carefully monitored, as well as the presence of contamination. ASTM D4378-97 “Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam and Gas Turbines” is one of the primary testing methods used for this purpose, but it is far from the only method. Other evaluations include:

Viscosity Testing

Viscosity is especially important in lubricating oils and determines oil film thickness. Turbine oil viscosity directly impacts blade clearances, which are critical to the success of power-generating operations. Changes in turbine oil viscosity can lead to two types of unwanted rotor movement:

Axial movement — Can hinder turbine blade efficiency and cause blade damage.

Radial movement — Can cause rotor whip, where the rotor does not settle into one radial position.

Barring heavy contamination or oxidation, the viscosity of in-service turbine oil should remain constant through years of use; a five percent change in an oil's viscosity is a warning limit according to ASTM D4378-97. Because it is essential to continued machine operation, oil viscosity should be tested quarterly at a minimum. Changes in oil viscosity by temperature must also be accounted for and are indicated by the oil's Viscosity Index (VI).

Oxidation Testing

The loss of oxidation resistance of in-service turbine oils can be monitored using the Rotating Pressure Vessel Oxidation Test (RPVOT). For this monitoring method to be effective, new oil will have to be tested, setting a standard RPVOT value that will act as a baseline. Future tests will be compared to the initial test, with ASTM D4378-97 setting an RPVOT value drop to 25 percent of the baseline value (concurrent with an increase in Acid Number) as a warning limit.

Testing for Water

Because it is a precursor to oxidation and rust, oil should be carefully monitored for the presence of water. The coulometric Karl Fischer Titration method (ASTM D6304) is widely used and identifies the presence and amount of water in an oil. The ASTM D4378-97 warning level for water in mineral oil is 1000 ppm or 0.1 percent. For PAG base oils, which are synthesized from ethylene oxide and/or propylene oxide building blocks, are more polar in nature than mineral oils. As a result PAGs can tolerate higher levels of water compared to mineral oils. For example, GE provides specific guidance in GEK32568 N where 7500 ppm of water is the maximum acceptable value for PAG turbine oil.

Acid Number Testing

An oil's acid number should be regularly monitored, as a spike in the number can be indicative of contamination or heavy oxidation. Testing should be conducted quarterly at a minimum, using the potentiometric titration method (ASTM D664), and, as with other tests, a baseline must be set by testing the oil when new. This initial acid number will vary between different types of oil.

For in-service turbine oils, warning limits are usually set at 0.1-0.2 milligrams of potassium hydroxide per gram (mg KOH/g). An increase of 0.3-0.4 percent above the baseline acid number indicates that the oil is nearing the end of its operational life. Even small increases in an oil's acid number can indicate problems, and such test results should prompt investigation and an increase in the frequency of oil sampling.

Testing for Rust

Rust testing should be performed at least annually or whenever the oil system is exposed to water. ASTM D665 A tests using distilled water, and a "light fail" is seen by ASTM D4378-97 as a warning limit.

Turbine Oil Cleanliness: Sampling and Levels

Clean oil is especially important in turbine operations due to turbine journal bearing clearances (10-20 microns) and servovalve clearances (3-5 microns). These tight clearances mean that if oil cleanliness is not maintained, excessive bearing wear can occur, and servovalves can stick.

Particle counting is used to determine the amount and size of particle contaminants in oil, but for this testing to be accurate, certain procedures must be followed. Firstly, the way in which the oil sample is retrieved from the machine presents many opportunities for sample contamination. Sampling tools and containers must be cleaned prior to use, and efforts must be taken to reduce the possibility of contaminating ingression once the oil is removed from the machine.

For a sample to be representative of the machine's conditions, it must be taken from the right location. Samples taken from the sump or reservoir, for example, will likely produce inconsistent results that are not representative of the total oil's cleanliness level. Ideally, samples will be taken from return lines or turbulent areas, such as bends in lubricant piping.

Wear Debris

Part of the battle against contamination is determining its source; this is especially true when measuring and analyzing wear debris. Creating a metallurgic map of the equipment (including the composition of each lubricated component) can make pinpointing wear debris sources easier. Because oil is typically flowing throughout the entire system, oil sampling location is again important in ensuring an accurate sample.

Cleanliness Levels

Turbine oil cleanliness levels are typically set using the ISO 4406:99 cleanliness code. OEM cleanliness recommendations for turbine oil vary, with some setting limits as high as 16/13 and others requiring cleanliness levels of 14/11. Achieving cleanliness levels lower than those set as limits can significantly improve equipment reliability and lifespan.

Responding to Contamination

To mitigate the harmful effects of these contaminants, appropriate contamination exclusion and removal practices are needed. Contamination exclusion is the practice of keeping contaminants out of lubricants and machines with the help of desiccant breathers on vents, appropriate seals, and good maintenance practices.

Externally Ingested

Contaminants can enter a system due to poor seal design, worn seal materials, and operational or environmental conditions. Failed shaft seal points may ingress external contaminants or internal process materials.

Any breathable headspace point also provides an opportunity for road dust, soil, rock dust, moisture or other contaminants to enter the system. Even when a machine is equipped with an appropriate breather, if there are gaps in the hatches, ports, etc., air is more likely to be “breathed” in within these areas of least resistance. Doing your best to protect lubricants from contaminant ingression in storage and while they are in service is always a good idea because the cost of excluding contaminants with the help of hardware like desiccant breathers is much less expensive than removing those

Typical Contaminants

Dirt

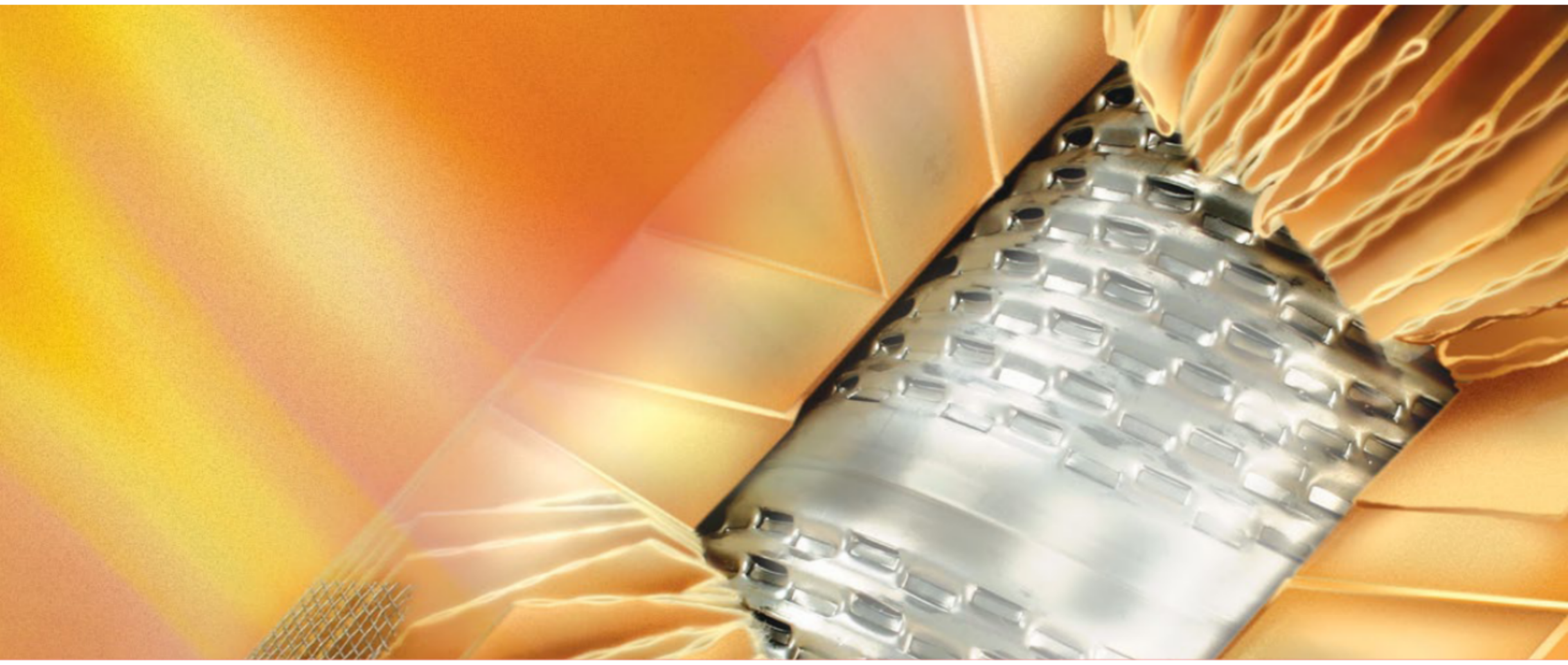
Dust and solid contaminants creep in from the surrounding atmosphere. Contaminants could include metal chips from machining, rust and wear products from seals, bearings and gears, and core sand from castings, among many others.

Water

The most troublesome sources vary depending on the application and environment, but condensation, cooler leaks, gland leakage and seal leakage are all common culprits. In steam turbine applications, water making its way through labyrinth seals is a major concern. Any free moisture may promote both rust and sludge by reacting with oil additives and metal surfaces.

Sludge

Sludge or varnish can begin to form, usually as a result of oil oxidation. High temperatures, particle contamination, or water in turbine oil all tend to accelerate oil oxidation, leading to further problems with varnish and silt causing increased friction, wear, and problems with sensitive valves.



same contaminants once they have already made their way into the machine. But still, both exclusion of contaminants and removal of contaminants through filtration, dehydration and other means is needed in most all applications, especially larger turbine oil systems where it is difficult to completely eliminate contamination ingression points.

Internally Generated

If left to oxidize or thermally degrade and used over an extended time period, a lubricant's constituents can turn into abrasive contaminants. This can result in oxidation insolubles, sludge, additive fallout, and other problems. Rust is a symptomatic contaminant from the ingression of water. It can cause iron to corrode and form red-iron oxides. Soot is a fine carbon insoluble that frequently is generated from the thermal breakdown of hydrocarbons. Fibers from seals, hoses, filters or other materials can also leave contaminants to invade the system. Additionally, friction can lead to particles forming as a result of adhesive, abrasive or fatigue wear.

Human-Introduced

When oil is added to a system, it is often dirtier than many maintenance professionals might expect. Even "new" oil and can bring a variety of potential contaminants if it is not stored properly after arriving onsite. Storing lubricants in a specific room that is kept clean, cool, and dry helps lubricants to perform better, last longer, and ultimately extend the service life of machines by keeping lubricants cleaner from the beginning.

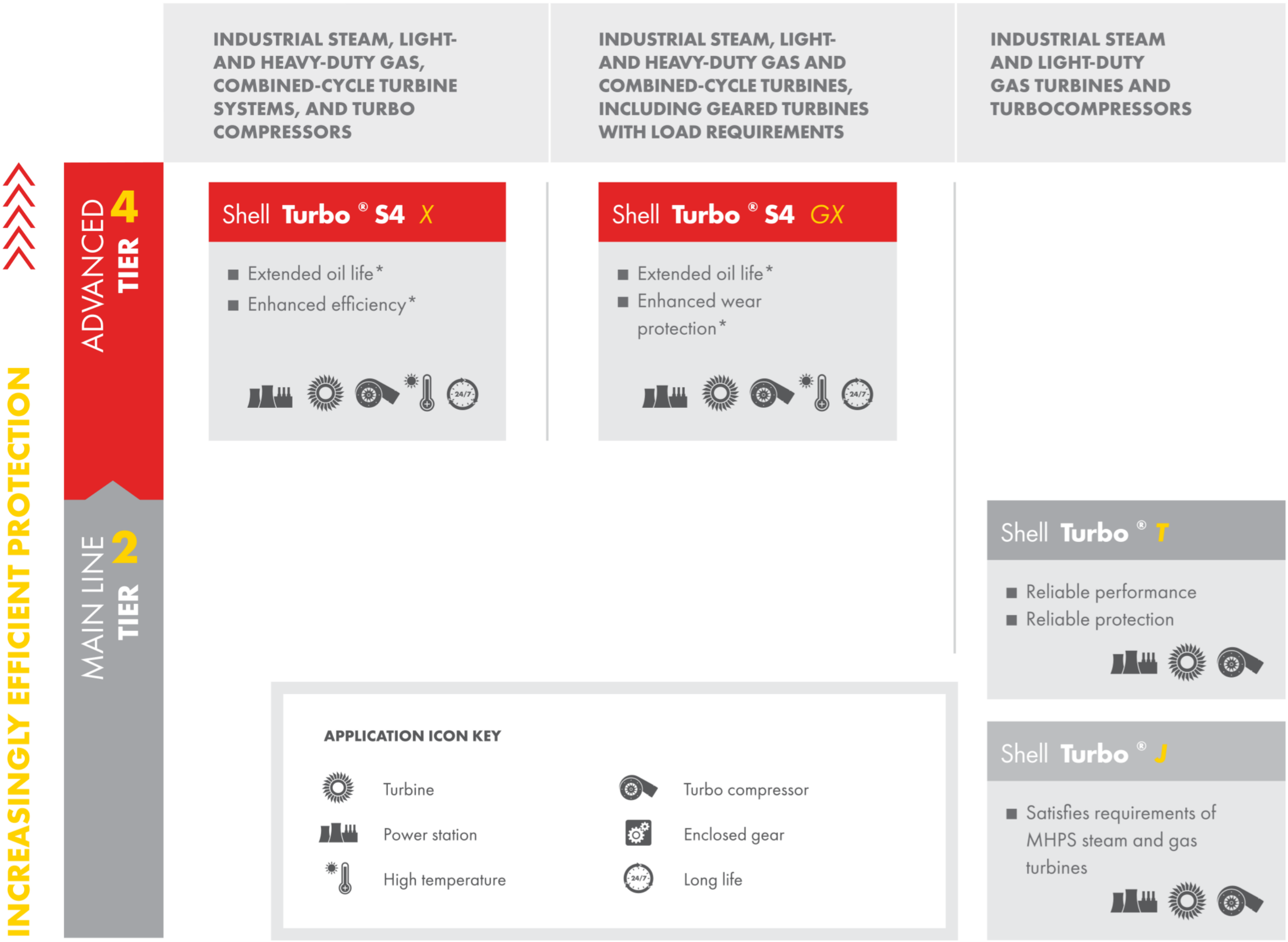
Human error can also cause problems when machines require internal work, such as to replace bearings and seals. During these work procedures, the fluid reservoir may be exposed to open air for some time. Even the work itself may introduce machining swarf, welding spatter and sealants or adhesive materials that impact the performance of the lubricant or cause accelerated wear in machine assets. In some cases, major repairs might require oil flushing services to clean out dangerous contaminants before attempting startup.

Conclusion

There are many factors that impact turbine oil performance and service life. Contamination, human error, or incorrect oil selection can all play a role, but often the root of the problem is a lack of knowledge. When we have the knowledge to care for our turbine oil properly, it becomes a reliability asset. When we do not, turbine oil varnish problems or rapid oxidation could be a chronic source of frustration, confusion, and costs. If you are responsible for maintaining turbine systems, be sure your lubricant supplier not only your needs, but your reliability goals as well. Choosing the right turbine oil for the application and putting a few best practices in place for proper storage and contamination control can unlock major savings. With these practices, more plants can reduce downtime, decrease oil consumption, and increase the service life of seals and other components.

A RANGE OF TURBINE OILS TO MEET YOUR NEEDS

To meet the challenges of a wide range of equipment designs and applications, Shell has designed a portfolio of oils that enables you to choose a product to match your technical and operational needs.



*Compared with market representative products

Learn more about Shell Turbo and related products at shell.us or shell.com.