TACKLING VARNISH FORMATION IN TURBOMACHINERY

MAXIMISE TURBINE AND COMPRESSOR AVAILABILITY

WHITE PAPER

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SHELL LUBRICANTS
TOGETHER ANYTHING IS POSSIBLE

Turbomachinery operators in the power generation, oil, gas and petrochemical industries are seeking ways to reduce their total cost of ownership and maintenance costs by maximising asset availability and reliability.

In addition, driven by the goals of reducing emissions and improving efficiency in the power generation sector, many older coal-fired power plants are being retired and replaced with higher-efficiency, lower-emission, combined-cycle and gas turbine power plants. Such generating capacity is more commonly being used in peaking or cycling duty rather than base-load generation, which is because the increased thermal cycling of the oil and the reduced oil flows and low-temperature conditions in key components such as inlet guide vanes lead to a higher incidence of varnish formation.

To achieve higher operating efficiencies, equipment designs are changing. For example, turbines operate at higher temperatures and have a smaller footprint and lower-volume lubricant oil reservoirs. Meanwhile, operators are seeking longer oil and asset life with less downtime. However, these operating and equipment design changes place additional oxidative and thermal stress on turbine oil that can result in premature ageing and degradation. The formation of oil-soluble and oil-insoluble degradation products, also referred to as varnish or deposits, can lead to operational problems and associated unplanned downtime.

UNDERSTANDING AND CONTROLLING THE RATE AT WHICH TURBINE OILS DEGRADE AND DEALING WITH THE BY-PRODUCTS FORMED ARE VITAL FOR MAXIMISING TURBOMACHINERY AVAILABILITY.

WHAT IS VARNISH?

All turbine oils, whether mineral or synthetic based, are composed of hydrocarbons that degrade over time. Understanding and controlling the rate at which these oils degrade and dealing with the by-products formed are vital for maximising turbomachinery availability. Shell scientists have this in mind when formulating turbine oils to provide increased resistance to the formation of varnish in service. Shell field-based technical staff also understand these oil degradation pathways when they work with operators on product selection, application and ongoing monitoring.

As turbine oils degrade in response to the effects of high, and in many cases variable, temperatures and/or loads, and external and internally generated contaminants and wear debris, a diverse range of organic hydrocarbon species may form. These hydrocarbon species originate from degraded base oil or additives such as antioxidants and will initially be soluble in the oil, for example, they may contribute to an increase in total acid number (TAN). Over time, however, they develop into insoluble, polar compounds that then precipitate out on surfaces such as journal and thrust bearings, servo valves, filters and auxiliary gear sets, or in the lubricant oil reservoir as varnish or deposits (Figure 1). The resultant varnish can disrupt heat transfer and thus lead to increased bearing temperatures, less-responsive servo valves, for example, inlet guide vane valves, and plugged filters, which can cause unplanned downtime and lower productivity.

Temperature plays a significant role. As the operating temperature increases, it raises the rate of oxidation and thermal degradation of the turbine oil, which means that sludge and varnish form more rapidly at higher temperatures. As a general rule of thumb, the Arrhenius rate law states that for every 10°C increase in temperature, the oxidation rate doubles.

Further, the solubility of the oxidation and varnish precursors in the oil is also temperature dependent. Some oil degradation species may be soluble in the oil at above 55°C, yet insoluble at lower temperatures and fall out of solution. Consider the analogy of dissolving sugar in a hot cup of coffee: while the coffee is hot, you can dissolve more and more sugar until it reaches a certain point (becomes saturated) and the temperature falls, then the sugar drops to the bottom of the cup.

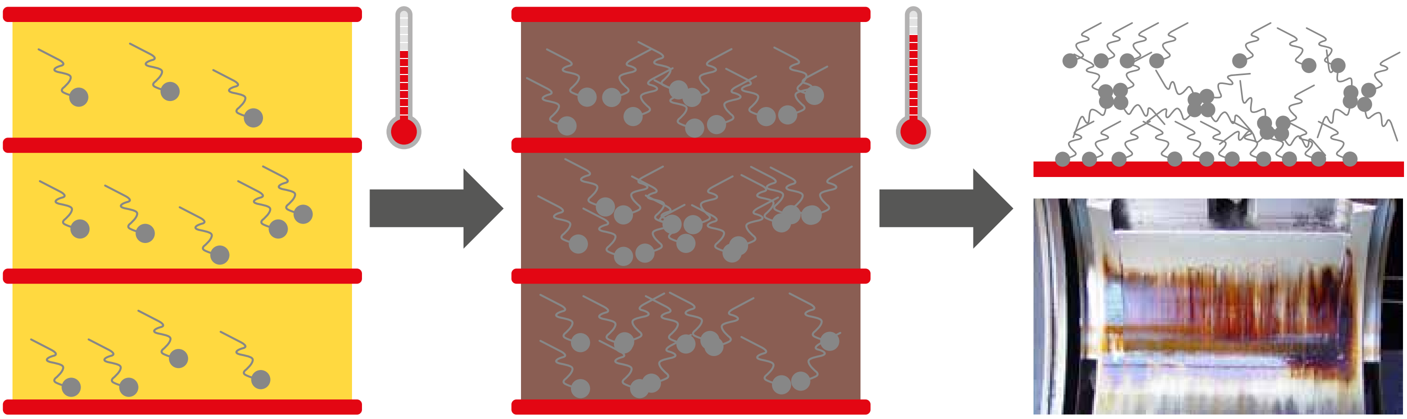


Figure 1: Progressive oxidative degradation.

THE INDUSTRY CONTINUES TO DEVELOP TEST PROCEDURES THAT SIMULATE BETTER THE PROPENSITY OF AN OIL TO FORM VARNISH IN SERVICE.

VARNISH FORMATION DRIVING MORE-DEMANDING SPECIFICATIONS

The topic of varnish and deposit formation in turbine oils, and indeed other lubricants, is not new and, as the design and ways of operating turbomachinery change, these oils face increasing levels of stress that can lead to the earlier-than-expected onset of varnish formation. In response, equipment manufacturers have developed more-stringent lubricant specifications and monitoring practices.

The industry continues to develop test procedures that simulate better the propensity of an oil to form varnish in service. Several service bulletins on this topic have been released, including

- GE Power: Lube oil varnishing (Technical Information Letter TIL 1528-3, November 2005)
- Siemens: Proactive turbine oil condition monitoring and varnish prevention (E50001-D510-A209-X-7600, 2011)
- MAN Diesel & Turbo: Turbine oils: Tendencies to form deposits and varnishing as well as resulting recommendations and measures (TMC 15-4338).

GE Power stated in TIL 1528-3 that as many as 33% of the (then installed) F-class turbine fleet show some signs of oil varnishing.

Table 1 provides a summary of some recent advances in turbine oil specifications from industry bodies and leading equipment manufacturers in response to issues with varnish formation and reduced oil service life.

Test procedures such as the turbine oil oxidation stability test (TOST) life test (ASTM D943) and rotating pressure vessel oxidation test (RPVOT, ASTM D 2272) provide an indication of a turbine oil's oxidation resistance. However, they do not address the oil's propensity to form varnish. As a result, more demanding tests such as the dry TOST test (ASTM D7873), the MAN Turbo & Diesel lubricant temperature ageing test and the Engie (Laborelec) cyclic turbine oil oxidation test are now being used to validate and approve lubricants, and to differentiate turbine oil performance.

OEM	SPECIFICATION	HIGHER PERFORMANCE SPECIFICATION
Siemens	TLV 901304 – Turbine oils with normal thermal stability	TLV 901305 – Turbine oils with higher thermal stability RPVOT added
GE Power	GEK 28143A – Recommendations for gas turbines	GEK 32568K – Gas turbines with high bearing ambient Increased RPVOT; TOST life increased
Mitsubishi Hitachi Power Systems	MS04-MA-CL002 – Lubricating oil recommendations for high temperature turbine application with bearing ambients above 250°C	MS04-MA-CL005 – Lubricating oil recommendations for high temperature turbine application with bearing ambients above 250°C (long life type) Increased RPVOT and TOST life; stricter dry TOST requirements
MAN Turbo & Diesel	TED 10000494596 – Quality requirements for lubricants	TED 10000494596 – Quality requirements for lubricants Increased RPVOT and TOST life; MAN LTAT stability test
DIN	DIN 51515-1 – Lubricants and governor fluids for turbines – Part 1: L-TD for normal service	DIN 51515-2 – Lubricants and governor fluids for turbines – Part 2: L-TG for higher temperature service Increased TOST Life; RPVOT

Table 1: Recent advances in turbine oil specifications from industry bodies and leading equipment manufacturers.

CONTINUOUS INNOVATION IN LUBRICANT TECHNOLOGY TO ADDRESS TURBINE OIL VARNISH

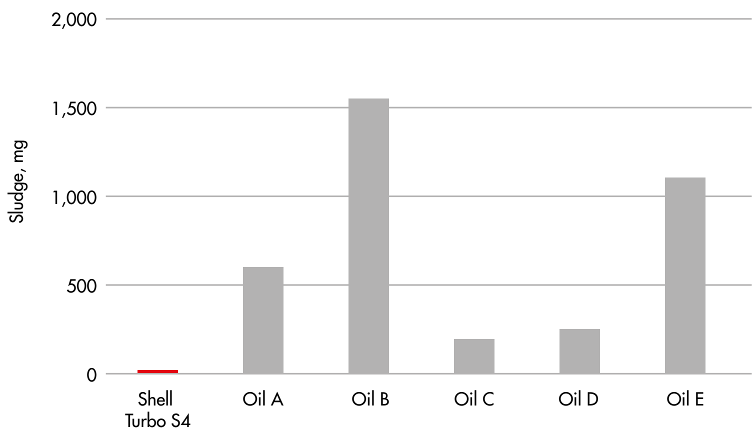
Shell's scientists have worked with leading turbine manufacturers and end-users over many years to understand the contributing factors to turbine oil varnish formation. The Shell Turbo oil family has been developed using this understanding to create a range of products that provide protection and performance that match customers' requirements. Shell Turbo T and Shell Turbo J oils demonstrate reliable performance in the areas of oxidation and thermal stability with their long TOST lives, high RPVOT values and low varnish forming potential. As a result, these products offer a level of performance and protection that gives customers peace of mind.

Further improvements in performance have been achieved with the introduction of the advanced Shell Turbo S4 X and Shell Turbo S4 GX turbine oil technology. These grades use Shell gas-to-liquids Group III base oils in combination with a specially developed additive system designed to extend oil life, reduce varnish and protect components. Tests in the laboratory and in the field have shown that these products have a high resistance to oxidation and thermal breakdown to minimise the formation of sludge and varnish on critical turbine surfaces. Figure 2 shows that Shell Turbo S4 X and Shell Turbo S4 GX oils, while also possessing excellent RPVOT and TOST life values, have significantly lower varnish formation potential than other commercially available turbine oils of similar equipment manufacturers' specification levels.

Consequently, Shell Turbo S4 X 32 and Shell Turbo S4 GX 32 oils have been classified as low varnishing type turbine oils by GE Oil & Gas in its latest specifications that cover turbine oils for turbomachinery, including gas and steam turbines, electric motors, generators and axial and centrifugal compressors. Oils classified as low varnishing type oils demonstrate the lowest tendency to form varnish and the highest performance in terms of oxidation and thermal stability. Shell Turbo S4 X and Shell Turbo S4 GX have also been approved by MAN Turbo & Diesel, and Shell Turbo S4 X 32 has been approved by Mitsubishi Hitachi Power Systems as a long-life oil.

Selecting an oil with lower varnish forming tendency such as Shell Turbo S4 X and Shell Turbo S4 GX at the outset of a project **can help to reduce the possibility of varnish-related trips and outages and production deferment costs.**

MAN LTAT oxidation test (beaker test) at 180°C



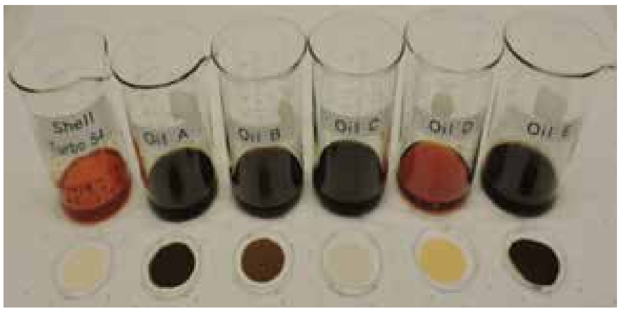


Figure 2: The varnish formation potential of commercially available turbine oils of similar equipment manufacturers' specification levels.

SEVERAL VARNISH REMOVAL TECHNOLOGIES HAVE DEMONSTRATED THEIR ABILITY TO CONTROL THE RATE OF VARNISH FORMATION, INCLUDING ELECTROPHYSICAL SEPARATION, ELECTROSTATIC TECHNOLOGY, BALANCED CHARGE AGGLOMERATION AND DEPTH FILTRATION.

IN-SERVICE STRATEGIES TO MINIMISE THE IMPACT OF VARNISH

In addition to selecting a low varnishing potential oil such as Shell Turbo S4 X or Shell Turbo S4 GX, a series of preventive maintenance measures can be employed to mitigate further against the risks of varnish formation. One of the most effective is a detailed oil condition monitoring programme such as the **Shell LubeAnalyst advanced turbine oil monitoring service** to determine the condition of the oil and the equipment. This service enables operators to understand the condition of their oil in terms of

- acid number formation by TAN
- antioxidant reserves using techniques such as RULER or RPVOT
- varnish formation potential by membrane patch colorimetry (MPC)
- the presence of external contaminants or wear particles by inductively coupled plasma optical emission spectrometry
- cleanliness
- other key properties, including foaming tendency, air release and water shedding characteristics.

It is important for operators to understand what information each of these tests provides and the necessary actions in response to any alarms flagged by looking at the entire dataset and trends over time. Shell LubeAnalyst limits have been aligned with the requirements from leading equipment manufacturers. Shell's technical specialists can provide the necessary guidance to operators on how to design and implement an effective turbine oil monitoring programme though the **Shell LubeCoach** and **Shell LubeAdvisor** value-adding services.

Several varnish removal techniques have demonstrated field experience in controlling the rate of varnish formation, including electrophysical separation, electrostatic technology, balanced charge agglomeration and depth filtration. These can also be used in combination with an effective oil changeout and flushing process to help in removing sludge and in-service oils having a high varnish formation potential before changing to an oil with lower varnish potential.

In systems experiencing electrostatic discharge, operators should look to use antistatic filter elements and ensure adequate grounding of bearings and shafts.

Shell field staff are available to support customers in managing their oil changeout requirements (refer to the Shell white paper, Maintaining your turbine oil to help extend oil and component life).

CONCLUSION

Turbomachinery operators are seeking to reduce unplanned downtime and the incidence of trips that may be related to varnish formation in service. By using a combination of high-performance, low varnish formation potential oils such as **Shell Turbo S4 X** and **Shell Turbo S4 GX** and a preventive maintenance strategy involving regular oil condition monitoring, varnish removal techniques and system flushing and cleaning procedures during oil changeover, operators can reduce their total cost of ownership and help to maximise equipment availability.

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(11) ASTM D2272 – 14a Standard test method for oxidation stability of steam turbine oils by rotating pressure vessel

(12) ASTM D7843 – 12 Standard test method for measurement of lubricant generated insoluble color bodies in in-service turbine oils using membrane patch colorimetry

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