CHALLENGES DURING THE LIFE OF YOUR TURBINE OIL

The operational issues that can occur during the life of the oil in your steam-, gas- or water-turbine power plant, or combined-cycle plant and the lubrication management best practices that may help you to avoid costly and disruptive problems

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WHITE PAPER, NOVEMBER 2018

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CONTENTS

HOW WOULD YOU RESPOND IF YOU IDENTIFIED…

- deposits on bearings?
- rapidly darkening oil?
- tripping servo valves?
- milky coloured oil in the sight glass?
- erratic bearing temperature readings?
- foam in the reservoir?

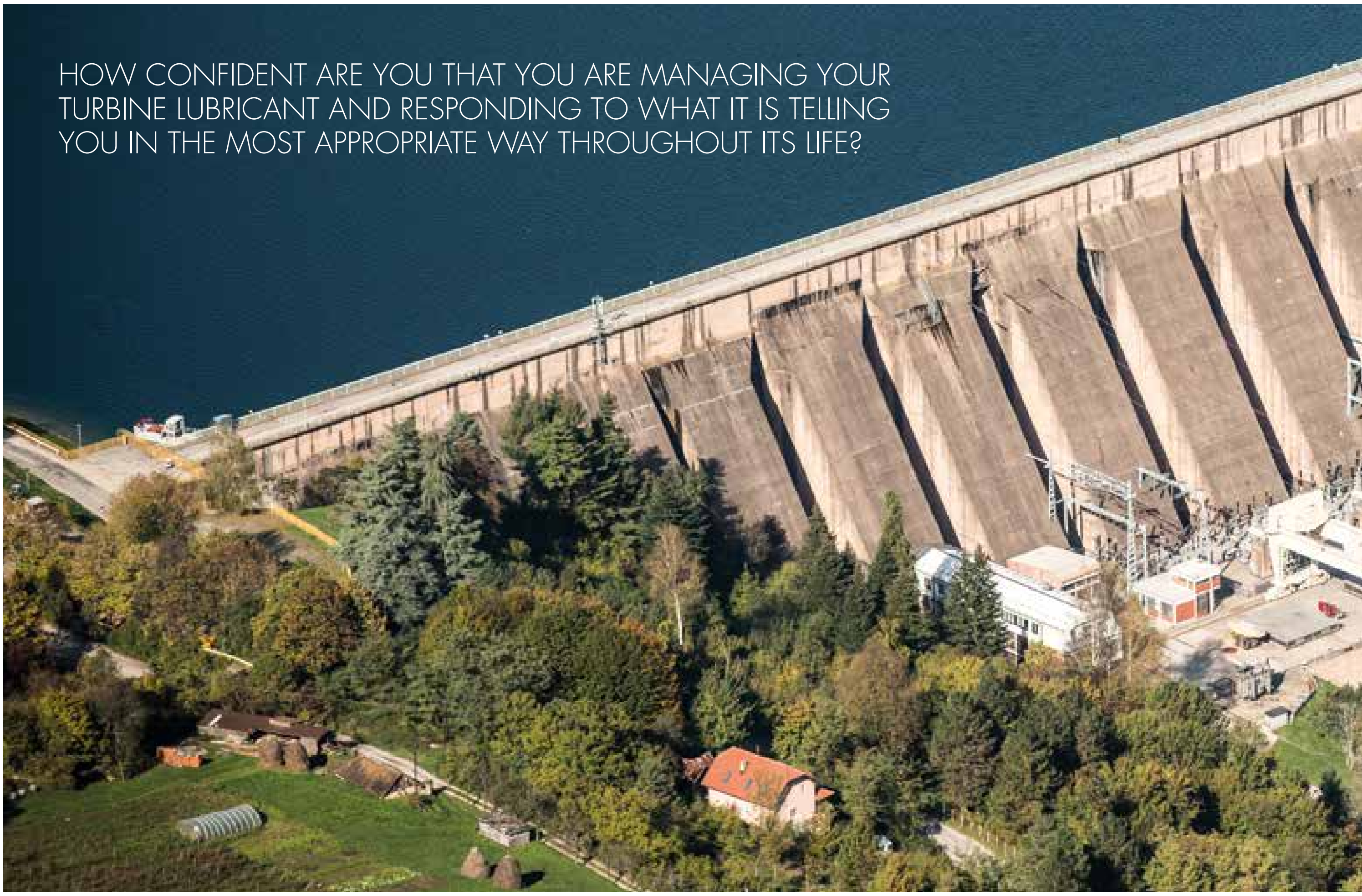
1. INTRODUCTION

As a single turbine outage can cost hundreds of thousands of dollars per hour, your ability to achieve continuous, trouble-free operations can be business critical. How confident are you that you are managing your turbine lubricant and responding to what it is telling you in the most appropriate way throughout its life?

You know that the lubricant and the way in which you monitor and manage it are key to avoiding costly and disruptive problems. However, this is a highly complex area and it can be difficult to develop an adequate response to every issue that occurs without an in-depth understanding of what is happening at the molecular level.

For instance, what is causing the colour change, deposits or foaming you are seeing? Is it bacteria, electrostatic discharge, oxidation or thermal stress? Was the wrong oil used at topping up or is there water contamination? Could additives be the solution? Should you replace the oil? What do those deposits indicate and is it alright to scrape them off and restart operations?

In this white paper, we reveal some of the issues that may occur over the oil's life and provide key insights to help you to avoid costly and disruptive problems in your turbine.



2. THE IMPACT OF TODAY'S HIGH-SEVERITY OPERATIONS ON TURBINE OILS

In the quest to deliver ever-greater power outputs and efficiencies, power generation turbines have a challenging life. They operate at higher temperatures, with gear sets under extreme pressures and shrinking sump sizes. These place extreme demands on the turbine oil.

Today's turbine operating conditions are more severe than ever, as manufacturers squeeze higher power outputs from smaller units and extend maintenance intervals. Higher severity means higher temperatures, which can lead to **deposit formation** and accelerate **oil degradation**.

Furthermore, to enable the turbines to be smaller, the manufacturers are decreasing the size of the oil sumps. Although this provides some benefits, especially lower unit cost, it increases the risk of excessive **aeration**, ineffective **water separation** and excessive **foaming** in the oil reservoir, which can lead to bearing damage and component corrosion issues.

Similarly, manufacturers' efforts to enable their turbines to ramp up or down quickly mean operators can react to fluctuating demand and capture valuable margin, but they also have a major impact on the oil. Such stop–start cyclic operations place far greater strain on the oil than steady, continuous running and can promote sludge and deposit formation.

3. KEY CHALLENGES THROUGHOUT THE OIL'S LIFE

Prolonging the life of your equipment and preventing downtime require the right product and effective lubricant management throughout the oil's life. The key phases are shown in Figure 1.

1 Select the right oil

2 Flush and drain, fill and filter at initial start-up

3 Monitoring

4 Avoid the issues commonly encountered by oils in service

5 Flush and drain, fill and filter when replacing the oil or topping up

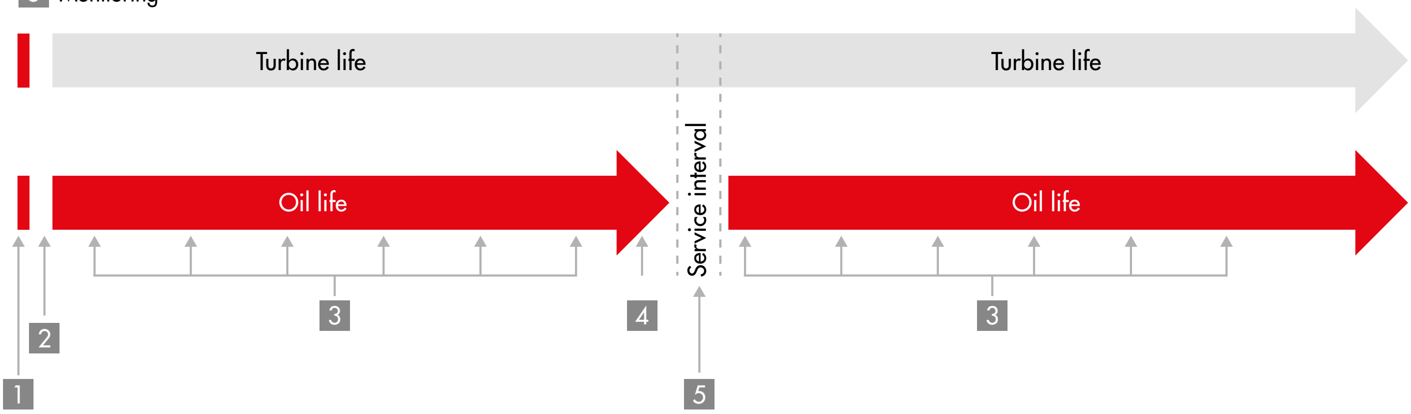


FIGURE 1: The key phases that require careful management throughout the oil's life.

3.1. SELECT THE RIGHT OIL

Selecting the right lubricant is a critical first step in improving productivity. To make smart choices for your system's operation, it is helpful if you understand what properties your oil should have to protect your turbine adequately.

The turbine oil must

a. have the correct viscosity for the application to provide a good oil film for the bearings to prevent metal-to-metal contact

b. release air rapidly to help prevent disruption of lubricating films for bearings

c. be low foaming to prevent poor lubrication and oxidation

d. be thermally and oxidatively stable to minimise the formation of sludge and varnish, and to help it last longer

e. inhibit rust and corrosion to ensure that all the key components in the system are protected

f. separate water rapidly in systems where water contamination is a concern

g. act as a coolant to absorb some of the heat from the turbine's internal surfaces and to transfer it away without thermally degrading or oxidising prematurely.

3.2. FLUSH AND DRAIN, AND FILL AND FILTER AT INITIAL START-UP

Failing to follow best practices at this early stage could dramatically shorten the oil's life or even damage your equipment. Here is why.

3.2.1. Flush and drain

Before the initial fill on-site, flush and drain the turbine to remove foreign solid matter (oil insolubles) such as loose scale and welding shop spatter. Left unchecked, these oil insolubles could damage bearings and valves, and significantly shorten their lives.

Flushing is also to remove any traces of metalworking fluids and corrosion preventives (oil solubles); it is imperative to remove these, as their chemicals may be antagonistic to the turbine oil and could destroy the oil's carefully engineered properties.

Furthermore, flushing should use a dedicated flushing oil. Some operators may consider using a straight mineral oil. However, the advantage of a special flushing oil is that it is designed to dissolve oil insolubles.

Some operators ask whether they can filter out the solids and reuse the flushing oil but this is not necessarily the best option. Oil-insoluble contaminants are removed from the flushing oil in this way but not the oil-soluble contaminants. The filtered flushing oil is still likely to contain chemical contaminants and degradation products; applying it in your multimillion-dollar turbine, where unplanned shutdowns can cost millions of dollars per day, may be a false economy.

MAINTAINING RECORDS AND TRENDING YOUR OIL ANALYSIS WILL GIVE YOU A GOOD PICTURE OF WHAT IS HAPPENING IN YOUR TURBINE COMPARED WITH A SINGLE DATA POINT, WHICH IS ONLY A SNAPSHOT IN TIME.

3.2.2. Fill and filter

Filling best practice includes using a dedicated pump, or ensuring that it is meticulously clean, and clean pipework to avoid deposits contamination. Your lubricant supplier can advise on the proper procedures, which will also include blanking off the bearings and other parts of the system, ensuring turbulent flow, heating the oil to the optimum temperatures and flushing it for long enough.

Filtering the new oil is good practice, as it goes into the turbine at the required filtration limits. This is vital, but care should be taken to avoid removing the additives. Filtration depends on various factors, including how aged the oil is and what type it is; your lubricant supplier can advise on this.

3.3. MONITORING

All turbine oils should be subjected to a proactive oil analysis monitoring. Maintaining records and trending your oil analysis will give you a good picture of what is happening in your turbine compared with a single data point, which is only a snapshot in time.

Oil condition monitoring considerations include

- what to test and why
- the limits
- the frequency
- the sampling point
- the decisions to be made based on the test results.

Key to a successful oil condition monitoring programme is expert interpretation. For example, although the test results may reveal the presence of wear metals, it can require specialist knowledge to pinpoint their source and, more critically, the optimum response.

Published turbine oil condition monitoring guidelines are available from ASTM, ISO and various equipment manufacturers and lubricant suppliers. A typical schedule for testing is shown in Table 1.

In addition to oil analysis records, keep good records for your system. Monitor the temperature of the oil in the reservoir and in the return from the main bearings.

Keep records of operating hours, amount of makeup fluid, filter changes and service hours. Trending of these data for an individual turbine and the other turbines in your portfolio can help to provide insightful information for troubleshooting if issues do arise.

TEST	FREQUENCY		SUGGESTED LIMITS
	Steam turbine	**Gas turbine**	
Appearance (visual)	Quarterly/biannually	Quarterly	Hazy
Colour (ASTM D1500)	Quarterly/biannually	Quarterly	Unusual/rapid darkening
Viscosity at 40°C	Quarterly/biannually	Quarterly	±5% of fresh oil value
Total acid number (TAN), mg KOH/g	Quarterly/biannually	Quarterly	Caution = 0.1–0.2 mg KOH/g above new oil value; warning = 0.3–0.4 above new oil value
Water content (KF), ppm	Quarterly/biannually	Quarterly	<0.1% steam turbine; <0.05% gas turbine
Elemental analysis (ICP)	Quarterly/biannually	Quarterly	Check contamination
Particle count (ISO 4406)	Quarterly/biannually	Quarterly	Manufacturers' limits 18/16/13
Rotating pressure vessel oxidation test, min	Annual	Quarterly	<25% fresh oil (review TAN)
Voltammetry/FTIR (antioxidant trending)	Annual	Quarterly	<25% of fresh oil
Demulsibility (ASTM D14010), ml-ml-ml (min)	Annual	Not required	>40–37 (40 min.)
Rust test (ASTM D665A)	Annual	Not required	Light fail
Membrane patch colorimetry (ASTM D7833)	Not required	Quarterly	<40 (MPC) (not part of ASTM standard)
Foaming (ASTM D892), ml-ml	Annual	Annual	450/10 max.
Air release (ASTM D3427)	Annual	Annual	2× fresh oil air release value

Table 1: A typical oil condition monitoring schedule.

3.4. AVOID THE ISSUES COMMONLY ENCOUNTERED BY OILS IN SERVICE

3.4.1. Varnish formation and deposits
Excellent oxidative and thermal stability are extremely important performance requirements for the latest high-performance turbine oils, whether for gas, steam, combined-cycle or water turbines. Oxidative and thermal stability are heavily influenced by both the base oil type and the antioxidant combination used (Figure 2).

Long-term resistance of turbine oils to the formation of sludge and varnish deposits is essential for system protection and process reliability. It reduces the risk of bearing temperature issues and control valve positioning problems, which can upset running stability and cause turbine trips. This is of key importance to the turbine operator, as significant deposit formation can lead to a cycle of restricted oil flow, hot spot generation and increased deposition that ultimately results in an outage. Maintaining and enhancing oxidative and thermal stability and particularly long-term deposit control in turbine oils continue to be fundamental areas of Shell's turbine oil research and development efforts.

3.4.2. Foaming and air entrainment
Performance problems associated with excessive foaming and air entrainment include reduced oil filterability and flow; lower fluid film lubrication; accelerated oxidation; cavitation, which can form sludge and deposits and result in a viscosity increase and associated oil pump and bearing damage; and loss of efficiency in hydraulic governor systems.

Mechanical problems such as a low oil level in the reservoir or a discharge line being too high above the reservoir can contribute to this problem, as can chemical problems such as additive depletion, oil contamination and oil degradation.

Air release is typically measured using the ASTM D3427-03 test method. Foaming is measured using the ASTM D892-03 method. Antifoaming additives are incorporated into turbine oils to control foaming. Although air release is generally a function of the base oil and cannot be improved with additives, some additives can worsen air release. Foaming values for good-quality ISO grade 32–46 fresh oils typically have foaming tendency values of 30 ml or less and air release values of 4 min or less, whereas poorer-quality oils can have foaming tendency values exceeding 500 ml and air release values significantly above 5 min.

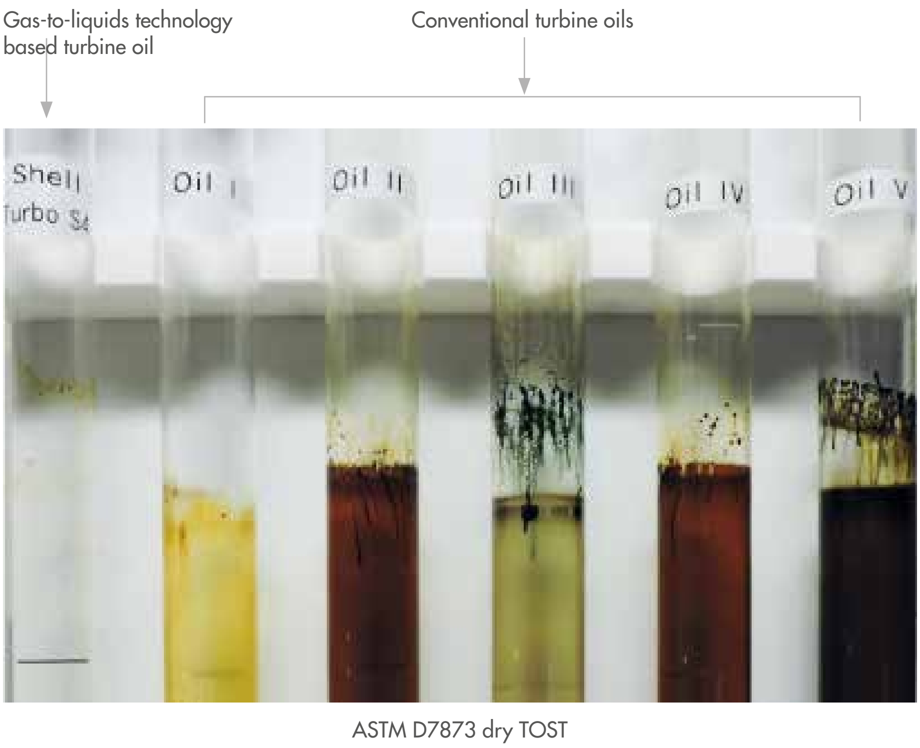


Figure 2: Shell Turbo S4 (far left) demonstrates exceptional degradation resistance in the ASTM D7873 dry turbine oil stability test (TOST) (1,008 hours). This test measures insoluble by-products of oxidation processes and residual antioxidancy.

SHELL TURBO S4 GX PROVIDES THE PROTECTION TO PREVENT ACCELERATED WEAR OF HIGHLY LOADED GEAR TEETH UNDER SEVERE OPERATING CONDITIONS.

3.4.3. Dirt particles

The presence of high levels of oil insolubles can result in additive depletion, sludge formation, foaming, poor water separation, air entrainment, filter blocking and increased abrasive wear. These particles can be caused by oxidation of the oil, chemical contamination (solid, liquid or gaseous contaminants reacting with the lubricant additives) and particulate contaminants such as rust, soot, dust and wear debris. Improving filtration can control these issues. Typically, cleanliness is measured using the ISO 4406: 1999 or NAS 1638 test method. The major equipment manufacturers tend to specify oil supply cleanliness levels of –/18/15 (NAS 9) or better, whereas in-service target specifications can be of the order of –/16/13 (NAS 7).

3.4.4. Component wear

Geared turbine oils tend to include extreme-pressure and antiwear additives to ensure they can meet the required load-carrying capacity for the gearbox, as measured using the DIN ISO 14635-1 test method. Turbine equipment manufacturers mainly specify minimum FZG failure load stages of 8 or 9 for such oils. ISO 32 and 46 grade oils without extreme pressure or antiwear additives typically give failure load stages of 6 to 7. Shell Turbo S4 GX, a gas-to-liquids technology based turbine oil, provides the protection to prevent accelerated wear of the highly loaded gear teeth under severe operating conditions (see figures 3 and 4).

3.4.5. Rust and corrosion

Rusting and corrosion can reduce oil cleanliness levels, promote abrasive wear and sludge formation, increase oil oxidation and foaming, block filters and lead to the failure of components such as bearings and damage or block control valves. Most turbine oils contain rust and corrosion inhibitors to prevent these issues. However, some are water-soluble and may be washed out by free water, which leads to the problems above.

The remedy, other than using only stainless steel pipework for the turbine, is to change to a turbine oil whose corrosion inhibitors will not be washed out by water. Rust inhibition is measured using ASTM D665-03 A/B or an equivalent method. Good-quality fresh oils should pass in both the A (distilled water) and B (salt-water) parts of the test; poorer-quality fresh oils may fail in part A and/or B.

ASTM D5182, FZG wear protection, failure load stages

Figure 3: FZG performance of Shell Turbo S4 GX against the ASTM D4303 type II requirements.

Figure 4: Gears showing increasing wear.

IF THE OIL DOES NOT READILY SEPARATE FROM WATER, THIS CAN LEAD TO THE FORMATION OF STABLE EMULSIONS THAT MAY RESTRICT TURBINE CIRCULATION, REDUCE THE EFFECTIVENESS OF FILTRATION AND LOWER THE OIL'S VISCOSITY AND FILM-FORMING PROPERTIES.

3.4.6. Water separation

Water separation is most relevant to steam and combined-cycle turbines with a common oil system, where water from steam leaks can become entrained in the oil. If the oil does not readily separate from water, this can lead to the formation of stable emulsions that may restrict the turbine circulation, reduce the effectiveness of filtration and lower the oil's viscosity and film forming properties.

These emulsions can give problems such as sludge formation and increased oxidation, rusting, corrosion, foaming and air entrainment. The risk of bacterial growth may also increase. Poor demulsibility can result from particulate contamination, which can be improved by filtration; excessive water content, which can be improved by centrifugation or vacuum dehydration; contamination with an inappropriate lubricant such as an engine or hydraulic oil; or age-related degradation of the oil. The latest-generation Shell Turbo S4 oils offer outstanding performance in all these areas (Figure 5). This ensures that lubrication is effective over a wide temperature range, excessive aeration and foaming are minimised, and that water is readily separated out, thereby reducing the likelihood of corrosion.

3.5. FLUSH AND DRAIN, AND FILL AND FILTER WHEN REPLACING THE OIL OR TOPPING UP

All oils in service age and degrade with time, so it is inevitable that oil will need replacing at some point. With incorrect procedures, however, the new oil could be compromised before the turbine has restarted.

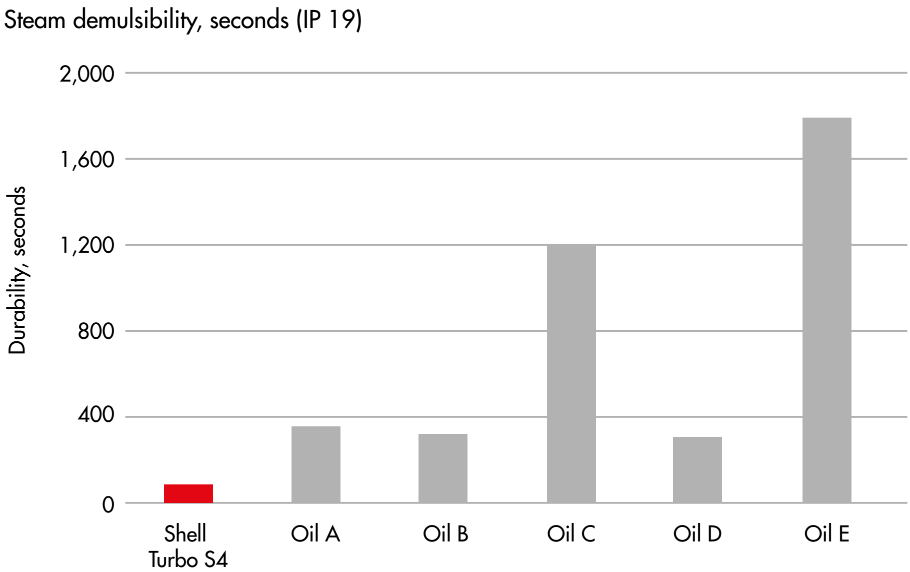


Figure 5: Steam demulsibility of turbine oils tested according to the IP 19 method.

3.5.1. Flush and drain

Even with the best operating procedures and monitoring, the oil will eventually age and need replacing. There are several reasons for this:

- thermal and oxidative degradation. The used oil will contain contaminants such as sludge, varnish and deposits that can lead to increased bearing temperatures, stuck valves and blocked filters.
- contamination. The used oil may contain water, wear metals or contaminants from dust ingress, which can be a problem for facilities in coastal regions (salt) and those near factories such as cement works that are emitting particulates. These contaminants can contribute to other degradation issues, including oil oxidation and hydrolysis.
- additive depletion. Excessive additive depletion can significantly reduce an oil's life and performance.

Some operators may consider simply draining the old oil and refilling with fresh oil, but flushing is also imperative. This is because there are likely to be doglegs and dead ends in the lubrication system. Typically, up to 5% of the old oil can remain in the system and could cause oxidation of the fresh oil that would age it prematurely. As in Section 3.2., it is important to use a dedicated flushing oil because it is designed to dissolve oil insolubles.

Occasionally, we hear of operators that have cut corners and opted not to flush and drain to save time and money. However, the tens of thousands of litres of oil that they use to refill will soon have the characteristics of oil that has been in service for several years.

3.5.2. Fill and filter

As in Section 3.2, an effective filtration system should be applied; check the proper filtration guidelines with the manufacturer of your turbine system.

4. EARLY INDICATORS OF AN UNDERPERFORMING TURBINE OIL

You should not ignore the following issues, as they could be signalling a deeper, and potentially costly, underlying issue.

WHAT TO LOOK OUT FOR	WHAT IT MEANS	POTENTIAL IMPACT
Excessive temperature spikes or levels in your bearings	The bearings may be suffering from varnish or deposit formation	Lower efficiency and rapid oil ageing
Corrosion	Water or steam may be leaking into the lubricant system	Reduced lubrication performance
Foaming in the oil reservoir	The oil has insufficient time to release all the air that it picks up during operation, thereby compromising the its lubrication performance	Excessive bearing wear
Oil condition monitoring results indicate high membrane patch calorimetry values	High levels of varnish may be forming in the bearings or ancillary valves	Premature wear
Oil condition monitoring results indicate reduced lower oxidation resistance or increased TAN	The oil is ageing	The oil may need to be changed earlier than planned, which will resulted in additional maintenance and incur additional costs
Servo valves are sticking	Varnish has formed through thermal and oxidative degradation	Unit alarms, trips or fail to starts

5. ARE YOUR RESPONSES ADDRESSING THE ROOT CAUSE OF THE PROBLEM?

When operational issues occur, operators may occasionally implement superficial responses that fail to address the underlying problem. In this section, we reveal a selection of these flawed actions and explain why further investigation is usually necessary.

5.1. SWITCHING FILTERS WHEN ONE BECOMES BLOCKED

Switching filters when one fails is good, standard practice. However, failure to investigate the underlying issue can have a lasting impact. In fact, the oil-insoluble products that are dropping out in the filter are not the main problem. Far more significant are the oil-soluble degradation products also likely to have formed. As a consequence, the oil coolers are likely to becoming blocked with sludge and soft deposits that form harder varnishes and lacquers on surfaces or in the reservoir. These degradation products would compromise the life of any fresh oil added to the system.

To avoid such problems, one should take steps to understand what is causing the sludge and deposits. Special filters may also be used to clean up the oil and dirt-resolving fluid can be used to clean the turbine before an oil change.

The takeaway: Always investigate the underlying cause of blocked filters.

5.2. SCRAPING DEPOSITS OFF A JOURNAL BEARING AND THEN RESTARTING THE UNIT

Deposits will interfere with the oil flow through the journal bearing and cause the temperature to increase. This will accelerate the degradation of the oil and lead to more deposits.

However, simply removing the deposits from the bearing is inadequate. When there is a high level of deposition on the bearing, experience shows that there are also likely to be deposits in the coolers and sludge in the reservoir.

As in Section 5.1, the sludge and deposits will compromise the life of any fresh oil added to the system. Identifying the cause of the sludge and deposits is again key. The use of special filters to clean up the oil and of dirt-resolving fluid to clean the turbine before an oil change are recommended.

The takeaway: Always investigate the underlying cause of deposits on a journal bearing.

5.3. REPLACING THE OIL BECAUSE THE OLD ONE FAILED THROUGH THERMAL STRESS

Occasionally, thermal stress can be misdiagnosed. For example, deposits are an indicator of thermal stress but they are also a symptom of electrostatic discharge from the rotor to the bearing, a classic failure mode that leaves an orange-peel effect underneath the deposits. Electrostatic discharge is caused by inadequate earthing and causes small pits in the bearing that lead to irregular oil flow and deposit formation.

The takeaway: Poor equipment design can cause oil failures.

5.4. REPLACING THE OIL BECAUSE THE OLD ONE HAS DARKENED

Historically, colour was used as an indicator of oil condition. However, this is less appropriate with today's state-of-the-art oils that often contain antioxidants that form coloured compounds. A colour change may simply mean that the antioxidant system is working.

If you notice the oil has darkened, look at your routine oil condition monitoring results; if the viscosity, acid values and flash point are within the specifications, the oil does not need replacing.

The takeaway: Darkening alone is not necessarily an indicator of a failing oil. Check other oil condition monitoring parameters before coming to a conclusion about used oil status.

6. DIFFICULT-TO-DIAGNOSE ISSUES

Some issues occur relatively infrequently and operators may not have experienced them. Furthermore, the symptoms do not clearly indicate the cause. In these instances, experience is key.

1. The turbine's shaft-displacement sensor, which measures its orientation along the horizontal axis, shows that the shaft has moved off centre to the one o'clock position.

Many operators are unaware that this displacement is a strong indicator of deposit formation. Deposits typically form at the seven o'clock position. As they build up, this pushes the shaft towards the one o'clock position. Shaft displacement is typically accompanied by a journal bearing temperature increase.

2. Oil analysis reveals that the acid number is increasing and the presence of oil-insoluble degradation products. However, the bearing temperatures are normal.

Sometimes, an off-specification component can cause issues. The lubricant reservoir temperature should be 40–50°C, but we have seen them closer to 70°C when the heaters are overpowered for the recirculation rates the system can achieve. However, higher temperatures can shorten oil life (as a rule of thumb, every 10°C rise in temperature doubles the rate of oil degradation). Consequently, overpowered heaters cause the acid number to increase and oil-insoluble degradation products to form because of the higher oil degradation rate.

3. There is a tidemark round the lubricant reservoir.

A tidemark round the oil reservoir is likely caused by a bacterial infestation resulting from water ingress. This can be resolved by applying a biocide. However, take great care when adding additional additives, as they can interfere with and have an antagonistic effect on the existing additives. Always consult your lubricant supplier for specialist advice.

7. KEY TAKEAWAYS

High-severity operations

Owing to today's more-challenging operating conditions and the greater reliability required, power generation turbines and their oils are under increasing pressure. This presents a variety of challenges that turbine operators need to manage proactively if they are to avoid costly downtime.

Choose the right product

Make sure that your oil meets, and preferably exceeds, the requirements set down by the equipment manufacturer. Products that deliver enhanced oxidation protection and rapid air release, and that have a high viscosity index can provide valuable performance advantages.

Lubrication management through the oil's life is key

All oils degrade in service, but effective lubrication management can help to slow the rate substantially. Conversely, inadequate responses can accelerate it. Key areas include oil selection oxidative and thermal stability, starting up, monitoring in service and replacing or topping up the oil.

Oil condition monitoring

Oil condition monitoring is a key way to help identify potential oil or equipment failures before they become critical.

Listen to the oil

Look out for key indicators such as excessive temperatures in the bearings, foaming in the oil reservoir, sticking servo valves or deposits on the journal bearings. Where necessary, seek specialist advice to ensure that you identify the root cause and the optimum response.