SKF

OIL DEGRADATION: ONE PARAMETER IS NOT ENOUGH

Why a multi-parameter approach is necessary to accurately assess oil health and performance.

RecondOil

Understanding oil degradation in context

Lubricants degrade continuously throughout their service life. The rate and nature of degradation depend on oil formulation, operating temperature, load, contamination levels and environmental conditions.

As oil degrades, it loses its lubricating properties, leading to increased friction, accelerated wear, micro-pitting and corrosion. Left unaddressed, this degradation can ultimately result in equipment failure.

Oil condition monitoring is essential to assess lubricant health and determine when intervention is required. However, oil degradation is a complex, multi-mechanism process. Relying on a single measured parameter rarely provides a complete or reliable picture of oil condition.

This white paper examines the most commonly used oil analysis methods for diagnosing degradation – particularly oxidation – and demonstrates why a multi-parameter approach is necessary to accurately assess oil health and performance.

Background:

How lubricants degrade

Oil degradation occurs through several interacting mechanisms, including oxidation, thermal stress, contamination and additive depletion. Among these, oxidation is one of the most significant drivers of long-term lubricant failure.

Oxidation is a chemical reaction between oil molecules and oxygen originating from ambient or entrained air. This reaction causes permanent changes to the base oil molecules, forming a range of degradation by-products. The oxidation rate is influenced by multiple factors, most notably temperature.

As described by the Arrhenius rate rule[1)], oxidation accelerates exponentially as operating temperature increases.

As oxidation progresses, degradation by-products accumulate, lubricant properties change, and the risk of varnish, sludge and corrosion increases. Monitoring these changes requires more than a single test result.

Diagnosing oil oxidation:

Limits of single-parameter analysis

Oil degradation is typically identified by changes in physical and chemical properties measured through routine oil analysis. Common indicators include viscosity, acid number, oxidation level and varnish potential.

While each parameter provides valuable insight, none can independently describe the true condition of the oil.

The following sections outline the strengths and limitations of commonly used diagnostic methods.

Color change (ASTM D1500):

A visual indicator

Color is one of the most immediate and visible indicators of oil condition. New lubricants have characteristic colors related to their viscosity and formulation.

Lower-viscosity oils, such as turbine and hydraulic fluids, are typically lighter than higher-viscosity gear or circulation oils.

As oils oxidize during service, they generally darken due to the formation of oxidation by-products such as chromophores.

Figures 1 and 2 illustrate color changes in ISO VG 320 gear oil and ISO VG 46 oil samples at different stages of degradation.

Figure 1. ISO VG 320 gear oil

Figure 2. ISO VG 46 oil samples

Color change is often the first observable sign of degradation and can provide useful trend information. However, color alone is not a reliable indicator of oil health.

Some oils may appear visually unchanged while being severely degraded, while others may darken significantly without having reached a critical condition. More precise analytical tools are therefore required.

[1)] How Heat Affects Lubricants: Understanding the Arrhenius Rate Rule | Machinery Lubrication

FTIR oxidation analysis (ASTM D7214):

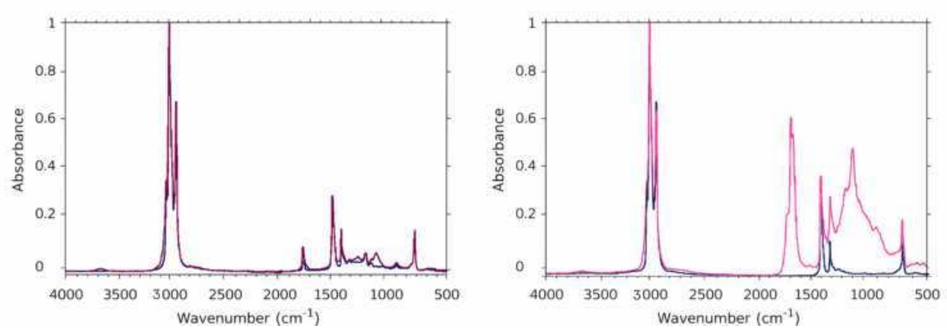
Measuring chemical change

Fourier Transform Infrared Spectroscopy (FTIR) provides a molecular fingerprint of the oil and is widely used to monitor oxidation. Oxidation produces compounds such as aldehydes, ketones, hydroperoxides and carboxylic acids, many of which contain carbonyl (C=O) groups.

Oxidation is measured by monitoring absorbance in the carbonyl region of the FTIR spectrum, typically between 1 800 and 1 670 cm^{-1}. Because new petroleum-based lubricants exhibit minimal absorbance in this region, increases over time directly indicate oxidation activity.

While FTIR is a powerful tool, it has limitations. The ASTM method for oil analysis was originally developed for transmission oils, and its precision may vary across lubricant types. Furthermore, FTIR measures oxidation level but does not directly predict remaining oil performance. Alternative standards (such as ASTM D7414 and D7412) exist, but each has limitations. This reinforces the need for complementary methods.

Figure 3 shows examples of FTIR spectra where the new oil (dark line) is compared with a degraded oil (colour line).



Total Acid Number (TAN):

A secondary indicator

The Total Acid Number (ASTM D974, D664) measures the concentration of acidic components in the oil. New oils have characteristic TAN values depending on formulation, as many additives – such as rust inhibitors – are acidic.

As oxidation progresses, acidic degradation products form, increasing the TAN relative to new oil. However, increases in TAN can also result from contamination, additive degradation or oil mixing.

Conversely, TAN may remain stable or even decrease as acidic additives are consumed, potentially masking ongoing degradation.

As shown in Tables 1 and 2, TAN alone can be misleading if interpreted without supporting data. It is therefore best used as a secondary indicator in combination with other parameters.

Table 1

	Colour	Viscosity (40 °C)	Particle count	Water content	TAN	MPC rate
		mm^2/s		ppm	mgKOH/g	
New		43.4	18/16/12	73	0.42	2.3
S1		43.5	21/18/12	0	0.51	6.1
S2		48.3	19/16/12	63	0.25	20.6
S3		43.7	22/18/12	56	0.33	6.1
S4		44.8	19/16/11	-	0.38	39.6
S5		45.8	22/21/18	32	0.29	1.1
S6		46.3	IMP	35 338	0.48	35.1

Table 1 shows an example of the same oil new and at different stages of degradation and contamination.

Table 2

	Colour	Viscosity (40 °C)	Particle count	Water content	TAN	MPC rate
		mm^2/s		ppm	mgKOH/g	
New		46.0	17/15/<1	20	0.30	1.1
After 312 h		46.4	14/11/8	29	0.34	37.1
After 624 h		45.2	15/12/9	41	0.33	49.6
After 936 h		45.9	15/12/7	46	0.32	54.2

Table 2 shows an example in which the same oil degrades but the TAN changes very little or even decreases due to additive consumption.

Membrane Patch Colorimetry (ASTM D7843):

Assessing varnish potential

Oxidation by-products such as carboxylic acids can undergo polymerization, forming high molecular weight compounds. As these molecules grow, their solubility decreases, leading to the formation of varnish and sludge. This process often coincides with increasing viscosity, as larger molecules dominate the oil composition.

Membrane Patch Colorimetry (MPC) quantifies insoluble degradation products by filtering oil through a 0.45 µm membrane and analyzing the color and intensity of retained residues using the CIELAB color space. The resulting ΔE value correlates with varnish and sludge potential.

Higher MPC values indicate increased levels of insoluble degradation products:

- MPC <15 indicates good oil condition
- MPC 15–29 requires close monitoring
- MPC 30–40 indicates abnormal condition
- MPC >40 is considered critical

MPC provides valuable insight into degradation mechanisms that are not captured by viscosity, TAN or FTIR alone.

Oxidation stability tests:

RPVOT and RULER

The Rotating Pressure Vessel Oxidation Test (RPVOT, ASTM D2272) is an accelerated oxidation test that evaluates remaining antioxidant performance. During the test, antioxidants protect the base oil until depleted, after which rapid oxidation occurs and vessel pressure drops.

RPVOT is useful for assessing oxidation stability, but it does not account for sludge or varnish formation. Certain additive chemistries may generate deposits even when RPVOT values remain high.

The Remaining Useful Life Evaluation Routine (RULER) directly measures antioxidant concentration using voltammetry. While RULER accurately reflects remaining antioxidant levels, it does not capture the presence of contaminants or degradation by-products that impair oil performance.

Both tests provide valuable – but incomplete – information when used in isolation.

Why one parameter is not enough

Oil degradation involves multiple, interacting mechanisms. No single analytical parameter can describe oil condition comprehensively. Interpreting results in isolation risks incomplete or misleading conclusions.

A multi-parameter approach – considering oxidation, acidity, insolubles, contamination and oxidation stability together – provides a far more accurate assessment of oil health and remaining service life.

This principle also applies when evaluating oil regeneration technologies.

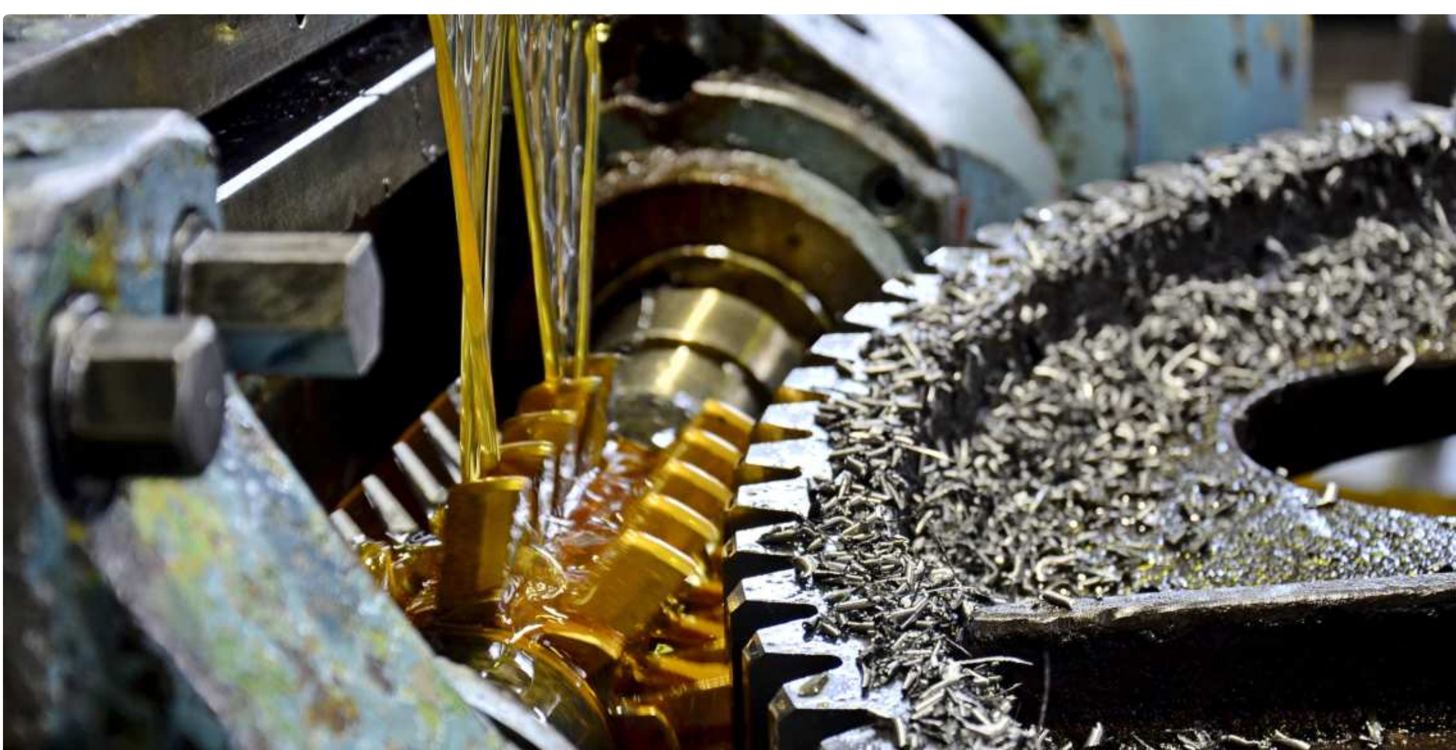
Assessing oil regeneration with RecondOil DST

The same parameters used to monitor degradation are used to evaluate oil regeneration with RecondOil's Double Separation Technology (DST). Importantly, oil regeneration does not reverse chemical degradation or replenish additives. Instead, it removes the smallest contaminants that accelerate oxidation and impair performance.

As a result:

- RPVOT values often improve after DST treatment, indicating increased oxidation stability due to contaminant removal.
- RULER values typically remain un changed, as antioxidant concentration is not altered.

Understanding this distinction is critical when interpreting post-treatment oil analysis results.



Case study 1

Compressor oil regeneration

In this study, a synthetic compressor oil (60 cSt at 40 °C) operating for 1 000 hours at an average sump temperature of 85 °C was analyzed before and after DST treatment.

Despite the oil retaining a dark color after treatment, detailed analysis revealed substantial improvements:

- Particle cleanliness was restored to near-new oil levels.
- TAN was reduced by more than 40%.
- MPC decreased by over 45%.
- RPVOT values recovered to new oil levels.

A dark color after the DST process is not an indication of ineffective oil regeneration or reduced oil functionality. Oil color can change during service for several reasons, including oxidation, irreversible chemical changes, deposits and contamination.

During the DST process, deposits and contaminants are effectively removed and a slight improvement, or brightening, of the oil color is often observed. However, discoloration caused by oxidation and permanent chemical changes to the base oil cannot be reversed.

As a result, while the oil may not return to the original clear appearance of new oil, its functional performance can be fully restored through effective removal of deposits and contaminants.

In this study, although visual appearance changed little, the functional condition of the oil after DST treatment was significantly closer to that of new oil than used oil. The table shows the physico-chemical analysis of compressor oil samples.

Method	New	Used	DST
Viscosity (40 °C) mm²/s	56.9	60.5	**59.5**
Particle count	17/16/10	18/16/13	**17/15/2**
Oxidation (A/cm)	NA	7.2	**0.2**
TAN (mgKOH/g)	0.06	0.78	**0.48**
MPC rate	0.4	8.4	**3.6**
RPVOT (min)	946	792	**951**

Case study 2

Hydraulic oil regeneration

A heavy-duty hydraulic oil was tested in parallel systems, with and without a RecondOil Box fitted with a Boost filter (DST) insert.

After 312 hours, both oil samples showed no visible change in color or viscosity. Particle count results suggest that both oils have a similar number of particles in them. However, deeper analysis revealed some improvements:

- DST-treated oil's MPC was 92% lower compared to the oil that had not been treated with a RecondOil Box. This is also visible on the patches, indicating the removal of smaller particles.
- PQ index and water content were slightly improved by DST.
- RPVOT values remained similar for both samples.

After 624 hours, interesting changes in physicochemical properties are seen:

- MPC values were reduced by up to 99% in the DST-treated system.
- Oxidation stability (RPVOT) was 25% higher than the oil that had not been treated with a RecondOil Box.
- TAN, water content and PQ index were consistently lower.
- A clear visual change between the samples suggests chemical degradation progressed slower for the oil treated with the Boost filter (DST).

While some parameters showed minimal differences early in operation, longer-term analysis revealed clear benefits of continuous contaminant removal. The results are seen below showing the physico-chemical analysis of oil samples in hydraulic test rig.

	Viscosity (40 °C)	Particle count	Water content	TAN	MPC rate	RPVOT
	mm²/s		ppm	mgKOH/g		min
New	46.0	17/15/<1	20	0.3	1.1	467
After 312 h	46.4	14/11/8	29	0.34	37.1	405
After 312 h with RecondOil Box	46.5	13/11/9	3	0.33	3	408
After 624 h	45.2	15/12/9	41	0.33	49.6	290
After 624 h with RecondOil Box	45.8	18/16/9	3	0.15	0.7	362

Conclusion:

A holistic approach to oil condition monitoring

These examples demonstrate that oil condition cannot be reliably assessed using a single parameter. Degradation is multifaceted, and meaningful diagnosis requires a holistic, data-driven approach.

By analyzing multiple interacting parameters, it becomes possible to accurately assess oil health, evaluate regeneration effectiveness and make informed maintenance decisions.

At SKF RecondOil, we are committed to advancing this understanding – demonstrating how DST technology improves oil health, extends service life and supports more sustainable, reliable industrial operations.

DOUBLE SEPARATION TECHNOLOGY BY SKF

Want to know more?

Find out more about RecondOil and Double Separation Technology (DST) here.