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Soluble and Insoluble Varnish Test Methods

Trending Varnish Buildup in Mineral Turbine Oil

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Publisher's Note

India successfully hosted the 18th G20 Summit in New Delhi during 9-10 September, 2023 under the theme of "One Earth, One Family, One Future". Our country was voice of addressing contentious environment issues and climate change in G20 summit. Apart from other important issues, climate and energy was discussed. The G20 backed a target of tripling global renewable energy capacity and referenced the need for emissions to peak before 2025. It also acknowledged limiting warming to 1.5 degrees Celsius (2.7 degrees Fahrenheit) which will require slashing greenhouse gases 43 percent by 2030 from 2019 levels.

Over the coming decades, India is expected to see continued strong economic growth that will bring with it an expanding middle class and higher living standards. In the process of this growth, industrial activity is rising and the demand for energy is growing. But the country is also facing a huge challenge: reduce its emissions intensity 45% by 2030 and reach net zero by 2070.

"Few would disagree that one of the most urgent societal challenges we face today is addressing the risks of climate change. How we meet the world's demand for the energy necessary for economic growth while mitigating the long-term impact on our environment is key to our sustainable future." – Darren W. Woods, Chairman, ExxonMobil. Industrial activity accounts for nearly a quarter of India's emissions. While powering facilities with a lower-emission fuel like natural gas is one step towards meeting climate goals, ensuring that industrial machinery works efficiently is also essential. By considering the economic benefits of eco-friendly maintenance practices, companies can make informed decisions about where to invest their resources. While there may be some upfront costs associated with implementing these practices, the long-term cost savings and benefits can far outweigh these costs. Ultimately, eco-friendly maintenance practices can improve a company's financial performance while also contributing to a more sustainable future. Sustainability involves producing lubricants with minimal environmental impact, conserving resources, developing products, embracing social responsibility, and complying with regulations.

Eco-friendly maintenance is an essential practice for companies that want to reduce their environmental impact, improve their bottom line, and enhance their reputation. By implementing best practices for reducing carbon footprint in maintenance operations, using tools and technologies for sustainable maintenance, and overcoming challenges to adoption, companies can achieve significant results. Continuous improvement is also critical to achieving long-term success. Companies can improve their sustainability performance, reduce costs, and improve asset performance.

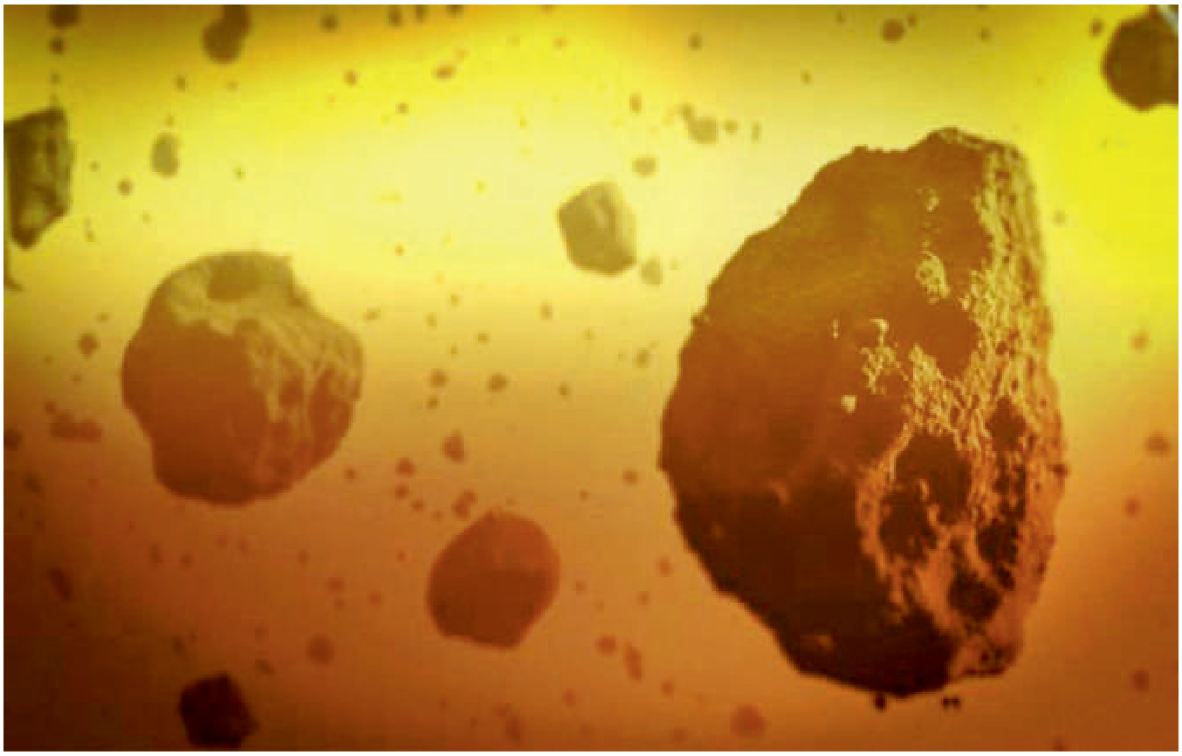
Let us embrace a more environmentally conscious future by nurturing our planet today. Sustainability isn't merely a choice; it signifies our collective responsibility to safeguard the Earth. Together, let's take significant steps towards ensuring a sustainable future for everyone.

Power plants, especially turbines, are expected to operate with high reliability and with control lable operating and maintenance costs. The cover story details a study in which in-service gas turbine oils from three different power plants were sampled and analyzed — the results indicates that the monitoring of insoluble varnish together with soluble varnish improves the diagnostic and early correction of varnish problems. Some other topics covered in this edition includes: Preventing equipment failure, condition-based oil changes, lubrication program development, dispersancy testing, assessing oxidation condition and lubricant refreshment in turbine oils, the importance of a lubricant list and much more. We look forward to your support and feedback to enable us to improve the content and layout of Machinery Lubrication India. We welcome readers to participate by sending their feedback & contributing articles and case studies. We look forward to the continued patronage of the advertisers and the subscribers.

Warm regards,
Udey Dhir

PREVENTING EQUIPMENT FAILURE, ONE PARTICLE AT A TIME

"Monitoring and controlling contamination in machines is how we prevent equipment failure—even before it begins."



"Only do something if wear metals show up on the oil analysis reports. Don't doanything with high particle counts."

— Unnamed Supervisor

These are the words of an unnamed supervisor of a lubrication technician in myrecent Oil Analysis Level II course. This technician knew that couldn't be right —as did I and just about everyone else in my class. It's a bit perplexing to hear a statement like that. How could he possibly think that? By the end of the week,not only was there a clear understanding of the importance of particle counts, but a very strong understanding as to why it might be the most important aspect in preventing equipment failure.

To understand this, let's start with why. Why do we analyze wear debris? Why do we analyze particle contamination?

Wear debris is a crucial early sign of machine failure. It's like a lit fuse to a catastrophic event, especially for critical machines. Most condition monitoring technologies and predictive maintenance strategies focus on discovering the signs of failure as soon as possible. After all, wear debris is a direct result of metal being removed from surfaces, usually from frictional interactions. The severity and urgency of wear debris issues should not be underestimated, and if discovered quickly and acted upon correctly, the progression of failure can be slowed down or delayed.

But why did the failure occur in the first place? What is the match that lit the fuse? While there could be many culprits, contamination is well-documented by machine OEMs and user group studies as the most common root cause of machine failure. And of the forms of contamination responsible for machine failure, particle contamination is the most common. Thus, monitoring and controlling contamination in machines is how we prevent equipment failure —even before it begins. How is this possible? By tracking particle counts on oil analysis.

Here are some of the reasons why tracking particle counts bring you benefits across the lifecycle of the lubricant, the lifecycle of the machine, and the many-maintenance activities in between:

1. Particle counts help validate a lubricant's conditions before it's even in the machine

When lubricants are purchased, their cleanliness must be determined.Unfortunately, new oil does not always mean clean oil. New oil cleanliness is critical, not just for avoiding particle-induced wear in the machine, but also for avoiding damage to the lubricant during periods in storage containers. Particles can strip additives and promote oxidation. And if lubricants are transferred to themachines using dirty transfer equipment or dirty top-up containers, this will be picked up quickly with particle counts as well.

2. Particle counts help monitor the contamination control objectives on the machine

Firstly, particle counts are great for trending and confirming target cleanlines levels over time, allowing for the detection of compromises in contamination exclusion practices, which can include a loss in the performance of shaft seals, headspace breathers and cylinder wiper seals. Similarly, particle counts can also monitor contamination removal effectiveness, such as impaired filter or centrifuge performance. The exclusion and removal practices must always be kept in balance for optimal proactive maintenance.

3. Particle counts help optimize the timing and urgency of maintenance activities

Simply knowing when to change a filter can be indicated by particle counts — often sooner than the differential pressure gauge on the filter. But similarly, if machine conditions change (including atmospheric contamination levels), particle counts can be validation that the filter choice is appropriate for the application. And for machines that do not have permanently installed filtration systems, particle counts can help determine the timing of filter cart usage.

4. Particle counts help optimize oil analysis activities

Monitoring for particle contamination is established as a routine oil analysis test for nearly all machines on oil analysis. High particle counts are simply a sign of an issue and a trigger for the technician to investigate the cause, which involves the analysis of data across several oil analysis tests, including the addition of exception tests. For example, analytical ferrography is too costly and unnecessary to perform routinely, but a series of rising particle counts, or one-abnormal spike, can be the justification for such tests.

5. Particle counts help catch operating or maintenance human-induced errors

If repair work was performed or machines were recently installed with new parts, particle counts can monitor for botched work. This may include debris from machining or welding or airborne contaminants that entered the machine while work was being performed that were not properly filtered out before

Machinery Lubrication

Publisher
Udey Dhir
udeydhir@tribologysolutions.com

Creative Director
Sumita Maniktala
smassociates@gmail.com

Advertisement Sales (US/Canada)
Brett O'Kelley - bokelley@noria.com

Advertisement Sales
(India/all other countries)
Kaustav Das
kaustuvdas@machinerylubricationindia.com

CORRESPONDENCE
You may address articles, case studies, special requests and other correspondence to our

Operation office :

Editor
213, Ashiana Centre, Adityapur,
Jamshedpur-831013, India
email : editor@machinerylubricationindia.com
Tel: +91-657-2383238
Tel:(USA): +1-918-960-9738

Marketing Office
Rider House, 136,
Sector 44, Gurgaon-122003, Haryana
National Capital Region, India

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start-up. Particle counts can also monitor for abnormal break-in wear.

6. Particle counts help discover machine issues or early signs of machine wear

Monitoring the overall health of machine components such as pumps, bearings and gears can be linked directly to the trends of particle counts. This includes monitoring for contamination intrusion and wear debris. But similarly, particle counts will watch ancillary components for issues that can lead to collateral damage to the primary components, like ruptured filters, unexpected filter bypass, or other filter failures from unusual operating conditions, such as cold-start conditions.

7. Particle counts help alert to lubricant issues

Various types of wear can occur when lubricants are not selected correctly or aren't performing as expected. Improper viscosity selection, additive depletion or impaired performance from other contaminants (such as air and water) can lead to cavitation wear, corrosive wear or oil film failure. This can be indicated by rising particle counts.

8. Particle counts help troubleshoot and solve problems

After problems are discovered, whether its high contamination, abnormal wear or even lubricant failure, particle counts can be a tool in the troubleshooting process. For example, analyzing the results of the particle counts after testing at different points in a circulating system can be a quick indicator of where the ingression source or wear generation source is located. Even after correctiveactions are in place, the ongoing monitoring of particle counts can validate that the solution was successful.

The Right Test Slate

Particle counters have a multitude of uses and, when used correctly, can greatly improve equipment reliability. Considering that the particles being monitored by the trending data from a particle counter include both contamination (which causes wear) and wear debris (the effect of wear), the particle counts can be both a leading indicator and a lagging indicator of machine failure.

Where many fall short in reaching the real opportunity of particle counts is connecting the dots between cause and effect. Take, for example, monitoring for wear metals with elemental analysis or ferrous density: These are critical indicators for machine failure and must be on most oil analysis test slates. But if one is only looking for wear debris by itself, then the damage is already inprogress and may be too far developed to correct the problem without shutting the machine down.

Particle counting isn't perfect. It's only looking at the concentration of particles at different specific sizes, with 4 microns as the smallest reported size. Thus, there are short comings when trying to identify contaminant type or monitor for contaminants at smaller micron sizes, which are both very important in oil analysis. Also, interference challenges can exist with certain types of particle counters, and even sampling practices can play a large role in creating false positives or false negatives. All of this can be remedied with the right awareness, training and implementation of best practices.

Particle counting alone isn't the answer to preventing failure, but it is an essential element in nearly all oil analysis test slates. The value is even greater when considering a particle counter as an onsite oil analysis instrument to allow for more frequent and immediate answers to particle contamination concerns. Staying focused on the root cause is the theme behind effective proactive maintenance. This includes establishing optimum cleanliness targets, taking specific action to control contamination, and measuring contaminant levels frequently. This cannot be accomplished without vigilant practices using particle counts.


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Ajman, United Arab Emirates
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Fax +971 67458487
email toppoly@eim.ae
www.toppolymers.com
+971 50 369 0110
Agents :
SKYRUBLUBE SYNTHETICS
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345 Mount Road,
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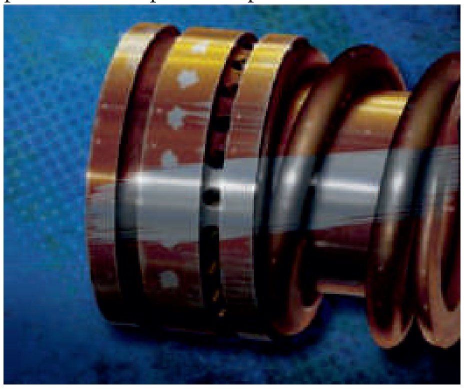
SOLUBLE AND INSOLUBLE VARNISH TEST METHODS FOR TRENDING VARNISH BUILDUP IN MINERAL TURBINE OIL

Varnish problems in the turbine oil of power plants in Thailand are still an issue today. The problems are the coefficient of oil friction, and will increase along with the increase in varnish concentration and varnish deposits. This creates problems in starting/re-starting the turbine. Even with the advent of oil manufacturing research to improve base oil quality and antioxidant additives, problems started by varnish contamination have been one of the most concerning issues for maintenance. The most recent version of ASTM D4378-20 suggests that maintenance personnel should test their in-service turbine oil and monitor the membrane patch colorimetry with a warning limit at ΔE 30. This monitoring test is known as ASTM D7843-20 Standard Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils using Membrane Patch Colorimetry (MPC). This study introduces the monitoring of soluble color bodies and insoluble ones at the same time. Focusing only on the value of insoluble-MPC test can sometimes be misleading and may cause inaccurate and ineffective maintenance decisions. For this paper, three power plants were monitored for both soluble and insoluble varnish, and both soluble and insoluble color body analytical results from in-service gas turbine oils will be presented. It will show how the use of a combination of soluble and insoluble color body assessments of the turbine oils would further improve the oil diagnostic services of turbine lubricants by providing insights into the capability of the lubricants to solubilize the oxidation by-products of the antioxidants and the highly refined base oil. Appropriate varnish removal technologies were also selected and applied to respond proactively to the varnish issues.

Introduction

Power plants, especially turbines, are expected to operate with high reliability and with controllable operating and maintenance costs. Turbines harness various types of kinetic energy generated by fluids such as water, steam and combustion gases, turning them into electrical energy. The most popular ones are the gas and steam turbines, which can be used individually or combined. The unexpected upsets in power generation are the undesirable occurrences that take place in power plants. Notwithstanding the obvious loss of electrical generating revenue, there may also be a penalty to the power plant for unexpected trips.



Because of this, choosing, using, and monitoring the right lube oil for the turbines is very critical. Turbine oils are needed to provide protection and contamination controlfor the turbine. However, the changes in gas-turbine designs over the last decade, coupled with the changes in turbine oil formulations, have led to a real and identifiable problem of oil-related turbine trips that are caused by an oxidation by-product of oils called varnish. The oxidation of the oil is a spontaneous process that, over time, may result in the production of these varnish products. Lubricant varnish generally is defined as athin, soft, lustrous, oil-insoluble deposit composed primarily of organic residue. These deposits are caused by thermal degradation, oxidation and/or contamination. They have limited solubility in the base oil. They can cause filter plugging and excessive wear on parts and could lead to the failure of bearings or other critical components, such as servo mechanisms (seizing). This varnish also results in a high coefficient of friction and restricts the movement of the turbine. Because of this, different Original Equipment Manufacturers (OEMs), such as Solar Turbines, Siemens, General Electric and Mitsubishi, recommend routine sampling and testing of lubricating oil quality (a more proactive approach to prevent serious problems), including monitoring oil's varnish formation potentials because varnish formation is a common issue to be monitored for in turbines, what ever the OEM is. The standard used for the monitoring of turbine oils is the ASTM D4378-20, Standard Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines. Varnish formation is monitored by collecting the insoluble colored bodies and measuring their color difference in reference to the InternationalCommission on Illumination (CIE) L*a*b color scale (more on this in section 2.2Determination of Insoluble Varnish). The difference between two colors in the L*a*b* scale is defined as ΔE. According to ASTM D4378, the ΔE of the turbine oils must not exceed 30. However, the monitoring of insoluble colored bodiesalone is not enough and might have blind spots regarding the oil and turbine health monitoring. This study aims to introduce the synergistic monitoring of soluble and in soluble varnish because soluble varnish is the first stage of insoluble varnish, and they must both be detected as early as possible.

In this study, in-service gas turbine oils from three different power plants were sampled and analyzed, including both insoluble and soluble varnish. The results presented here indicate that the monitoring of insoluble varnish together with soluble varnish improves the diagnostic and early correction of varnish problems in gas turbines.

2. Methodology

2.1 Outline

The in-service turbine oil samples were taken from three different power plants to analyze using methods based on the American Society for Testing and Materials (ASTM) stan dard and the modified method for soluble and insoluble membrane patch colorimetry (MPC). These three natural gas power plants have turbines generally operating with gas turbine speeds of about 5,250-6,600 rpm, exhaust temperatures of about 560-597 C (1040-1106 F), and out put power of 50-70 MW. The major inspections and maintenance are done every six years or 48,000 hours.

2.2 Determination of Insoluble Varnish

The method ASTM D7843-20 is known as insoluble MPC. Oil samples were mixed with petroleum ether and filtered through a membrane patch. The color of the patch caused by captured colored insoluble bodies was measured colorimetrically in the CIE L*a*b* color scale using a spectrophotometer. The L*a*b* is a three-dimensional color space that covers the entire spectrum of colors perceivable by human vision. The a* is positive towards the red direction and negative towards the green direction; b* is positive towards yellow and negative towards the blue direction. L* is positive towards the lightness direction and negative in the darkness direction. This color space system is produced by plotting the rectangular coordinates L*, a* and b*, which are defined by equations 1-4:

$$L^* = 116^*\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 \quad (1)$$

$$a^* = 500\left((X/X_n)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right) \quad (2)$$

$$b^* = 200\left(\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right) \quad (3)$$

$$\frac{X}{X_n}, \frac{Y}{Y_n}, \frac{Z}{Z_n} > 0.01 \quad (4)$$

$$\Delta E = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{1/2} \quad (5)$$

The tristimulus values of Xn, Yn and Zn define thecolor of the normally white object as a referencepoint (which, in this method, is the unused membrane patch), while the tristimulus values of X, Y and Z define the resulting color of themembrane patch after collecting the colored bodies brought by the insoluble varnish from the used oil sample. After the filtration and collection of colored bodies, the CIEL*a*b* color space was used to quantify small differences in color. The results were given as ΔE by equation 5:

2.3 Determination of Soluble Varnish

The modified method ASTM D7843-20 is known as the soluble MPC. This method uses the same patch and color measurement as the insoluble MPC method. The two methods differ in sample preparation, as the soluble MPC proceeds without dissolving the oil samples in a solvent. Samples were blotted directly onto a membrane patch without filtration. Because of this, all the color edbodies, both insoluble and soluble, were collected on the membrane patch. Colored oxidation by-products were deposited and separated on the membrane patch through capillary action. The color of the patch caused by captured colored bodies was also measured colorimetrically in the CIE L*a*b* color scale using a spectrophotometer, and the results were given as ΔE.

2.4 Additional Test Methods for Oil Condition Monitoring

2.4.1 Determination of Viscosity

Kinematic viscosities at 40 C (104 F) were measured using a viscosity bathapparatus and viscometers. The time for the oil to reach the starting point andend point in the viscometers was measured and multiplied by the viscometerconstant to calculate the viscosity. The method conforms to ASTM D445 .

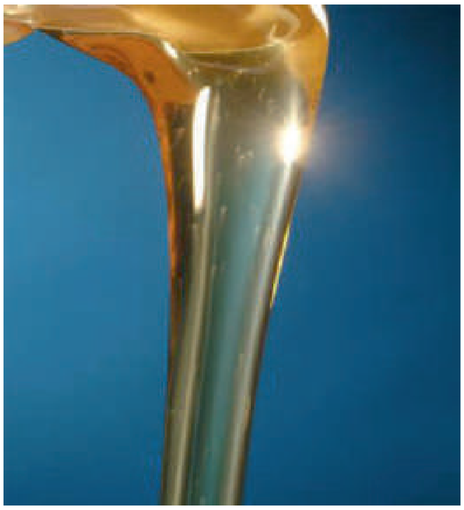
2.4.2 Fourier Transform Infrared Spectrometer

Analytical spectra of the oil samples were taken using a Fourier Transform Infrared Spectrometer (FTIR) instrument to monitor the oxidation effects. The sample cell was a potassium bromide (KBr) cell with a pathlength of 0.05 mm. The oxidation area of measurement was at 1800-1660 cm-1. The method conforms to ASTM D7414 .

2.4.3 Voltammetry

The relationship of oxidation, varnish formation and additive depletion was tested using a commercially available voltammeter and the remaining useful life evaluation routine (RULER) technology. Neutral electrolytic test solutions were used to monitor both aromatic amines and phenolic antioxidants. RULER's software calculates the remaining useful life (RUL %) of the oil per additive type. The method conforms to ASTM D6971-14.

2.4.4 Determination of Total Acid Number



As the oil oxidizes, it produces acidic by-products and becomes acidic in nature. Therefore, the monitoring of the total acid number is a handy tool for monitoring the age and usefulness of the oil. The oil was dissolved in a suitable solvent and was titrated against a basic titrant: potassium hydroxide solution. Total acid number was measured by recording the amount of potassium hydroxide needed to neutralize the acid present per one gram of the oilsample (mg-KOH/g sample). Total acid numbers were performed using ASTM D974.

2.4.5 Rotating Pressure Vessel Oxidation Test

This test method is to determine the oxidation stability of the oil. The tests were performed using a rotating pressure vessel oxidation test (RPVOT) instrument, subjecting the oil to a stressful environment consisting of water, a coppercatalyst, and high-pressure with oxygen. The antioxidants present in the oil samples resisted the oxidation brought by the extreme testing condition until all of them were consumed. This was reported in remaining percentage of oxidation stability. The method conforms to ASTM D2272

2.4.6 Particle Count

This test was done to determine the oil cleanliness using a laser particle counter. The cleanliness levels were represented by the classification system ISO 4406 standard [13], which reported the number of particles in >4 µm size, >6 µm size, and >14 µm size per 1 mL of oil.

3. Results and Discussion

3.1 Case Study #1

3.1.1 General

Plant #1's oil samples were taken for analysis every two months for a period of two years. Table 1 shows the summary of its oil analysis results. During outage, all accessible parts were inspected, particularly the reservoir, main journal bearing, and regulating valves. Varnish deposits were found on the bearing pad, as shown in Figure 1. gas turbine from gas separation plant.

Figure 1: Varnish deposit on bearing pad of gas turbine from gas separation plant.

3.1.2 MonitoringOxidative Health ofTurbine Lubricants

Upon analyzing other oil analysis parameters, there is a positive indication that these varnish deposits were due to oil degradation. Increasing oxidation levels were observed using FTIR analysis. Degraded oil had an increasing FTIR oxidation at 1713 cm-1, as seen in Figure 2. During the oxidation process, hydrocarbon molecules of base oil

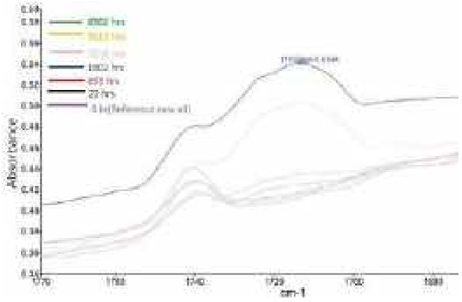


Figure 2: Increasing FTIR oxidation peak at 1713 cm-1 due to oil degradation.

will break down, and reaction products will be formed, including acidic by-products, varnish and sludge. The increasing trends of both oxidation and acidic by-products of oxidation are shown in Figure 3. As oxidation levels increase, the total acidic products present in the oil also increase. The increased number of these acidic products may escalate the production of other oxidation by-products, such asvarnish and sludge. The graph below shows that FTIR oxidation and total acid number both increase with the oil hours.

Due to the spontaneous course of oxidation, radicals, which are very reactive, might also be formed. Subsequent reactions of these radicals lead to the formation of peroxides. These by-products must be quenched by the antioxidants in order to preserve the lubricant integrity or its RUL. If the RUL of the oil reachesits critical state, the formation of acids, resins, and other undesired chemicalcompounds is inevitable; these are seen as final reaction compounds and meanthat it is too late to react with the turbine's maintenance or repair program.

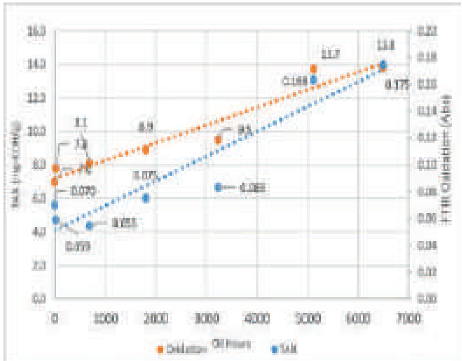


Figure 3: Relationship of increase in FTIR oxidation and increase in TAN

3.1.3 Deposit on Bearing Pad Related to Sludge on Insoluble-MPC Patch

Figure 4 summarizes the trend for both insoluble and soluble MPC. It is shown that soluble-MPC and insoluble-MPC increase with oil hours. The varnish life cycle can be explained : As soluble varnish builds up, the lubricant's saturation is eventually reached. At this point, any additional varnish produced will be insoluble since the capacity of the lubricant to hold varnish has beenexceeded. Therefore, continued degradation of an already saturated lubricant produces insoluble varnish particles, which can eventually agglomerate to produce deposits. In this case, both soluble and insoluble should still be lower than ΔE 30. Particle count is an early indicator of when the soluble varnish starts to become insoluble varnish. It shows that insoluble-MPC was responsible for the deposition of the bearing. The appearance of deposits on the bearing during power plant outage was observed, and it was confirmed that sludge formation on insoluble-MPC affects the deposit on the bearing pad, as shown in Figure 1.Monitoring the insoluble-MPC shows us if the varnish is already sticking out of the surfaces, while monitoring the soluble MPC gives us information on the saturation level of varnish in the oil, which could further lead to more sludgesticking on to surfaces. It is proactive to do so, so the early removal of the solublevarnish by varnish removal technologies (VRT) before transforming to the insoluble phase can increase the longevity of the oil life by keeping the oil in asoluble condition. Table 1 on page : 12 summarizes all the data for the oil analysis of Plant#1's turbine oil. Both the soluble (modified method, highlighted in yellow) and insoluble varnish (standard method, highlighted in blue) were tested for the oil samples.

Upon checking the summary of the oil analysis results from Table 1 on page 12 , the criticallevels of ΔE 30 for turbine oils based on ASTM D4378-20 are not applicable at all times to all oil types and equipment combinations. In this plant, their turbine already accumulated varnish problems even with their ΔE 24.6 — lower than the standard value of 30. This means that published OEM and ASTM limits are for general practices only. Trending and monitoring of oil analysis results, including the soluble and insoluble varnish potentials, along side physical examination of the equipment, are much better — the warning limits can be set specifically for each oil and equipment combination. Furthermore, the mechanical inspectionreveals that a better alarm limit would be lower than ΔE 24.6.

Monitoring the oil analysis results of the turbines, including both insoluble and soluble MPC for varnish monitoring, can help extend the life of the oil and overhauling schedules. Generally, most OEMs recommend major overhauls tobe done after 48,000 operation hours. But for this case, it can be seen that varnish and sludge had already formed at around 28,000 operation hours. Predicting and extending the life of the oil differs from one equipment and oil combination to another. First, the trend is established and monitored. Second, the root cause is examined, and appropriate action to address the problem is taken. In this case, since both the soluble and insoluble MPC were tested, varnish issues should be addressed. After ward, the unit will be monitored via oil analysis, personalizing the predictability and extension of the oil's life spande pending on analysis such as the RPVOT, oxidation level indicators, wear condition, and contamination condition.

Note: Equipment type (Gas Separation Plant), Lube Oil capacity (4,600 L), Oiltype (R&O Inhibited ISO 32), Antioxidant (Amine type).

3.2 Case Study #2

3.2.1 General

Plant #2's gas turbine oil routine samples were used to monitor quality and varnish buildup. Table 2 on page no 13. shows the summary of its oil analysis results.

3.2.2 Additive Depletion Related to Varnish Buildup

Varnish buildup is not only caused by oxidation but is also due to additive depletion. Figure 5 shows the decrease of % remaining aminic and phenolic antioxidant additives while both soluble and insoluble MPCs increase. The results also showed that the phenolic antioxidant depletes more rapidly than the aminic antioxidant. This phenomenon is known as premature phenolic depletion.

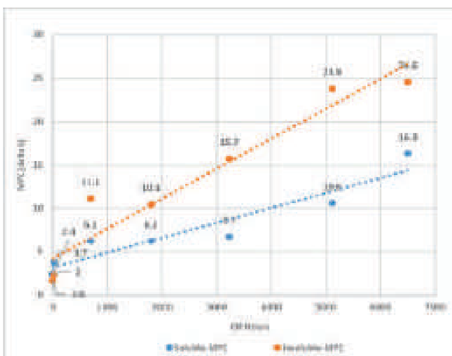


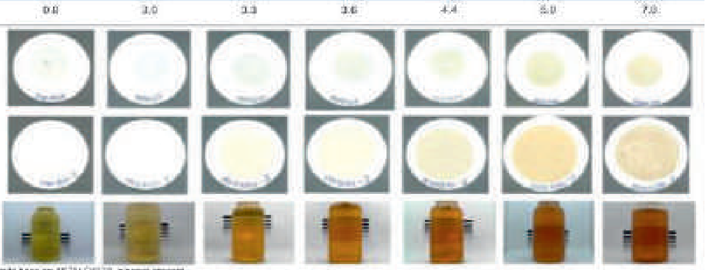
Figure 4: Increase of Insoluble-MPC and Soluble-MPC with oil hours.

Sequence #	Limit*	Reference	1	2	3	4	5	6
Date Sampled		New Oil	5/30/2019	6/27/2019	9/30/2019	16/01/2019	1/30/2020	5/28/2020
Oil Hours		0	22	690	1602	3230	5121	6592
Turbine Hours		-	22908	23579	24003	20122	28007	29391
Viscosity @40C, cSt	30.6-33.9	32.3	32.6	32.4	32.7	32.7	32.3	32.7
Water Content (%Wt)	<0.02	0.012	0.010	0.029	0.010	0.023	0.024	0.013
Total Acid Number (mg KOH/g)	<0.17	0.070	0.059	0.055	0.075	0.083	0.163	0.175
% Aminic AO Remaining	>25	100	99	92.5	90.3	88.8	87.7	78.4
% Phenolic AO Remaining	>25	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Particle Count > 4µm	<1300	656	2631	2463	6250	3808	6000	100511
Particle Count > 6µm	<320	80	193	121	1070	564	558	12559
Particle Count > 14µm	<40	6	11	5	24	83	46	2950
Oxidation (abs by FTIR)	<10.5	7.0	7.8	8.1	8.9	9.8	13.7	13.8
Soluble-MPC (ΔE)	<30	2.4	3.7	6.2	6.2	6.7	10.8	18.3
Insoluble-MPC (ΔE)	<30	1.6	2.3	11.1	10.3	15.7	23.8	24.6
Sludge Weight (mg/100ml)	<10	0.0	3.0	3.3	3.6	4.4	5.0	7.0

Soluble-MPC view

Insoluble-MPC view

Sample bottle



Note : *Warning limits base on ASTM D6378, n/p=not present

Table 1: Oil analysis results for Plant #1 turbine oil.

The rapid phenolic depletion is also explained by the phenolic acting to preserve or protect the amine antioxidant, combined with the oxidation resistance of turbine oil. As indicated in Table 2 on page 13, RPVOT has not yet declined to 50%; however, the oil begins to form sludge. A problem related to the varnish issue is the phenomenon of additive depletion. Aminic type additives are used as an antioxidant, and phenolic types are usually used for demulsifiers and varnish control. Both aminic and phenolic type additive depletion was monitored using linear sweep voltammetric analysis to quantify the remaining concentration of antioxidants by comparing the voltammetric response of the new oil against the used oil. The earliest sign of oil degradation is detected with linear sweep voltammetry since the antioxidants are the most reactive species in the turbine oils, and they are the first to be depleted.

3.2.3 Particle Count Related to Insoluble-MPC

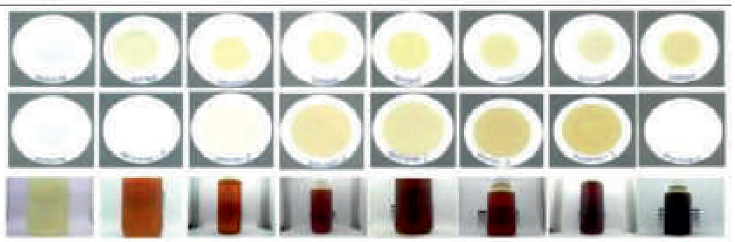
Laser particle counter results are in accordance with ISO 4406, which counts suspended particles in oil. In this standard, particles larger than 4 µm, 6 µm and14 µm are examined and counted. As seen in Table 2, there is a correlation between particle size greater than 4 µm and insoluble-MPC. Moreover, it is observed that the sludge weight also increases with insoluble-MPC. In this case, when the MPC reached ΔE 30,the power plant decided to use a VRT, a depth media filter, to clean the oil system. Depth media filters are stacked disc filters that can filter out suspended soft contaminants. After depth media filtration, the insoluble-MPC and particle count data improved. If tested only for insoluble MPC, the results might give the impression that the problem was already solved because the insoluble-MPC and particle count levels improved. However, as seen in Table 2, the values for soluble MPC are still above the warning limits of ΔE 30. This means that the oil is still saturated with varnish up to its saturation point, and sooner or later, insoluble varnish will stick onto the surfaces again. The application of the current VRTalone is not addressing the root cause of the problem. A depth media filtration system can remove the insoluble sludge, but the problem of soluble varnish-

Sequence #	Limit*	Reference	1	2	3	4	5	6	7
Date Sampled		New Oil	7/3/2019	3/11/2020	6/18/2020	12/23/2020	3/28/2021	6/29/2021	10/18/2021
Oil Hours		0	7709	13308	15308	19497	21514	23368	25948
GasTurbine Hours		-	7709	13308	15308	19497	21514	23368	25948
Viscosity @40C, cSt	41.1-46.8	43.4	42.0	43.1	43.0	43.4	43.2	43.2	43.1
Water Content (%Wt)	0.020	0.012	0.017	0.019	0.017	0.012	0.021	0.022	0.011
TAN (mg-KOH/g)	0.17	0.07	0.044	0.053	0.086	0.141	0.137	0.135	0.008
% Aminic AO Remaining	25	100	95	98.4	94.3	93.6	93.1	89.1	87.6
% Phenolic AO Remaining	25	100	60.7	31.6	31.4	37.8	29.4	19.5	14.2
RPVOT % Oxidation Stability	25	100	90		87	85		83	
Particle Count > 4µm	<1300	309	15029	6669	17926	10917	28194	31806	328
Particle Count > 6µm	<320	82	7373	5233	3388	2754	21979	9156	88
Particle Count > 14µm	<40	26	1403	1433	1486	185	2369	20	13
Oxidation (abs by FTIR)	<19.5	13.0	14.8	15.4	16.9	15.6	16.1	15.2	14.9
Soluble-MPC (ΔE)	<30	1.2	24.9	27.7	34.5	44.1	38.8	24.5	41.7
Insoluble-MPC (ΔE)	<30	1.6	6.9	5.4	32.4	21.4	40.0	57.8	2.6
Sludge Weight (mg/100ml)	<10	1.0	1.2	3.8	4.4	7.9	12.1	22.2	1.8

Soluble-MPC view

Insoluble-MPC view

Sample bottle



*Warning limits base on ASTM D4378

Table 2: Summary of Oil Analysis results for Plant #2.

Note: Equipment type (Combined cycle gas turbine), Capacity (126 MW), Lubeoil capacity (12,000 L), Oil type (R&O Inhibited ISO 46), Antioxidant (Aminic andPhenolic type).

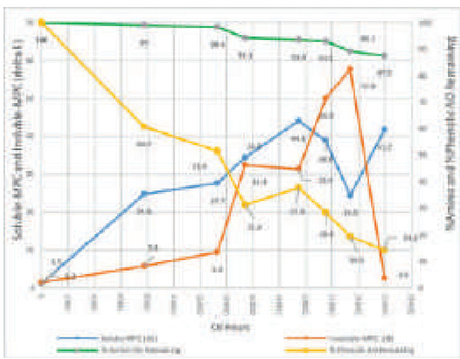


Figure 5: Decrease of antioxidant additive related to the increase of soluble and insoluble MPC.

cannot be addressed. Through monitoring of the soluble sludge, a more suitable VRT can be applied to address the problem and prevent the enhanced rate of insoluble varnish for mation. Electrostatic filters are other options under VRTs that can also address the soluble varnish. Deciding the appropriate VRT to use to address varnish problems will be made easier if both soluble and insoluble MPC are monitored. If the varnish present is in an insoluble state, depth media filters can be used. If the varnish present is in a soluble state and is already problematic because it is near the saturation point of the oil, electrostatic filters can be used. Electrostatic filters use electrostatic precipitation and balance-charge agglomeration concepts to catch even the charged soluble varnish. Ion exchange resin technology is also a type of VRT that can remove organic soft contaminants.

Also, according to Table 2, the phenolic antioxidant levels for this sample already-dropped to critical levels. The dropping additive levels should also be addressed to decrease the saturation level of the oil. This is an example of how soluble-MPC can show the varnish-holding capacity of the oil and, conversely, if the oilhas reached the varnish saturation point.

3.3 Case Study # 3

Plant #3 oil analysis results are summarized in Table 3. Gas turbine oil of small power producers (SPPs) power plant was monito red. There is an over heating problem with this turbine system. The base oil degrades through thermal degradation. Coking can occur and can produce insoluble black suspended particles that are carbonized products caused by the rmal degradation; this is not necessarily varnish. However, since these carbonized products are also insoluble in oil and are also colored bodies, they become interferences on insoluble MPC results. Instead of a brown patch, a black patch was observed on the insoluble MPC results, as seen in Table 3.

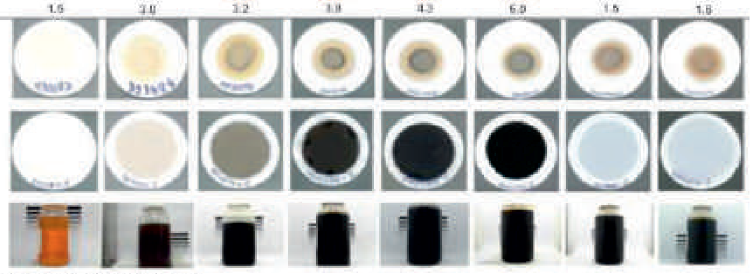
According to ASTM D7843, MPC color of the patch residue is measure dcolorimetrically in the international CIE L*a*b* color scale and darkness with color analyzer. The black insoluble particle directly affects the insoluble-MPC. The dark color of these particles interferes with the color analyzer in CIE L*a*b*color scale. In this example, a color measurement reading of CIE L*a*b* ΔL would have yielded more trend able results than the ΔE measurement since ΔL is the black-white axis and ΔE are color axes. There by the insoluble-MPC shows a very high reading which is not varnish. Some of the black suspended particles are carbonized products caused by thermal degradation;

Sequence #	Limit*	Reference	1	2	3	4	5	6	7
Date Sampled		New Oil	11/22/2017	2/27/2019	9/9/2019	2/14/2020	3/27/2020	4/28/2020	6/28/2020
Oil Hours		0	4325	16126	20976	22932	23962	27168	29468
GasTurbine Hours		-	153624	164424	170290	173258	174240	176472	177792
Viscosity @40C, cSt	29.6-32.7	31.2	31.4	31.8	32.1	32.1	32.0	32.0	32.2
Water Content (%Wt)	<0.02	0.01	0.01	0.02	0.02	0.03	0.02	0.02	0.01
TAN (mg-KOH/g)	<0.4	0.15	0.20	0.13	0.23	0.18	0.18	0.12	0.11
% Aminic AO Remaining	>25	100	80.4	75.7	70.7	66.2	62.4	57.3	56.9
% Phenolic AO Remaining	>25	n/p	n/p	n/p	n/p	n/p	n/p	n/p	n/p
Particle Count > 4µm	<1300	355	611	8263	30645	28253	21244	318	238
Particle Count > 6µm	<320	71	102	97	712	900	15279	58	50
Particle Count > 14µm	<40	8	13	14	17	15	79	12	4
Oxidation (abs by FTIR)	<12.9	8.8	9.2	9.7	10.0	10.6	10.7	10.0	10.0
Soluble-MPC (ΔE)	<30	2.1	17.4	30.7	31.3	33.7	35.8	37.8	39.5
Insoluble-MPC (ΔE)	<30	1.5	16.9	41.4	68.3	89.5	75.4	12.1	12.0
Sludge Weight (mg/100ml)	<10	1.5	3.0	3.2	3.8	4.3	6.9	1.5	1.8

Soluble-MPC view

Insoluble-MPC view

Sample bottle



*Warning limits base on ASTM D4378, n/p=not present

Table 3: Summary of Oil Analysis results for Plant #3.

Note: Equipment type Small Power Producers (SPPs) Power Plant, Capacity(113 MW), Lube oil capacity (20,000 L), Oil type (R&O Inhibited ISO 32),Antioxidant (Aminic type).

these aren't varnish.The trending for varnish formation using only the insoluble MPC method might be misleading and can lead to inaccurate and ineffective decisions On the other hand, the soluble MPC method can directly differentiate the varnish (brown stain) and the coking products (black stain). Through this, the varnish potential of the sample can be measured and interpreted without interference from the coking products. After the power plant used an off-line filtration to clean the black particles, the insoluble MPC results improved a lot; however, the soluble MPC results still show varnish in the turbine oil. This implies that the oil is at its saturation point, and sooner or later, insoluble varnish might stick out again on the surfaces.

4. Conclusion and Recommendation

Today's power plants face several lubrication oil related challenges. Therefore,the following are recommended:

1) Power plants should investigate the use of lubricating oil for the long-term economic benefits.

2) Unexpected turbine trips due to varnish are problems that can be resolved through routine monitoring of the lubricant properties, which includes combined soluble and insoluble MPC tests for varnish potential testing, in tandem with the improvement of contamination by using purification systems.

3) The synergistic effect of testing both soluble and insoluble MPC helps give more effective and accurate decisions: interferences are eliminated, and other root causes can be justified. The appropriate varnish removal technology can also be applied depending on the results of both soluble and insoluble MPC. These two tests combined give a more complete view of the varnish potential of the oil, rather than waiting until the varnish problems become severe.

5. Acknowledgment

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CONDITION-BASED OIL CHANGES: **SAVE MONEY AND PROTECT THE ENVIRONMENT**

Protecting the climate and saving energy and resources are topics that are right on trend. Almost every company is working hard to reduce its carbon footprint. Meanwhile, with manufacturing costs only rising in recent months, returning a profit is becoming increasingly difficult. Savings, wherever possible, are on everyone's agenda, and all operational processes are being put in the spotlight. Too often, however, little attention is paid to lubricants. Even if higher-quality premium lubricants are used for the first time, they are often replaced far too early because they have always been changed at fixed intervals or because it has been stipulated by the oil supplier.

However, when lubricants are monitored properly (e.g., using OELCHECK all-inclusive analysis kits), they can be changed based on their actual condition. At the same time, the analyses detect contaminants and any wear processes, ensuring the systems' operational safety. This means the cost-effective analyses pay for themselves in short time.

If oils are changed based on their condition instead of at fixed intervals, you'll be doing your bit for the environment. Fewer oil-changes mean:

- Less need for fresh oil
- Less oil extraction and crude oil transport
- Fewer energy-intensive refinery processes
- Less transport of fresh and used oils
- Less reprocessing or disposal of used oils

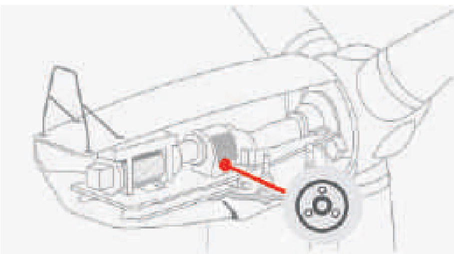
The bottom line is that fewer oil changes reduce the formation of CO_2. The production and disposal of lubricants alone creates CO_2 emissions of approximately 1.5 kg CO_2 per liter of oil. However, fewer unnecessary oil changes also have an additional effect that should not be underestimated, particularly in today's climate — they have a positive effect on the cost balance sheet. We illustrate the amounts involved using two practical examples.

3MW Wind Turbine —Main Gearbox

The components in a wind turbine are hard to access. Inspections, maintenance work and oil changes take place at high altitudes, and failing components result in lengthy operational interruptions. Changing the oil just once costs several thousand euros.

Components in a wind turbine require a range of different lubrication oils, greases and coolants. To clarify the cost-benefit balance of condition-dependent oil changes, which are accompanied by oil analyses, only

the 1,100 liters of synthetic gear oil that lubricate the planetary gear of a 3MW system have been taken into account in the example. Analyses of the gear oil carried out every six months have shown that the gear oil's service life can be doubled from 30,000 operating hours (5-6 years) to 60,000 operating hours (10-12 years).



Initial situation

Component: Planetary gear of a 3MW wind turbine
Gear oil type: Synthetic CLP gear oil ISO VG 320
Oil volume: 1,100L
Costs per litre of gear oil: Approx €9.50

Costs for changing the gear oil after 30,000 operating hours Fixed interval; no oil analysis costs	
Gear oil	€10,500
+ Loss of production [3MW* €0.2* 6 hours]	€3,600
+ Service technician [external]*	€1,500
Total	€15,600

Costs for changing the gear oil after 60,000 operating hours based on 12 OILCHECK all-inclusive analyses	
Gear oil	€10,500
+ Loss of production [3MW* €0.2* 6 hours]	€3,600
+ Service technician [external]*	€1,500
+ 12x OELCHECK analysis kits [approx. €80/kit per year]	€960
+ 12 x 2-hour service technicians €80/hour for sampling*	€1,920
Total	€18,480

Savings on an oil change after 60,000 operating hours instead of 30,000 operating hours	
Total costs for two oil changes every 30,000 operating hours	€31,200
Total costs including oil analyses after 60,000 operating hours + service technician [external]*	€18,480
Cost savings after 60,000 operating hours [10 years] Annual cost reduction	€12,720 Approx. €1,000

* Values are approximate and rounded

Goods Vehicles —Euro 6D Six-Cylinder Diesel Engine

A well-known German freight forwarder is leading the way in reducing CO2 emissions. They have around 150 trucks on their books that run solely on biodiesel (B100), which reduces CO2 emissions by around 80% compared to running on diesel (B7). With an average consumption of 33 liters per 100 kilometers and a mileage of around 120,000 kilometers peryear, each heavy goods vehicleemits 70 tons less CO2 each year.

Unfortunately, there's a catch. Several years of findings relating to running engines on pure, non-esterified rapeseed oil indicate that engine manufacturers still stipulate that B100 engine oils should be changed at shorter intervals. This should eliminate the risk of increased fuel entry when running on B100 and any subsequent damage to the engine. To meet the engine manufacturer's warranty conditions as defined in the lease contracts, the freight forwarder had to shorten the oil change intervals from the usual 120,000 kilometers to 30,000 kilometers. Shortening the intervals led the cost accounts for oil changes and the CO2 balance sheet to soar due to the following:

- The amount of used and fresh oil increased four-fold
- The costs for changing the oil and the associated downtime quadrupled
- Additional, avoidable CO2 emissions generated during the production, transport and disposal of engine oils

Based on the initial situation, the freight forwarder and OELCHECK launched a trial in collaboration with the truck manufacturer.

Initial situation

Components:
Four Euro 6D six-cylinder diesel engines in long-haul trucks
Engine oil type:
SAE 5W-30 based on polyalphaolefin and ester, meets the specifications ACEA E4, E6, E7, E9; API CJ-4; JASO DH-2
Oil volume: 41.5L per engine

Costs for changing the engine oil	
Includes fresh oil, oil filter and labour	
According to the freight forwarder's specifications	€500

As part of the test, the engine oils in the four trucks with Euro 6D six-cylinder diesel engines were analyzed every 5,000 kilometers. The limit values of the individual parameters were agreed upon with the vehicle manufacturer in advance. In this light, the following values came under particular scrutiny in the OELCHECK lab: any B100 fuel entry into the engine oils, a change in viscosity, oil oxidation and wear parameters. The short analysis intervals of 5,000 kilometers acted as a safeguard so we could intervene at short notice should serious deviations be detected, therefore avoiding significant damage to the engines.

In all four trucks, the engine oils reached the 30,000-kilometer milestone — the point at which an oil change would otherwise have been due, according to the manufacturer's instructions — without presenting any issues. The oil quality also returned good results at that point. The oil showed signs of aging in the following 30,000 kilometers (up to 60,000 kilometers). However, this proved to be within scope. As expected, the fuel content in the oil increased throughout the test. The fuel entry was only proven to be moderate in all four vehicles observed, and the viscosity did not change as a result. The limit values agreed with the manufacturer were never reached, while wear metals could only be detected in low concentrations.

Saving per truck with an extended oil change interval after 90,000 kilometres	
Previous costs for two oil changes every 60,000 kilometres2 x €500	€1,000
Current costs for an extended oil change interval after 60,000 kilometers	€500
Annual cost savings per truck	€500

The analysis data showed that the vehicles' oil should be changed every 90,000 kilometers. To be on the safe side, however, the vehicle manufacturer involved in the test approved extended oil service intervals of up to 65,000 kilometers based on the data established for the haulage vehicles used in long-haul transport. The freight forwarder, which runs over 150 vehicles on biodiesel (B100), would save over €75,000 in engine oil costs per year due to tripling the oil change intervals as determined by the oil analyses. In addition to the cheaper biodiesel costs, the for warder would secure a much more favorable cost structure in the much-discussed freight for warding industry as well as a better CO2 balance.

TASK-BASED TRAINING | INSPECTING A COLUMNAR LEVEL GAUGE

What is a columnar level gauge?

A columnar level gauge is a type of sight glass. It is a tube made of clear material that, when installed on a machine, allows the oil to be seen and shows the oil level. These tubes are typically installed on a lower port or drain of a machine. Once installed, the tube is filled with oil.

Figure 1: A columnar level gauge filled with oil.

Why use a columnar level gauge?

A columnar level gauge provides a quicker and more insightful level reading than some of the other oil indicators like dipsticks, plugs, etc. Additionally, a columnar level gauge will allow some aspects of the lubricant's condition to be inspected: these gauges allow inspectors to see particulates, debris, emulsified water, darkening oil or the formation of varnish.

Why inspect a columnar level gauge?

The sight glasses themselves must be inspected because they have the potential to become damaged or stained over time. Inspection of the sight glass should also focus on ensuring that the device is properly installed and functioning. Depending on how they are vented, columnar level gauges may not be reading or breathing properly, so they need to be checked regularly, especially when they are installed with breathers, tubes or valves.

Figure 2: A columnar level gauge installed with a desiccant breather.

When we are confident that the columnar level gauge is in working order, we can use it to inspect for early warning signs of machine or lubricant failure —previously mentioned issues like cloudiness, darkening oil, or the presence of particulates.

Where are they installed?

The lubricant storage component of most machines has several ports. When choosing where to install the columnar level gauge, you'll want to select a port that is lower than the oil level. You'll also want to make sure that the column extends slightly above the oil level. This allows the true oil level to be seen in the sight glass.

Figure 3: A columnar level gauge installed at the proper level.

It is also a good idea to implement a shut-off valve that can be used to quickly shut the port if the columnar sight glass breaks.

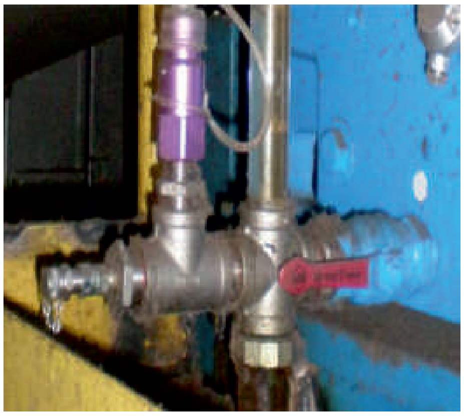


Figure 4: A columnar level gauge with a shut-off valve.

The top of the columnar level gauge can also be piped back into the headspace. This forms a closed loop and ensures any air the columnar is breathing has gone through the breather installed on the machine.

Figure 5: A columnar level gauge with a pipe leading to the machine'sheadspace.

When you are installing a columnar sight glass, it is important to install it in sucha way as to avoid trapping oil in the gauge. To avoid this, you'll want to use as few fittings as possible and install the device straight on to the machine. Upwardor downward bends in the pipe connecting the gauge to the machine will prevent the free flow of oil.

Figure 6: The bends in this pipe will trap oil in the gauge.

How do columnar level gauges work?

Columnar level gauges use fluid pressure from the oil to create an equilibrium, meaning that, as long as oil flow between the machine and the sight glass is unobstructed, the level of oil in the sight glass will be the same as the level in the machine.

Figure 7: An equilibrium between the lubricant in the machine and the lubricantin the sight glass.

Because fluid pressure alone is used to create an equilibrium in the lubricant levels, closed valves or plugged breathers can restrict the free flow of lubricant and air, making the gauge inaccurate.

Which levels should be marked?

Columnar level gauges should have two to three bands or marks identifying different oil levels. The first level to mark is the cold oil level; you'll then want to measure and mark the oil level while the machine is running: this level may be higher or lower than the cold oil level. Finally, you will want to mark the critical oil level: the level that the oil should not drop below. Having this marked llows anyone walking by the machine to notice if the oil is too low and more oil is needed.

Who inspects columnar level gauges?

Typically, the operators, engineers and maintenance personnel are the ones inspecting these sight glasses. But because these sight glasses clearly indicate oil level, anyone walking by the machine can inspect it.

Inspecting a columnar level gauge

Step 1: Clean the surface of the level gauge with a lint-free industrial towel. Usea flashlight or laser pointer to illuminate the fluid within the sight glass.

Step 2: Check the oil level. It should fall between the "okay" level mark:

Figure 8: The "okay" level indicator.

And the "low/add" level mark:

Figure 9: The "low/add" level indicator.

Step 3: If the oil level is below the "low/add" mark, look for any signs of leaks, and report right away. If the oil is above the "okay" level mark, look for signs of water or process fluid ingression.

Step 4: Check the bottom of the columnar level gauge for particulates; look for signs of foam, and examine the oil color for cloudiness and darkening.

Step 5: Report any of the previously mentioned issues, as well as issues like abnormal temperature, vibration or noises.

Key Takeaways

- Ensure columnar level gauges are installed in easy-to-see locations.
- Ensure oil level indications are clearly marked.
- Inspect oil condition in addition to oil level.
- Record and track your findings.

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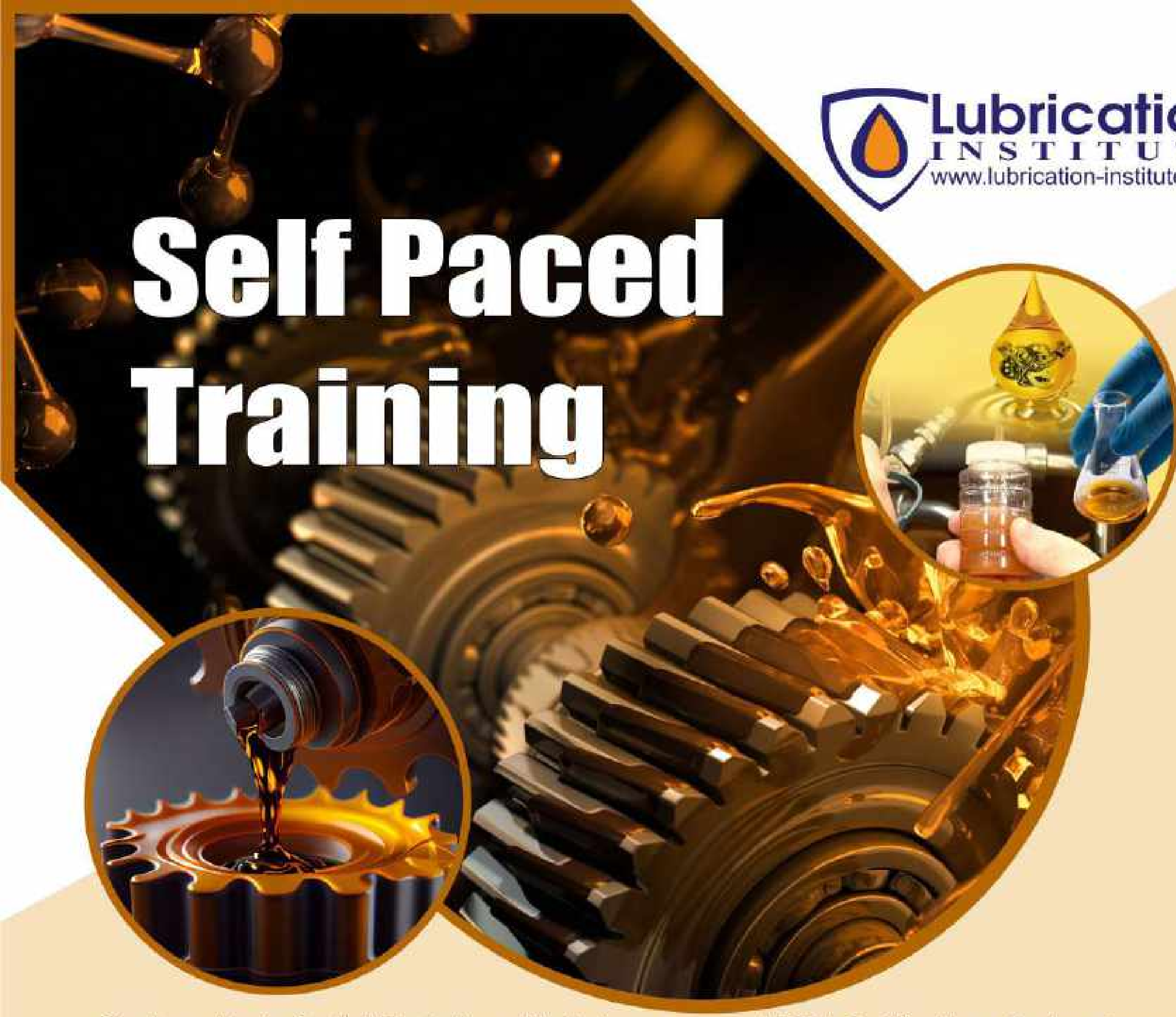

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LUBRICATION PROGRAM DEVELOPMENT: ASSESS, PLAN AND EXECUTE

Achieving a goal doesn't happen on a whim. My personal process for achieving goals is to assess, plan and execute — this is very similar to the process that can help your plant achieve its lubrication goals. Your facility should have reliability goals, and within those goals lie lubrication-specific goals.

Assess

The first step in developing or improving a lubrication program is an assessment— to get where you want to be, you need to know where you currently are. What should you do to prepare? As an experienced assessor, I can tell you that the best answer is "Nothing." Don't do anything to prepare for an assessment besides collecting the necessary information about the plant and machinery.

When undertaking an assessment, we want to see the lubrication program as it stands at this very moment. Don't start implementing changes to try to improve the results of the assessment; just focus on gaining an understanding of exactly where the program is at — then, we can worry about where to go and how to get there.

The assessment is a thorough look at the current lubrication program. Every facet of the program, from lubricant selection to disposal practices and everything in between, must be analyzed utilizing a cradle-to-grave approach.

The assessment should be as thorough as possible and ultimately deliver two very important pieces of a program. Number one is the Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. This is what

I like to call the"quick-hitters" — short-term improvements that should be and can be quickly improved upon. Second is the full report of the analysis. This detailed report should outline all of the current practices and improvement recommendations moving forward. That is the roadmap to building a world-class lubrication program.

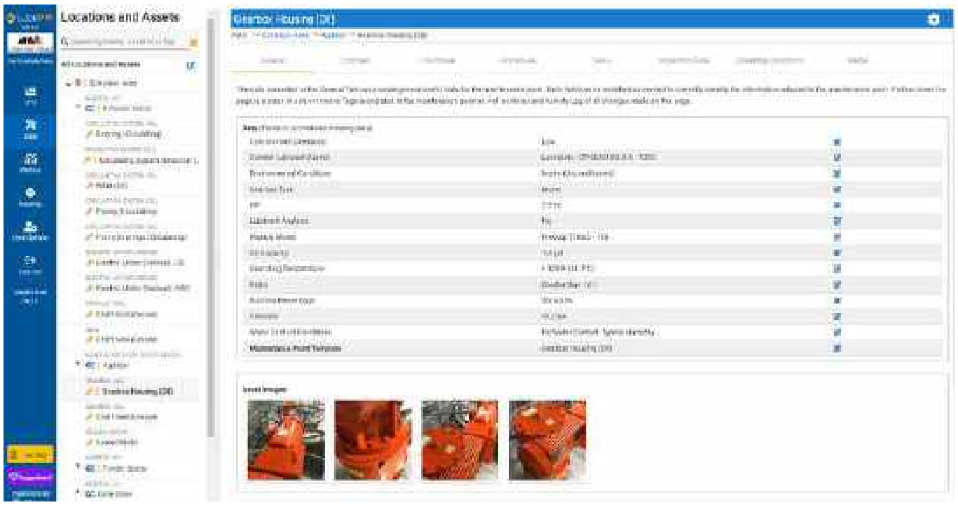
Plan

Now that the assessment is complete, the plant needs to make a plan for action. With program impact numbers, you can quickly and efficiently make a plan to implement changes in the highest priority areas. Let's say, for example, that based on the assessment score, a plant needs to focus on Contamination Control Objectives first. This is going to give the plant the greatest gains in the shortest amount of time. Second, they can start to implement changes in their Lu-

bricant Storage and Lube Rooms. As you see in Figure 1, there is a three-letter ID that corresponds to the section of the assessment report with the improvement recommendations for that part of the program. It's important to prioritize the initiatives for your company to make a plan. I always say when things are easy to do, they get done right.
So now, the facility has made a plan to improve the lubrication program. A big part of the plan, especially when it comes to Contamination Control, is generally Contamination Control Hardware, i.e., breathers, BS&W bowls, sight glasses, etc. Remember, in any lubrication program, the name of the gameis contamination exclusion and removal: keeping that lubricant clean, cool and dry.

The next phase involves the collection of pertinent data on all rotating and lubricated machinery: bearing sizes, HP, RPM, environmental severity, operating condition, and many other data fields. With the collected information, contamination control hardware and optimal lubricants can be selected, and we can consolidate all plant lubricants. Regarding lubricants, focus should be specifically placed on viscosities, base oils and additive packages (and thickeners, if grease is being used).

All of this information should then be stored in a Lubrication Management Software (LMS). A lubrication program management software can allow you to view all of the aforementioned data fields. You can view and edit data, images, hardware recommendations, and lubricant recommendations. It should also have the capability to make lubricant identification tags and labeling and even buildand manage the lubrication routes right at your fingertips. This is all of yourplant's data organized, planned, and ready to execute improvements.



Execute

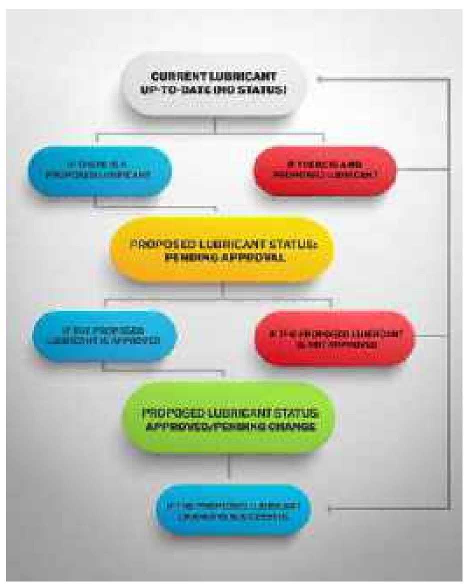
"Most leaders would agree that they'd be better off having an average strategy with superb execution than a superb strategy with poor execution. Those who execute always have the upper hand."

- Stephen R. Covey

We're not reinventing the wheel here. We have sought out our weaknesses, assessed, prioritized, and planned. That all means absolutely zip if we do not execute. Before execution, we have to review the data collected. We always must account for human error in any project. Trust then verify. After reviewing the data fields and making the necessary edits, we then need to review all of the recommended hardware and lubricants. By review, I mean to approve or deny the change. The program managers need to review the recommendations and make a decision on moving forward with the recommendations, tracking all changes along the way.

After everything is reviewed and approved, it's time to build and implement routes to enact all the changes across the plant — the map has been created, and now it's time to start the car. The route is then assigned to a technician and scheduled by the program manager to implement the change. Once approved, assigned and scheduled, it is now the technician's job to physically implement the change and complete the route. Think about that last part — "Physically implement the change." That is, by definition, exactly what Execution is. It could be installing hardware, changing lubricants, installing labels, etc.

Once the change has been physically implemented, the technician then enters "route-completed" into the handheld device of their choosing and effectively communicates that the work is done. The information is then sent back up the chain of command. Every single detail and task is tracked with LMS-software. The importance of tracking is due to the amount of time it takes to implement this much change over a large plant with hundreds or even thousands of assets. This could take years; remember, this is a marathon, not a sprint.



Gerardo Trujillo | Noria Media

DISPERSANCY TESTING

Soot is the by-product of incomplete combustion in diesel engines and, as I see it, one of the least understood in oil analysis. Soot can accumulate in the engine oil over time and is one of the reasons why oil needs to be changed. When the levels of soot in the oil become too high, it can cause a range of problems, including wear, depletion of additives, and deposits.

Although injection systems have significantly improved in modern engines to maximize the fuel's heat output, and blends with biodiesel are used to reduce the generation of particulate matter, exhaust gas recirculation systems that produce more soot in the engine have also been incorporated. Soot has always existed— it's just more prevalent now.

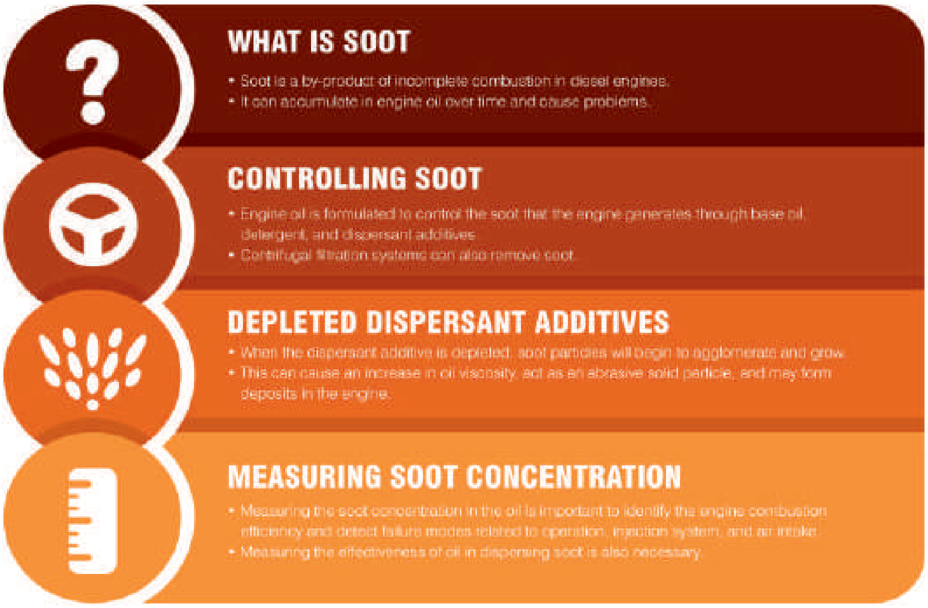
Engine oil is formulated to control the soot that the engine generates through the base oil, detergent, and dispersant additives. Engines can also incorporate centrifugal filtration systems that can remove soot.

When an engine generates soot, the additive disperses it through spherical stabilization based on the principle of polarity (attraction between polar compounds) between the soot particle and the polar compound of the additive. The additive has an oil-soluble section, and in this way, it remains in suspension in the oil. By surrounding the soot particle with dispersant additives, its polarity

is deactivated, preventing the soot particles from agglomerating and keeping the mat a size between 0.02 and 0.2 µm. With increasing operation hours, the dispersant additive may become depleted if the amount of soot generated in combustion is too high or due to overextended oil change intervals.

When the dispersant additive is depleted, the soot will begin to agglomerate and grow, forming clusters of 2 µm or larger. These agglomerated soot particles will cause an increase in oil viscosity, act as an abrasive solid particle, and may form deposits in the engine. Studies on the effect of oil contaminated with soot on engine wear indicate that an excess of soot can interact negatively with anti-wear additives or compete with them for metal surfaces, decreasing their protection. This has a greater impact on those areas and components that work with limit and mixed lubrication regimes.

When evaluating fleet performance or seeking to extend oil change intervals, very few-consider the lubricant's ability to disperse soot loads and usually rely on the correlation of viscosity increase with soot concentration in the oil. This correlation, although correct, could be a signal that is too late when it comes to finding the optimal oil change time and the reliability of the engine. An increase in viscosity caused by soot means that it is already too late to change the oil. Viscosity increases when the dispersant has been depleted, and now the soot is agglomerated and deposited on the engine surfaces. A simple oil change will not be able to remove that soot, and the new oil charge will see its ability to protect the engine diminished.



Measuring the soot concentration is very important as it allows for identifying the engine combustion efficiency and detecting failure modes related to operation, injection system, and air intake. Changes in the soot formation trends should be investigated to prevent major problems. However, measuring the soot concentration in the oil is not enough when it comes to increasing the reliability of these engines — it is also necessary to measure the soot dispersancy.

To measure the effectiveness of oil in dispersing soot, the ASTM D7899-19 standard “Standard Test Method for Measuring the Merit of Dispersancy of In-Service Engine Oils with Blotter Spot Method” is the most accurate method. Unlike the traditional blotter spot test, which depends on the visual interpretation of a specialist and is subjective, this method defines a standard method of blotter preparation to ensure consistency and uses a charged coupled device (CCD) to take a photograph of the drop and analyze it pixel by pixel to measure different parameters such as how far the drop travels on the paper, the size of the drop center, and the homogeneity ratio of the drop’s opacity compared to a theoretical reference pattern of 32 mm in diameter.

To qualify the dispersancy condition of the oil, the method defines seven observation zones that allow identifying the amount and type of contaminants in the oil. Due to the physical phenomenon of lamination, particles of the same size will be deposited on the paper in concentric zones. The compounds of larger size and weight will be in the zone closest to the center, while the medium-sized and small particles, along with oxidation products, will be in the following zones; at-the outermost end, a transparent halo may form, corresponding to the base oil. The distribution of particles in the different zones determines the dispersancy condition of the oil.

The more contaminant particles the oil has, the darker the drop will be, and the larger the diameter of the drop, the better the oil’s dispersancy. When dispersancy fails, the soot particles will be agglomerated and will not travel with the base oil, showing a small, pasty black center and a large, transparent outer halo.

The type of paper is as important as the amount of oil when preparing the drop. The method specifies a drop of 20 µl of oil on the paper must be placed in an oven at 80 C (176 F) for one hour to facilitate the formation of the drop, which must be inspected within the next 60 minutes, as the drop may continue to grow.

The test apparatus (AD Systems DT 100 DL Dispersancy Tester) calculates the diameter and Contamination Index (CI) by measuring the grayscale of each pixelin the droplet and dividing by the total number of pixels. The software then calculates the Dispersancy Merit (MD) by measuring the homogeneity and distribution of the droplet opacity and comparing it to an ideal reference of 32 mm.

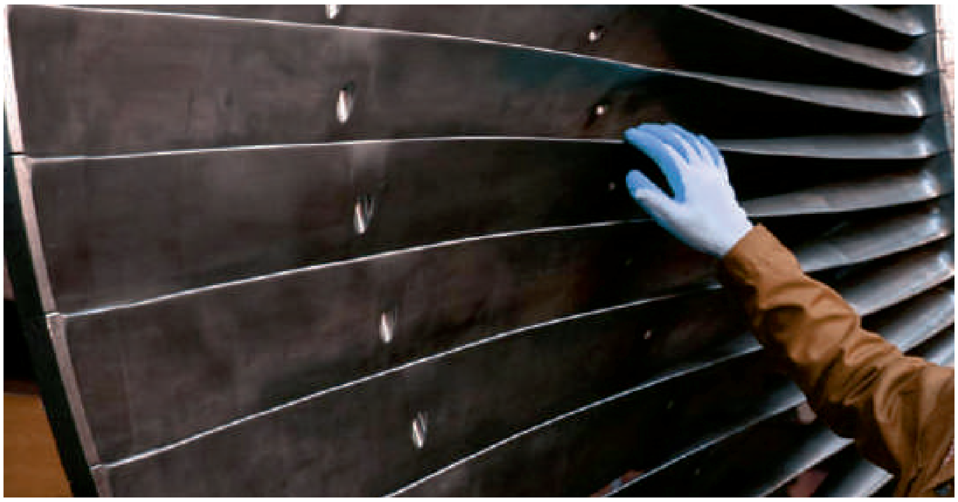
The most important result is the Dispersancy Merit (MD) value, which indicates the oil’s ability to suspend soot and is expressed as a number from 0 to 100. (MD= 0; poor dispersion: the contaminants are all concentrated in the center of the oil spot in the test; the soot is agglomerated. MD = 100; excellent dispersion: the distribution of the soot on the filter paper is homogeneous). Additionally, the Contamination Index (CI) can be considered, which is the concentration of insoluble soot in the diesel engine oil and is expressed as a weight percentage and can range from 0% to 4.8%. Weighted Demerits can also be calculated using the following formula: DP=(100-MD) *CI. In the coming years, we will see more and more fleets looking to extend their oil change intervals to reduce their carbon footprint. The dispersancy test will be essential in achieving this objective for a reliable engine.

Assessing Oxidation Condition and Lubricant Refreshment in Turbine Oils

Turbines are critical equipment for power plants and industries. Varnish formation is the first root cause of downtime and loss of reliability in turbines. Lubricant oxidation conditions can be effectively monitored through RULER, MPC and RPVOT tests. Besides the nominal value they offer, significant information can be gathered from digging into these tests and integrating their outcomes.

One major application for this integration is the estimation of the lubricant refreshment for lean operation. Through lab tests, this can be accurately estimated, planning ahead of the upcoming maintenance intervention.

This method will be shown together with case studies.



1. Introduction

Turbines are critical equipment for power plants and heavy industries. Turbines are expensive equipment that must operate reliably; in the case of heavy industry, downstream operation fully depends on their power generation. In power plants, downtime implies production loss and penalties for contract non-compliance.

In turbines, lubrication undergoes a hydrodynamic regime in which wear arises only after very poor lubricant conditions. Conversely, the main root cause of turbine failure is the formation of deposits.

Deposits produce several detrimental effects on these systems, such as sticking valves, orifice obstruction and inefficient heat exchange. Deposits can also have different natures, i.e., inorganic, organic or biological (Wooton & Livingstone, 2013).

In the case of gas turbines, where the lubricant suffers mainly from thermal stress, deposits are usually associated with the formation of varnish. Varnish is commonly associated with oxidation processes and is composed of sacrificed antioxidants and oxidation products that coalesce to form sticky soft matter. The cost of varnish is very high, both in downtime and in equipment replacement. For this reason, monitoring the oxidation condition of turbine oils is of utmost importance.

To prevent the base oil from oxidation, turbine lubricants are additized with about 1% of antioxidants. These antioxidants sacrifice themselves to protect the base oil from free radicals and oxidative stress. It is usually accepted that turbine oils can be used until their remaining active antioxidants are 25% of the original formulation. In many cases, however, depending on the oil, varnish issues arise before this point. Both laboratory tests (Yano et al., 2004) and turbine oil condition monitoring show that varnish may start to build up even when remaining antioxidants are as high as 60%.

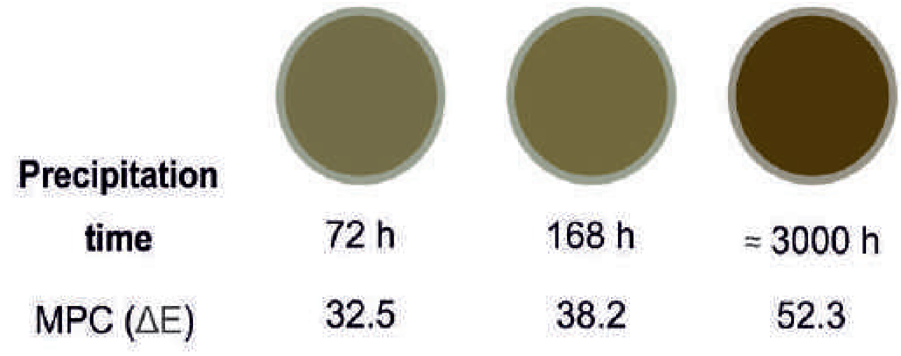


Figure 1: MPC is a standardized method in which precipitation time is critical. A turbine oil was heated to 60˚C (140˚F) for 24 hours and stood to precipitate for 72 hours, 168 hours, and four months before filtering and determining MPC value. The results show that MPC significantly rises with longer precipitation times.

To keep the operation reliable, the oxidation condition of a turbine must be kept between safe boundaries. This implies keeping antioxidants high dose, the varnish potential low, and prognosticating a high oxidation resistance. Oil refreshment is a viable option to keep turbines free of varnish. By integrating the outcomes of lubricant analytics such as RULER, RPVOT and MPC, it is possible to estimate the refreshment required to keep the turbine under lean operation.

2. MPC, RPVOT And RULER Are Complementary Tests in Oxidation Condition Monitoring

2.1 MPC

Membrane Patch Colorimetry (ASTM D7843) is a method for determining varnish formation in mineral turbine oils. In analytical chemistry, procedures can be classified as either end point or standardized. Typical end point procedures are titrations such as Acid Number (ASTM D974) or Karl Fischer (ASTM D6304). In these, the test ends with an end point indicator, which can be colorimetric, potentiometric, amperometric, etc.

Conversely, MPC (ASTM D7843) is a standardized procedure. In this procedure, the lubricant must be heated at 60˚C (140˚F) for 24 hours. This mimics the turbine operation temperature and re-dissolves varnish. After heating, the oil must stand for 72 hours in the dark for the varnish to re-precipitate. This is the critical standardized step since varnish precipitation increases with time.

After filtering through a 0.45 µm-pore membrane, the color of the patch is measured using the CIELAB color space, and the ΔE, which indicates intensity, is measured. A higher ΔE (or MPC) indicates that more varnish has been retained by the membrane patch. The consensus is that an MPC > 30 is condemning, MPC > 20 is alarming, and MPC < 15 is a safety zone.

A sample was filtered after different precipitation times to prove the criticality of the precipitation step. Figure 1 shows MPC results for an oil after 72 hours precipitation, 168 hours precipitation, and four months after oil sampling (≈ 3000hours). The results show the importance of keeping standardized times to have repetitive results, which can be trended for adequate condition monitoring.

2.2 RPVOT

The Rotating Pressurized Vessel Oxidation Test (ASTM D2272) is an oxidation simulator. Briefly, a sample of lubricant is pressurized at 190 psi under an oxygen atmosphere at 150˚C (302˚F) and rotated in the presence of a copper catalyst and water vapor. The time curve of the vessel pressure is recorded. During the test, the lubricant tends to oxidize due to the high oxygen potential.

In the first stages of the test, antioxidants sacrifice themselves to protect the base oil, and therefore oxygen pressure remains steady. Once antioxidants are fully depleted, the base oil starts bulk oxidation, and oxygen pressure drops.

ASTM D2272 defines the induction period of a lubricant as the time until the pressure drops by 25.4 psi. Figure 2 shows the RPVOT curves for different lubricant formulations. In the case of turbine oils formulated with Group I base stocks (Figure 2a), the RPVOT curve remains steady until the antioxidants are depleted. It is usual to see intermediate inflection points showing titration of each antioxidant.

Once antioxidants are depleted, the base oil suffers massive bulk oxidation, and the pressure drops sharply. In the case of Group II base stocks (Figure 2b), RPVOT curves also present an initial steady phase during antioxidant protection, but later, oxygen pressure declines in a gradual manner. This accounts for the enhanced resistance of hydro-treated base stocks to oxidation. However, this does not imply an enhanced resistance to varnish formation. Hydrotreated basestocks are less polar than Group I base stocks, and therefore varnish is usuallyless soluble in Group II base stocks.

Finally, Figure 2c shows an RPVOT curve for a polyol-ester base aeroderivative turbine oil. This case is interesting because the vessel remains pressurized at about 100 psi, indicating the formation of gaseous species as oxidation products. Also, in this case, the endpoint of the test, according to ASTM D2272, falls far from the pressure drop.

From this, we learn that a lot of information is present in the complete RPVOT curve and therefore this test should not be stopped after a 25.4 psi pressure drop but should be continued until the pressure drops by at least 90 psi.

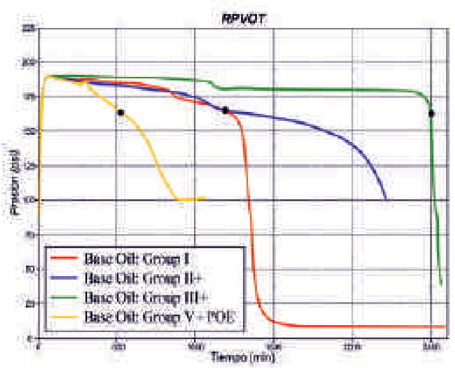


Figure 2: RPVOT pressure graphs for different new turbine oils. Lubricants have different RPVOT curves depending on the base oil and antioxidant formulation. The ASTM test was designed for Group I oil (red), in which the standard induction period (•) coincides with oxidation of the bulk oil.(Blue) shows the curve for a Group II+ base lubricant and (green) for a Group III+ GTL-based lubricant. (Yellow) is the RPVOT for an aeroderivative polyol-ester base lubricant. In both (b) and (d), the standard induction period is far from the bulk oxidation. For this reason, RPVOT tests should bedriven until a 90 psi pressure drop.

2.3 RULER

RULER is a voltammetric method for dosing antioxidants. Briefly, an oil aliquot isdiluted in a vial, which extracts the antioxidants and decants the base oil. The sample is then probed under a potentiostat with a linear increasing voltage applied. Each antioxidant, depending on its nature, is oxidized at a specific potential and an amperometric peak arises.

In oils additized with aromatic amines and phenols, two peaks can be observed. The area under the curve for each peak is proportional to the antioxidant concentration. The area of an in-service lubricant compared to that of its original formulation dictates each remaining antioxidant percentage in

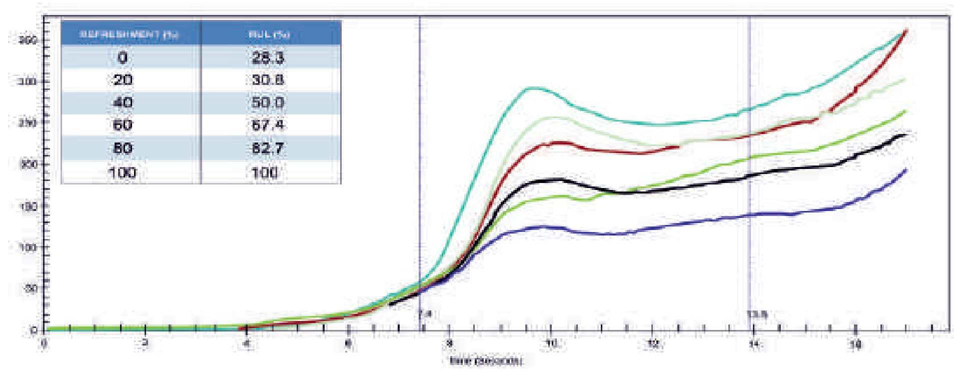


Figure 3a

the in-service oil. An educated reading of the amperogram provides additional information on the health of the in-service oil. As the oil degrades, it is seen how the antioxidant peaks shift from their original potential.

RULER is an excellent methodology for monitoring the remaining active antioxidants. Given that the method actually oxidizes the antioxidant, the result is trusty of the real remaining antioxidant potential. However, when the remaining antioxidants are very low and the peaks are very shallow, it is possible to make errors in the antioxidant quantification, typically in excess.

Excess quantification in degraded samples is dangerous because should antioxidants completely deplete, the lubricant will fall into massive oxidation in a very short period causing huge damage. To prevent from falling into this analytical pit, it is possible to better estimate the remaining antioxidantpercentage by extrapolation.

When preparing mixtures of new and used oil, we can define the Refreshment percentage such that:

- Refreshment = 0% implies used oil
- Refreshment = 100% implies full lubricant replacement

Consider the following case study of a gas turbine with a mineral ISO VG 32 lubricant additized with aminic antioxidants after 43,000 operation hours. The RULER for this sample resulted in 28.3% antioxidant, very close to the condemning limit.

To better assess the RULER value, we proceeded to perform the extrapolation method. For this, complementary mixtures of new and used oil to cover 0% to 100% refreshments were prepared. After thorough homogenization, RULER was tested for all samples. Figure 3 shows the RULER outcome.

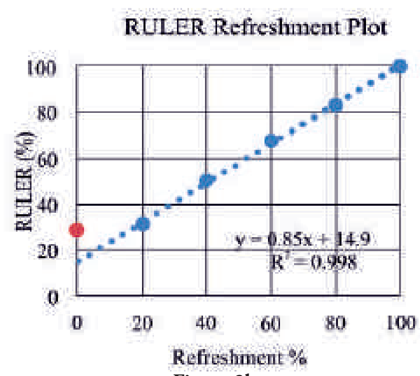


Figure 3b

Given that the prepared samples are a mixture of new and used oil, the remaining antioxidant percentage must be linear. However, if we plot the seresults (Figure 3b) we can see how the plain in-service oil (0%R) clearly falls out of the linear curve. Hence, the actual remaining antioxidant concentration in the in-service oil is 14.9% (y-intercept) and not 28.3% as would have been estimated by the traditional RULER method.

Through RULER analysis, it is also possible to check the synergy between antioxidant chemistries. Turbines usually operate using a mixed antioxidant lubricant. This is a mixture of phenols and amines. Amines and phenols work synergistically in keeping the base oil healthy. Amines are reactive antioxidants that rapidly take free radicals protecting the base oils by terminating chain reactions that would otherwise degrade the base oil. Hindered phenols, on the other hand, are slower reactants, but have the potential to regenerate the oxidized amines and become stable free radicals themselves (Fig. 4b).

RULER analyses can demonstrate antioxidant interaction. Consider a gas turbine lubricated with a Group I oil additized with a mixed antioxidant package. This system has run for 55,000 operating hours with a 10% refreshment after 44,000 operating hours. Refreshment plots were performed for this lubricant.

Figure 4 shows the synergic effect of aminic and phenolic antioxidants. In the plain in-service oil, the phenolic antioxidant has completely depleted and the aminic antioxidant keeps 70% of the original formulation.

If antioxidants would not interact, the refreshment plots should be linear for each antioxidant, as shown in the dotted lines. Instead, when a 40% Refreshment sample is analyzed, it is observed how the aminic antioxidant recovers by excess to a 93% and how the phenolic antioxidant recoves by defect, only to a 25%.

During the preparation of the RULER test, the phenolic antioxidants have regenerated the aminic antioxidants almost to their full potential. This reaction is immediate compared to the turbine operation time scales.

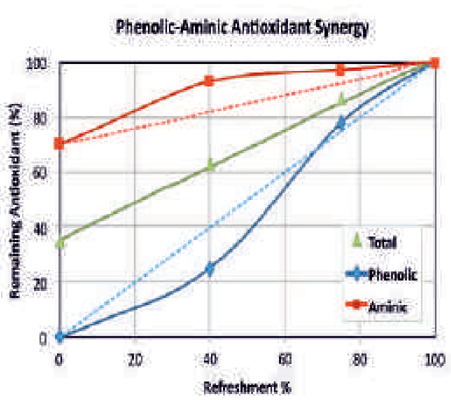


Figure 4a

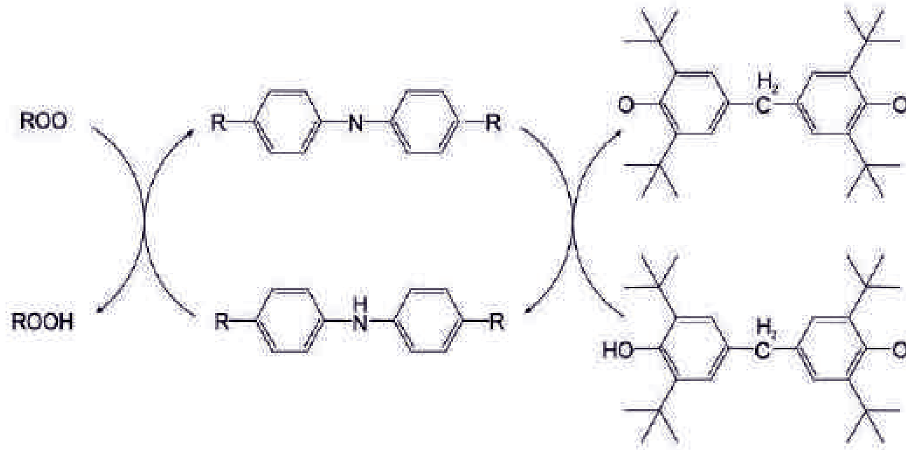


Figure 4b

Figure 4. Refreshment plots are a useful tool to verify antioxidant synergy in turbine oils. (a) A turbine oil depleted of phenolic antioxidants was refreshed with new oil. The dotted lines indicate the theoretical behavior without lubricant interaction. While the total antioxidant trace is linear, experimental data for aminic antioxidants are higher than the linear trace, and experimental data for the phenolic antioxidants are lower than the theoretical trace. This indicates that fresh phenols regenerate oxidized amines. (b) Chemical reactions showing amine refreshment by fresh phenols. Figure extracted from Gatto et al, 2006 & 2007.

We can also calculate the Total Antioxidant Percentage as the sum of the antioxidants areas in the in-service oil divided by the sum of the antioxidants areas in the fresh oil. The reader and analyst should be aware that calculating the Total Antioxidant Percentage is different from the analytic named Total RULER in the RDMS software.

Most interesting, the Total Antioxidant Percentage draws a perfect linear fit, a fact that correlates to the model. From the condition monitoring perspective, the fact that a lubricant keeps full synergy between antioxidants indicates that antioxidants have not oxidized irreversibly. Should irreversible oxidation occur, it would be expected to find a high varnish load in the oil and on the lubricated-surfaces of the gas turbine.

3. Building an Oxidation Condition Model for Estimating Lubricant Refreshment

The motive for integrating oxidation condition analysis and performing refreshment plots is to plan lubricant refreshments for turbines. In order to build a model for lubricant refreshment, one must assess the different scenarios that exist between the actual condition of the turbine and a hypothetical situation resulting in a full lubricant change. The study will be conducted on the gas turbine described in Figures 1 and 3. This gas turbine is lubricated with a Group I - ISO VG 32 oil additized with aminic antioxidants. The lubricant has been in service for 43,000 hours.

For this analysis, the lab will need to count with 1L of in-service turbine oil plus 1L of fresh oil. Analyzing the in-service oil, we find the following data:

In-service Oil		**New Oil**
RULER	14.9 %	100 %
RPVOT	142 min	1369 min
MPC	34	1

The oxidation condition of the lubricant is poor, and a project to analyze the oxidation condition and to propose a lubricant refreshment was commissioned to the lab. At first, MPC and RPVOT tests were performed for 0% and 100% Refreshments. As we have shown, RULER analytics of degraded samples can be quite uncertain, so full refreshment analysis was conducted, where the actual remaining antioxidant resulted to be 14.9% instead.

The preliminary model shows that antioxidants fall under the recommended 25%.

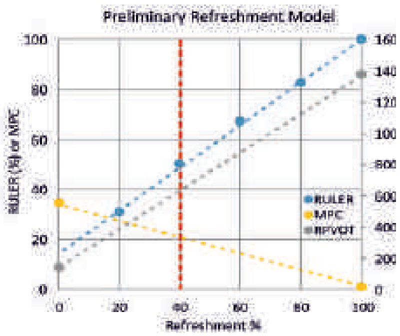


Figure 5. Preliminary model for turbine oil refreshment. The preliminary refreshment model is built with the MPC and RPVOT data of the in-service and new oils and the refreshment RULER data. The preliminary model allows to make a gross refreshment estimation for MPC and RPVOT refreshment simulation.

RPVOT shows a similar trend, being the in-service induction period only 142 min, about 10% of the fresh oil result. This value, in agreement with the RULER, is very low and may result in bulk oil oxidation in the short term.

Lastly, the MPC value of 34 has exceeded the alarm limit and is close to the condemning value. The preliminary conclusion is that the lubricant in this turbineis getting close to the end of its life cycle, however, if a full change is not possible, refreshment can help the turbine run reliably in the meantime.

The desirable oxidation condition for the turbine to run lean should be:

- ANTIOXIDANT > 50%
- MPC ≈ 15
- RPVOT > 500 minutes

According to the preliminary model, this can be achieved if a 40% of the lubricant is changed. In such a scenario, antioxidants rise to 50%, MPC is reduced to about 21, and RPVOT can be estimated in about 600 minutes. However, to have better confidence in the prediction, 40% Refreshment samples are prepared for RPVOT and MPC analysis. With this data, we can build the following iterated model presented in Figure 6.

The RPVOT value for the 40% refreshment is significantly higher than the expected RPVOT for the linear model. This trend is seen in all refreshment studies. It is interesting to compare this trend with that of RULER.

In the RULER analysis, we can see a curve with a perfect linear fit for the total remaining antioxidant percentage. This is a consequence of direct antioxidant additions when making Refreshment samples. On the other hand, RPVOT assesses the whole oxidation condition including antioxidants and base oil. From this, we can learn that even though antioxidants prevent the base oil from degrading, these are not 100% effective and during the aging of the lubricant, the base oil also suffers to some extent.

Another lesson that can be learned from this analysis is the reason why lubricants form varnish before the antioxidants run short. The MPC for a simulated 40% refreshment was reduced from ΔE = 21, as would have

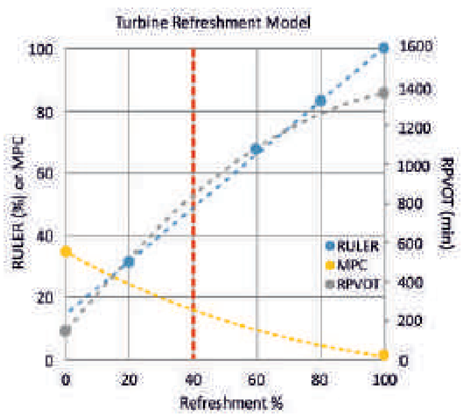


Figure 6. Turbine Oil Refreshment Model. The preliminary model is refined with experimental data for MPC and RPVOT of 40% refreshments. The RPVOT value of the refreshed sample is higher than the predicted linear model. Also, the MPC value is lower than the predicted linear model.

been expected by a linear model, to ΔE = 16. This is also a significant reduction in the varnish formation potential. It is a normal statement in the condition monitoring community that adding fresh oil to a system helps to re-dissolve varnish to some extent. When adding fresh oil to a system the saturation of molecules with varnish potential decreases and a fraction of these dissolve inthe oil. This partially explains why the MPC value drops. However, this cannot explain the observed "synergistic" effect.

As explained above, the MPC procedure involves varnish re-dissolving and standardized re-precipitation. In a refreshment sample, varnish becomes more diluted, and this results in a slower re-precipitation which can influence the MPC reading. To test this, 40% refreshment samples were heated at 60˚C for 24 hours and stood to precipitate for either 72 or 168 hours.

Figure 7 shows that after one week of precipitation, the MPC values rise, indicating that the precipitation did not reach an endpoint after 72 hours. Given that the rate of precipitation is slower when samples are diluted with fresh oil, the "synergic effect" in the MPC value observed in the refreshment plot is probably due to this phenomenon.

To further assess this phenomenon, refreshment plots were made for the MPCvalue of samples precipitated for either standard 72 hours or experimental 168 hours (Fig 8b). Interestingly, the refreshment plots for the 168-hour precipitation are linear (Rsq = 0,9996), a fact that correlates with a simple dilution effect. In conclusion, in laboratory procedures, oil refreshment does not have a synergic effect on varnish solubilization.

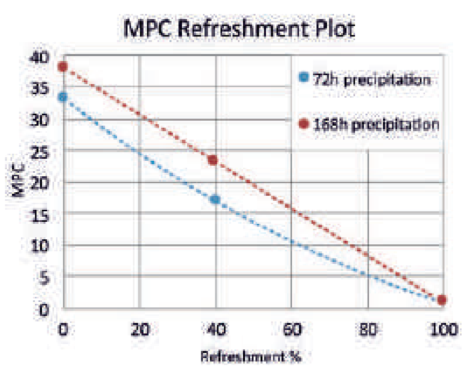


Figure 7. MPC is a standardized method in which the precipitation time is the critical step. 40% refreshment samples were heated for 24 hours and stood for either 72 or 168 hours before filtering. Refreshment plots for 72 or 168 hours precipitation are built together with the data from Fig. 1.When samples are precipitated for 72 hours, the 40% refreshment MPC value is lower than that predicted by a linear model. Conversely, when thesamples are precipitated for 168 hours, the refreshment plots are linear, which correlates with simple dilution.

Varnish solves in and out of the oil as a function of temperature. When scaling the results to an actual turbine, we should bear in mind that refreshed oil will decrease the varnish saturation, and at operational temperatures, may solubilize varnish deposits in the system. For this reason, after lubricant refreshment, it is usual to find a preliminary fall in the MPC value which rises according to when deposits are solubilized.

Even though from the lubricant condition perspective this looks as if there has been no progress, from the turbine condition perspective the lubricant is chemically removing varnish from surfaces which is indeed a desirable effect.The best practice, in this case, is to couple the turbine to a varnish mitigation system.

4. Refreshment Proposal

After studying the full model, we are prepared to propose the intervention on the turbine by refreshing 40% of the lubricating oil. This option will result in a 50% antioxidant charge, a RPVOT of 849 minutes, and an MPC of 16. Under this condition, the turbine is equipped for lean operation in the short term.

However, given that the original MPC is very high, it is reasonable to think of deposits in the turbine surfaces re-dissolving. This might rise in the MPC in the short term, hence it is recommended to install a varnish mitigation system together with the oil replenishment.

Refreshment models allow us to analyze turbine oxidation conditions in depth. This results in understanding the potential of an in-service oil and the expected performance of the turbine in the short and mid-term, focusing on the prevention of varnish and on reliability enhancement. Finally, the methods allow us to propose maintenance actions – exact and educated oil refreshment and recommendations on varnish mitigation.

5. Refreshment Strategies

Different from the commissioning of new turbines, refreshment studies are applied to operating machinery, in which every case study is different. Differences arise in the condition of the turbine, in the maintenance and economical strategy of the machinery owner, and in the available services in each region.

There are several strategies for maintaining antioxidants, high-dose, and oxidation conditions with in reliability parameters. The first line in keeping the antioxidants high is the regular lubricant top-off. This makes up for about 5% of the lubricant per year. In each addition, fresh antioxidants are introduced into the system. However, 5% each year does not usually satisfy the total oxidation rate in a turbine, so an additional strategy must be applied.

There are two possible paths to follow – bleed and feed or antioxidant replenishment. Bleed and feed is the conservative option. This option is expensive from an economical perspective because when bleeding oil from the turbine, unless the oxidation has gone too far, the base oil molecules are usually not oxidized (Living stone, 2014). In this way, even though only the antioxidants (1%) needed refreshment, the bled base oil (99%) is wasted.

The other cons in bleed and feed is that when an oil refreshment of 30% or more is needed, the antioxidants in the new oil refresh oxidized antioxidants both in the in-service oil and those forming reversible deposits. In this way, 1,000 hours after refreshment, the dosed antioxidant tends to be less than expected. However, making bleed and feed is the safest procedure for refreshing the lubricant.

When making bleed and feed, as long as the same lubricant and good lubricating practices are kept, there are no concerns about formulation-derived incompatibilities. Even though the procedure may be expensive, it is acceptable for many industries. Also, bleed and feed is a fast operation. Depending on the turbine and on the required refreshment percentage, bleed and feed can be done without stopping operation or with minimal downtime.

The second possible strategy is additive replenishment. In this strategy, an antioxidant concentrate is slowly fed to the turbine oil with minimal in-service oil bleed. In this way, the base oil is conserved, and antioxidants are re-dosed to a desired level. This strategy must be carried out by an experienced formulator who has intimate knowledge of the chemistry of the base oil and the antioxidants in the system, and the chemistry of the deposits formed in the particular system.

Additive chemistry is a complex science – as we have shown, additive chemistries interact, and this interaction can be either synergic or antagonistic. Synergy accounts for the regeneration of aminic front-line antioxidants by fresh phenolic antioxidants. On the other hand, when turbine oil forms varnish, it is heavily composed of both fresh and oxidized antioxidants. When reformulating in-service oil, it is of utter importance that formulation-derived deposits will not be formed.

One major issue to consider is that when adding antioxidants to an in-service oil, the total antioxidant concentration, dead or alive, rises, and without a keen knowledge of the system, this may easily result in antioxidant precipitation or undesired reactions between antioxidant species taking place inside the turbine to form varnish.

To achieve high reliability, the compatibility and performance of both the concentrate and the reformulated oil must be extensively tested in a laboratory. Testing must include characterization of the resulting physical properties, functional properties such as foaming, air release, demulsibility and prognostication the aging, and resulting oxidation condition of the reformulation.

Lastly, tests defying deposit formation must be passed. Once the chemistry of the additive replenishment is adequately tested, the in-plant execution must be carefully driven by recognized technicians. This accounts for assuring adequate mixing of the fluids, avoiding precipitation, and having a contingency plan if deposit formation should arise.

Conclusion

In conclusion, additive replenishment is the best option from an economic perspective. From the technical perspective, excellent results are achieved, and successful projects have multiplied the in-service period of turbine oils. However, it is a practice that implies higher risks and is usually planned and executed by third-party services.

Even though gas and steam turbines are spread through out the world, it is not possible to find in all regions adequate laboratory services for testing and technical services for in-plant execution of these projects. In these cases, even though economically more expensive, bleed and feed procedures continue to be carried out.

Authors

Andrés B. Lantos, Sebastián Lauría, Andrés Bodner, Gabriel Lucchiari, and Esteban Lantos
Laboratorio Dr. Lantos - Wearcheck Argentina
Buenos Aires, Argentina
Dave Wooton, Wooton Consulting
Beaverdam, VA, USA

LUBMAT IBERTRIB 2024 "The closest encounter between industry and science" 18th-20th June 2024 San Sebastian - SPAIN

LUBMAT was a common initiative between TEKNIKER and JOST Institute for Lubrication and Tribology. Both realized that, even though there were numerous international congresses dealing with the scientific approach for lubrication and wear, there were not any specific industrially focused. So that LUBMAT intends to address the industrial public without losing sight of the academic and scientific vision.
The conference slogan "The closest encounter between industry and science" seeks to reinforce the links between actual practice in companies and research and development, which enables us to innovate and create products and services with increased added value.

On this occasion, LUBMAT conference a well-established event that is in its 9th edition is held together with the 12th Iberian Conference on Tribology, IBERTRIB a biennial symposium assembling researchers working on Tribology from Spain and Portugal, alternating the location between both countries.

Contributions are expected, until the 19th of January 2024, on all aspects of these three main topics:

- Lubricants And Lubrication Management
- Tribology
- Maintenance 4.0 And Condition Monitoring

Travis Richardson | Noria Corporation

THE IMPORTANCE OF A LUBRICANT LIST

One practice I often see at plants I travel to is the kitting of parts and materials. This might be for a minor repair or a major shutdown where many worn components are replaced. The back bone of the kitting process is to have a list of materials and parts each machine uses.

This data is usually kept in a CMMS system and updated as old machines are mothballed and replaced with new ones. Kitting would be impossible if it weren't for this "catalog" of parts in the CMMS system.

Along the same lines, something that always baffles me is when I ask what lubricant is being used in a particular machine, and half the time, the answer is,"I'm not sure." If all the other data for a machine is listed in the CMMS, then why isn't the Lubricant? Is the lubricant not one of the most important pieces to keep the machine running?

Over the years, I have heard many reasons why, including:

- "They're on the poster in the lube room."
- "The lubricant in the CMMS system is old – we don't even carry that lubricant anymore, so we don't look there for it."
- "Our technicians know in their head what lubricant is to be used."

This is where a Lubrication Management System (LMS) can help.

A critical component of an LMS system would be a list of all lubricants used on-site. I emphasize "all" because I have seen many times a list of lubricants being used that are of a particular brand; if another brand is being used on a "one-off"machine, it will not be included in this list.

Other key components that should be housed in the LMS pertaining to lubricants-would be:

- An image of the lubricant tag or label
- Brand name of the lubricant
- Lubricant Identification System (LIS) code for that particular lubricant
- The applications in which the lubricant is being used
- The Safety Data Sheet & Technical Data Sheet (SDS & TDS)

Lubricant Tag

The lubricant tag is a quick way of knowing what lubricant is used in a:

- Bulk storage tank
- Sealable & Refillable (S&R) jug

- Grease gun
- Filter cart
- Maintenance point

When building a lubricant tag, three things should be included: color, shape and text that might be the specific brand and name of the lubricant or the LIS code of the lubricant. Adding some sort of text is important in case there is a technician on site that may be color blind. Having a quick, easy way of making tags is also essential.

Brand Name of the Lubricant

I know this seems like a no-brainer, but youmay be surprised how many lubricant lists I find that lack the actual name of the lubricant. I often see things like 68 Hydraulic Oil or Mobil ISO VG 220. While this detailhelps break it down a little, neither points to the exact lubricant to use.

We all know thousands of ISO VG 46 hydraulic oils are out there, and Mobil makes several types of ISO VG 220 Oil. With this little information, we still have that lingering question of what oil is truly being used in a machine.

If using the brand name of a lubricant for labeling purposes, you need to remember that if lubricant brands are changed at the plant, your labeling system is now out of date. Sometimes it is best to use a generic code like the one listed below.

A sample of a LIS label

Lubricant Identification System Code

ISO 6743 is the standard for lubricant classification. In short, this standard breaks down the lubricant by make-up (base oil and additives) and by application to assign an ISO Symbol. This system uses great detail without getting too far in the weeds.

One code you might have seen before is HM for use in general Hydraulic Oils. On Noria lube tags, you will also find the ISO VG of the lubricant, the base oil, and for grease, the thickener used, as well as the NLGI grade.

You may ask yourself why this information belongs on a lubricant list, which is a great question. Imagine If you create a lube tag with the brand name of the lubricant being used, then once all your machines are tagged, you have to switch brands for whatever reason, and now you have to re-tag all those machines. However, if you have the LIS on the lube tag, you can find a compatible lubricant in another brand and keep the same lube tag on the machine.

Applications

There are two things I like to see on a lube list when it comes to applications – the types of machines the lubricant is being used in and the volume of lubricant used on the site. Knowing the equipment the lubricant is used in can help arrange colors on the lube tags.

For instance, all gear oils might be orange. Mixing lubricants is never a good idea, but mixing two lubricants in the same class with different viscosities is less dangerous than mixing lubricants in different classes, such as a hydraulic oil and a gear oil. Knowing the amount of lubricant being used on site can help a lube program know how much needs to be stored in the lube room, and it is vital when planning for future maintenance events such as shut-downs or large oil changes.

Safety Data Sheets & Technical Data Sheets

Most industrial plants have a policy stating that there should be an SDS for all lubricants held on-site. During an assessment, if I ask if there are SDSs for allthe lubricants on site, I get “yes.” However, when I ask to see them, the squirming begins.

Having all the SDS in the LMS means they are in a central place, and anyone in the lube program can quickly access them. The technical data sheets can assist if there are any questions about where a particular lubricant can and can’t be used. Also, they can tell you the different limits of a grease, such as high and low working temperatures.

Documentation is Key

What it comes down to is detailed documentation. I like to say, “When it comes to a lubrication program, success is found in the details.” Document every little detail, starting with creating a consolidated lubricant list. A legible, color-coded, labeled lube list is the key to ensuring that your lubrication program is starting off on the right foot.

TRIBOINDIA 2023: INTERNATIONAL CONFERENCE ON TRIBOLOGY, 5th TO 7th OCTOBER 2023

Theme: Sustainable Development through Tribology

The Department of Mechanical Engineering, National Institute of Technology (NIT), Srinagar was privileged to host TriboIndia 2023 from 5th to 7th Oct 2023, in the picturesque city of Srinagar. It was organized under the aegis of the Tribology Society of India. The primary goal of this conference was to gather prominent engineers, scientists, scholars and students on a platform to discuss latest research and developments in the field of Tribology.

Inaugural Function on 5th Oct 2023

The conference was kicked off on 5th Oct, 2023. The inaugural function of the conference highlighted the importance of sustainable development through Tribology in the context of today's global warming and unpredictable weather patterns. It was presided over by the Vice Chancellor of University of Kashmir, Prof. Nilofer Khan, who was also Chief Guest of the event, President of the Tribology Society of India (TSI), Prof. Satish Vasu Kailash, Director NIT Srinagar, Prof. Sudhakar Yedla, Patron of TriboIndia 2023, Conference chairman, Prof. M.F. Wani, Prof. Adnan Qayoum (HoD MED), Prof. G A Harmain (HAG), Prof. Kazuyuki Yahi, Japan and Prof. Irina Goryacheva, RAS, Russia President TSI.

More than 250 abstracts were received this year in the shortest possible time, from different parts of the world like Russia, Japan, Malaysia, France, Uzbekistan, Netherland, Kyrgyzstan and USA etc. Out of these, 170 abstracts were accepted for presentation as mentioned by Prof M.F. Wani. The selected papers will be published in the special issues of reputed journals like – Tribology International, Journal of Engineering, and Indian Journal of Tribology. Other papers will be published in a special book by Springer Nature.

Plenary and Technical sessions 5th to 7th Oct 2023

Four leading researchers: Prof. Kazuyuki Yagi from Japan, Prof. Marat Bronovets from RAS Russia, Prof. Irina Goryacheva from Russia, and Dr. S S V Ramakumar, Ex-Director IOCL R&D delivered plenary talks during the conference. Eight (08) Keynote, 10 Invited and 03 Special talks were delivered by experts from academia and industry. These discussed how to address the issues in the field of tribology relevant to Materials for Tribology, Tribology for sustainability, nano Tribology, Lubrication, Coatings, Bio Tribology, Extreme environment tribology and MIS in I 4.0. Four parallel technical sessions and a poster session were held for presentation of 170 research papers. Research scholars and faculty from various Institute and laboratories within and outside India presented their research work. A technical exhibition was also held where various manufacturers and companies like Bruker, Markolaser/Spinks world, Ducomand Rtec Instruments participated in the exhibition and showcased their products and technologies. A formal business meet was also organised where Ducom and Markolaser/ Spinks world participated. They proposed their products and presented the possibilities that can be related to their latest products.

TSI General Body meet was organised on 6th Oct. 2023. During the meeting rigorous discussion were held regarding the constitution and future plan of TSI. This was followed by a cultural program and Gala dinner especially traditional Kashmiri wazwan.

Valedictory on 7th Oct 2023

On the final day, the Plenary Talk was delivered by Dr S S V Ramakumar (Ex-director IOCL R&D), who was Chief Guest on the occasion. He highlighted the current state of the automotive industry in India, with approximately 30 million vehicles currently in operation. A vote of thanks was delivered by Conference Chairman Prof. M.F. Wani. The speech mentioned that main aim of this conference was to inculcate a sense of urgency among budding researchers, to incorporate sustainability into their future endeavours. Participants who exhibited outstanding performance were honored and presented with certificates. At the end TriboIndia-2023 was concluded by a visit to the tribology lab, where the delegates received a comprehensive briefing about the equipments and research infrastructure.

HPCL AND CHEVRON PARTNER TO LAUNCH CALTEX LUBRICANTS IN INDIA

Hindustan Petroleum Corporation Limited (HPCL) and Chevron Brands International LLC (Chevron), a subsidiary of Chevron Corporation, have entered into a long-term agreement encompassing the licensing, production, distribution, and marketing of Chevron's lubricant products under the Caltex brand, including Chevron's proprietary Havoline® and Delo® branded lubricant products in India.

Danielle Lincoln, Vice President of Chevron International Products said, " We are pleased to bring quality and premium Caltex products to India. HPCL is a market leader in India, and together we plan to build on the strength of the Caltex brand and our premium product portfolio. We look forward to a long and successful partnership with HPCL, complementing their product offerings with Caltex premium products, including Chevron's proprietary Havoline and Delo product range in India."

Spread over 17.5 acres, HPCL's state-of-the-art manufacturing facility at Silvassa will manufacture the premium range of Caltex lubricants.

Amit Garg, Director – Marketing, HPCL added, " The collaboration between HPCL and Chevron, leveraging HP Lubricants' market leadership position in India and Chevron's world-class heritage, is set to deliver increased value to Indian consumers through an expanded offering of premium products. Our long-term cooperation with Chevron is anchored in HPCL's expertise in production, distribution, and marketing of lubricants and greases".

SHELL INDIA'S 'CHANGEMAKERS OF TOMORROW' UNVEILED IN BANGALORE

Minister of Science & Technology, Minor Irrigation, Government of Karnataka N.S. Boseraju and Minister for Revenue, Government of Karnataka, Krishna Byre Gowda inaugurated Shell India's 'Changemakers of Tomorrow' at the Shell Technology Centre in Bangalore.

Boseraju expressed enthusiasm about the event, emphasising its significance for Karnataka's innovation and technology hub. He noted the alignment of the initiative with the state's commitment to sustainable growth and technology-driven solutions. Gowda highlighted the platform's importance in driving growth in the energy landscape through climate-friendly innovations, underscoring its potential for economic development.

'Changemakers of Tomorrow' seeks to address India's energy trilemma by uniting the efforts of the government, industry leaders, entrepreneurs, and young innovators. The agenda includes initiatives such as Shell Eco-marathon World Championship, Nxplorers, Shell.ai Hackathon, and Shell E4, fostering collaboration and innovation among future leaders.

Chairman Mansi Madan Tripathy affirmed Shell's dedication to driving positive change in the energy sector and empowering the next generation of energy innovators, fostering a cleaner and more accessible energy landscape.