Varnish Analysis: Introducing New Testing Techniques

Elaine A. Hepley CLS, OMA, Data Analysis Manager, POLARIS Laboratories®

Introduction

Varnish formation is a by-product of oil that has oxidised and degraded over time. The source of varnish formation can also come from electro-static discharge, spark discharge, micro-dieseling, hydrolysis, thermal degradation, fluid incompatibility and catalysed wear particles just to name a few. Initially varnish will form as micro-agglomerations that remain soluble in the oil, over time varnish continues to form saturating the oil. As a result, the suspended varnish will begin to fall out of solution and plate out and adhere to the surfaces of the system. Varnish can take on various formations varying from gummy like agglomerations, hardened abrasive particles to baked on layers on the surfaces of the system. These formations will increase wear in a system, restrict moving mechanical parts, plug filters and even create hot spots leading to a loss of heat transfer and increase in operational temperatures.

For more than 30 years, varnish has been plaguing turbines, hydraulic and compressors. Causing issues with valves and spools sticking and fail to start modes, varnish can also act as an insulator of heat, creating hot spots and micro-dieseling issues. Several useful tests have been developed to help detect varnish and they have been a staple for monitoring varnish formation and aide in the mitigation of varnish. While very useful, they are not able to detect varnish type formation, soluble varnish or the presence of wear because of varnish. Below is a list of common tests performed to monitor varnish formation.

Test Methods

MPC ASTM D7843 – Detects the potential for varnish formation that is insoluble by measuring the concentration of colour and includes the L*a*b* values. Provides overall severity.

S-MPC (internal method) – Detects the potential for varnish formation by measuring colour concentration that is both soluble and insoluble in the oil and includes L*a*b* values. Provides overall severity.

RPVOT ASTM D7220 – Detects the fluid oxidative stability, remaining useful life. A value of <25% can mean the oil has undergone significant oxidisation, and the potential for varnish can increase. Reported in minutes.

LSV (Ruler) ASTM D6971 – Measures the depletion of antioxidants (amines and/or phenols) through applied current. As the antioxidants deplete, the potential for varnish will increase. Reported as % of new.

FTIR – ASTM E2412 – Detects the oxidation value of the fluid as well as phenolic degradation and chemical change.

The Case Study: Steam Turbine Failure

Paul Whiting CEO of DeltaXero, a manufacturer of offline fluid conditioning systems, was servicing a Steam Turbine at a Nuclear Power Plant in the UK that had failed due to the steam encountering the oil, resulting in hydrolysis. The oil was filtered with a nano filtration system, it was observed that the oil had dark carbonous particles along with a clear lacquer like particles. POLARIS Laboratories ® was approached to help with the root cause analysis of failure but also to help determine what caused the formation of these clear like particles to form. Together, POLARIS Laboratories® has partnered with DeltaXero to identify solutions for customers experiencing varnish contamination. We had already performed standard varnish analysis testing and determined that there was a micro-dieseling issue, while helpful, it didn't tell the full story of what caused the failure. Paul's mission was to understand varnish in all its guises, internal tests were not robust enough to give the answers to his clients and provide capable solutions. Clear gummy-like agglomerations were also identified in the system, but it was unsure if they were indeed varnish or a reaction from the steam interacting with the oil. Paul asked if there were any other tests that could be performed to help identify what exactly caused the failure and if we can detect the clear-like varnish formation in the oil. It was extremely important for us to understand what caused the catastrophic failure. After much discussion and troubleshooting together, I suggested a Micropatch analysis. This test would provide us with a visual aid and a more in-depth look at the contamination detected.

Micropatch Analysis

A Micropatch analysis utilises a patch that is a 0.8-micron size, in which we take 1 ml of oil and filter it through the patch to capture non-ferrous wear and contamination that would otherwise not be captured in an Analytical Ferrography. Once the sample has been filtered and the patch had dried, we then review the patch under a Microscope to help identify what caused the failure. It was a long shot, but I wanted to do everything possible to help Paul and his customer. Once the testing was completed what we found was astonishing. The Micropatch ended up detecting carbon particles that were encapsulated in a varnish agglomeration, upon further review we found large wear particles that had embedded in the carbon particle itself. Figure 1 shows the carbon particle that measured at 489 microns in size and the embedded wear metal had a micron size of 186.
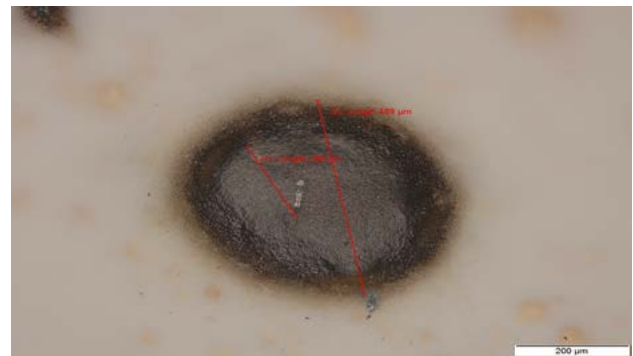

Figure 1

This analysis confirmed initial suspicion that the clear gummy-like agglomerations were indeed varnish, but also highlighted a severe wear-related issue that otherwise would have gone unforeseen. Unfortunately, elemental analysis has a detection size limit of up to 8 to 10 microns in size. Any larger particles would not have otherwise been captured. Microscopic analysis is a useful tool to obtain a better visual for contamination, wear regime and/or oil degradation.

After seeing the value in what Micropatch analysis can do to detect not only wear, carbon, contamination, and varnish formation and other things, it led me to ask myself, is there value in doing Micropatch analysis on these types of systems with varnish contamination? Further investigation and research were needed to verify, and so began my 2-year research and development into Micropatch analysis for varnish. Over

the course of my research, I found that Micropatch analysis can detect various types and different stages of varnish formation, contamination not detected through standard testing and wear that was a result. Figure 2 is a Micropatch which captured varnish, carbon, oxides and contamination. Figure 3, provided by DeltaXero's customer, shows the clear glossy-like finish where we clear varnish due to Hydrolysis.
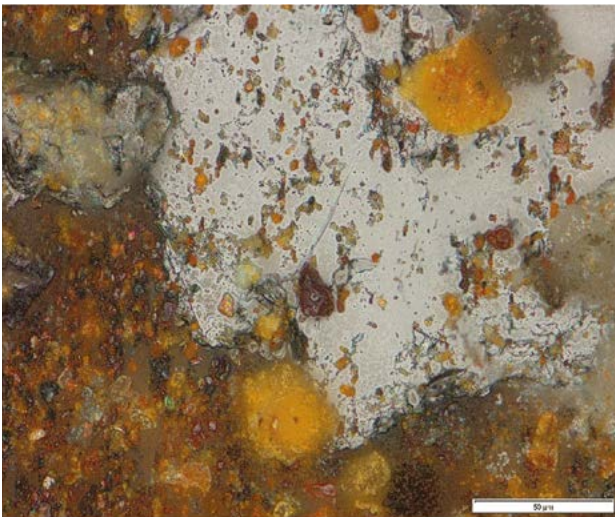

Figure 2

Figure 3

Varnish Formations in a System

When varnish is first beginning to form, you will see very small micro-agglomeration (at submicron size) begin to form. The varnish can have a clear-to-rose-gold sheen to it and a smooth lacquer-like finish to it. At this stage, the varnish is still soluble in the oil

and this is when it is easiest to remove the varnish from the system and the ideal stage to act. Figure 4 is what I would consider the beginning stage of varnish formation.

Figure 4

Over time, the varnish will begin to harden and fall out of solution and adhere to the cooler surfaces of the system, such as valves, spools, heat exchangers, etc. As a result of this, a layer of the micro agglomerations of varnish will begin to harden and form a layer that coats the surfaces. This creates "hot spots" that can lead to Micro-dieseling issues if no action is taken at this stage. Figure 5 highlights the clear varnish agglomeration and carbon formed due to micro-dieseling issues.
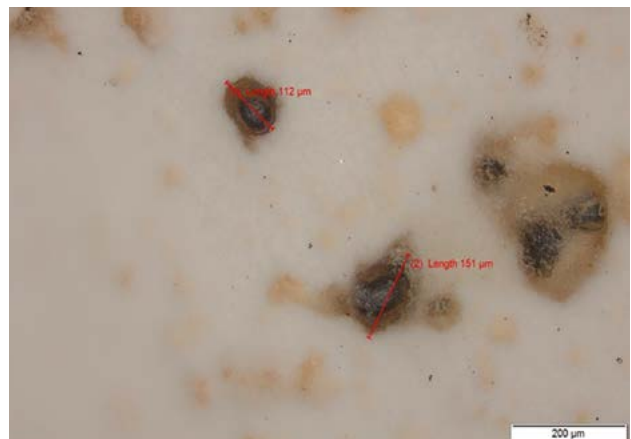

Figure 5

Once the varnish cakes or bakes onto the surfaces of the system, it acts as an insulator of heat, increasing the operational temperature of the system and overheating the oil. Eventually, the hardened layers of varnish will have particles that become dislodged, and these abrasive particles are now circulating in the system, impacting wear. As you can see Figure 6, some of these varnish particles will start translucent or thin and hard. With continued exposure to high temperatures, the colour of the varnish formation darkens and hardens further. Figure 6 shows how the varnish bakes and forms on the surfaces creating that layer of insulation. After some time, the varnish will become dislodged and the abrasive particles are now formed, seen in Figure 7, containing the rock like varnish formation.
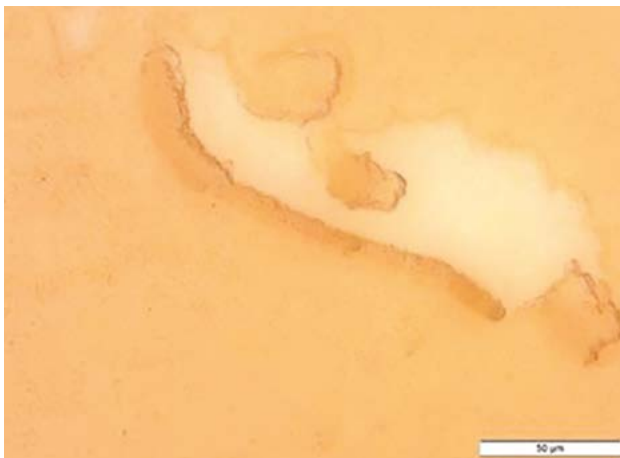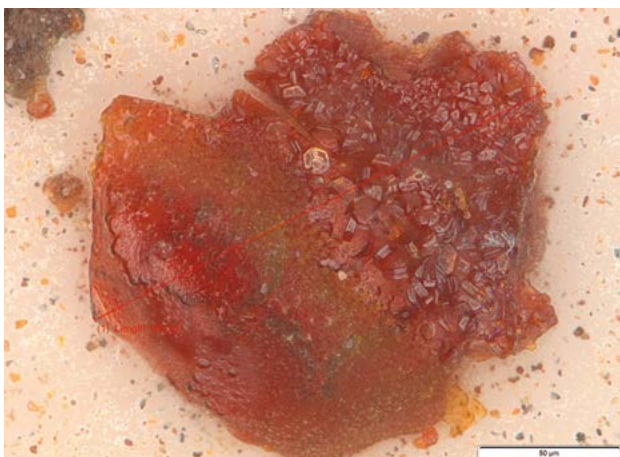

Figure 6

Figure 7

Different Varnish Agglomerations

These types of varnish formations can be seen at more advanced stages of varnish; they are very gummy/ sticky, meaning contaminants and wear particles will begin to adhere, causing them to become abrasive and contribute to increased wear. As you can see in Figures 8 and 9, these agglomerations can vary in colour from gold to clear, to reddish-brown. If the system is heavily contaminated with abrasive particles, they will adhere to these agglomerations and act like sandpaper in the system. Figure 8 shows a gummy-like varnish agglomeration that also has abrasives encapsulated, making this the perfect abrasive particle.
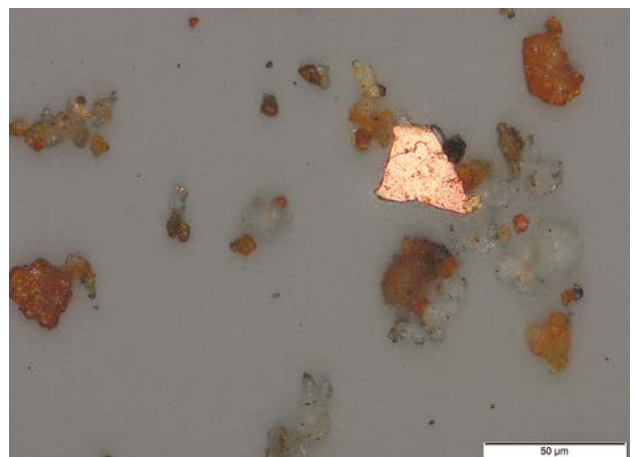

Figure 8

Figure 9

Detecting Insoluble Varnish is Only Part of the Story

Micropatch analysis is only part of the story, a few months later we were approached to see if we could detect soluble varnish. Currently, the Membrane Patch Colorimetry Test (ASTM D7843), can only detect varnish that is insoluble. POLARIS Laboratories'® Director of Technical Services, David Swanson, began researching various ways to see how we would be able to detect soluble varnish. The current testing method technique required heating the oil and then immediately placing it in the dark for 72 hours. In order to detect soluble varnish, the oil had to be hot, and the varnish was still suspended. Similar to ASTM D7843, we bake the oil in the oven at 60 degrees Celsius for 23 to 25 hours. Then, 1 drop of oil is placed on a 0.45-micron filtration patch and it is then placed in the dark to dry for 24 hours. Afterwards, we then take a reading of the colour and the CIE Δ L*a*b* values. No filtering or solvent is utilised during this process, as the goal is to preserve as much of the soluble varnish as possible. By allowing the oil to dry, the soluble varnish will then plate out and be absorbed by the patch (see Figure 10).

Up until now, no one has been able to detect the formation of varnish in its early stages. Just imagine the savings on downtime, labour, loss in revenue, maintenance and repairs that can result in this varnish testing. It would prevent serious failures like the one at the Nuclear Power Plant in the UK.

What is Soluble and Insoluble Varnish and why is it beneficial to detect both?

Soluble varnish is the precursor that will lead to full-blown varnish formation. When the varnish is suspended in the oil, that is when to begin looking at varnish mitigation. Why? The sooner the varnish is detected, the longer the life of the oil and equipment. Less downtime, loss in revenue, production as well as maintenance and repair cost savings. If soluble varnish isn't mitigated, in time, the oil will become overly saturated by varnish and begin to fall out

of solution, plate out and begin its agglomeration process to become insoluble varnish – leading to further operational and mechanical issues. The varnish will stay suspended so long as the oil is hot, however, once the oil has cooled, that is when varnish will plate out and gravitate to the cooler parts of the systems. This can lead to further thermal degradation and an increase in operational temperatures. The cycle is endless and continues to just get more detrimental over time. Therefore, we wanted to provide customers with a solution and the development of soluble varnish detection began. Figures 10 and 11 are some examples of soluble varnish patches.

Figure 10

Figure 11

L*a*b* Values and their significance

During the research and development phase, S-MPC was ran alongside samples receiving the standard MPC testing and recorded the CIE Δ L*a*b*. This allowed us to gather data, analyse it and determine valuable correlations with each MPC test and L*a*b* values. These values can also indicate other types of causes of the varnish and other properties that can identify the type of varnish formation and oil degradation. These values are detected during our reading of the MPC patch, within the CIE Δ color scale. A description of each L*a*b* value is listed below.

L* (Lightness) the L* value detects the white and black on the colour scale ranging from 0-100. The closer a value is to 100, the brighter/whiter the colour on the patch should be. Values closer to 0 will have a darker colour. A low L* value can indicate one

of the following: micro-dieseling, electric static spark or electric static discharge – all in which contribute to varnish formation in a system. Micro-dieseling will form abrasive carbon molecules that can contribute to the increase in wear. Making sure the proper anti-filtration system is installed, also ensuring the system is properly grounded can alleviate these issues. The patch can also appear to have a greyish/ brownish tint.
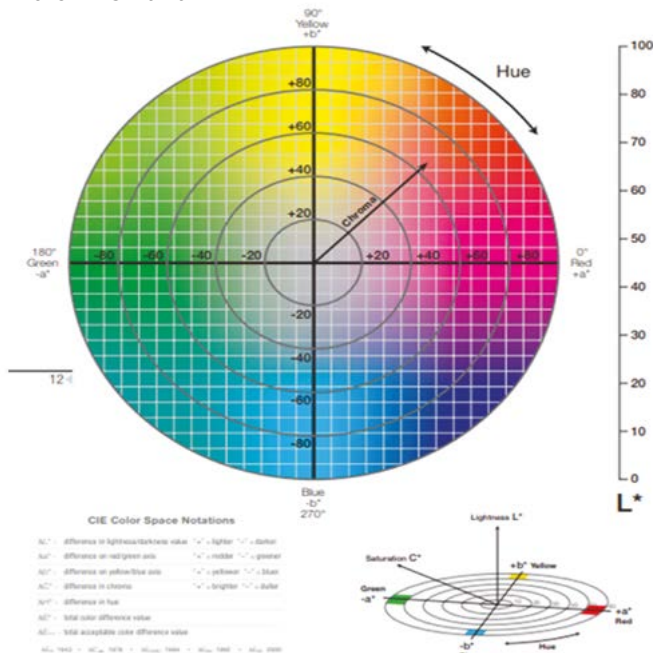

Figure 12 (provided by Xrite Patone)

a* (Green and Red) the a* value detects the green and red on the color scale. The difference between this value and L* is that the colour range can range from -100 to 100, a negative value will favour green on the scale, and a positive value will favour red on the scale. The a* value can indicate the EP additives are decreasing and/or sludge corrosive particles are reacting and becoming catalysts, further impacting the formation for varnish. If using a turbine oil formulation with EP additives, the a* value should be closely monitored to help indicate any depletion of additives and it can indicate wear in the system which can act as catalyst to further the formation of varnish. b* (Yellow and Blue) the b* value detects the Yellow

and Blue on the colour scale. Similar to a*, the b* value has the same colour range of -100 to 100 with the negative value being more on the blue part of the scale, whereas a positive value will be yellow. The b* value can indicate sticky deposits are likely being formed, these can adhere to abrasive deposits and cause an increase in wear. The b* value can also help indicate if wear is being generated. Gummy-like deposits will form at a more advanced stage of varnish and immediate action is highly recommended to prevent future failures.

The L*a*b* values, along with each MPC value, can be correlated to provide a better understanding of the severity of the varnish in the system and what can be the cause and/or oil degradation that is causing varnish to form. Understanding these values will also help identify the root cause and mitigation needed. In the past, some of the most severe cases of varnish had to be removed utilising more than one type of varnish removal to completely clean a system, increasing costs.

In recent years, the development of filtration systems, additive/cleaners, ion exchange or formulation changes have all proven themselves to be effective, decreasing costs overall. That is why it's important to understand the type of varnish in the system to help decide which method of mitigation would be the most effective. It's recommended to reach out to your equipment OEM, fluid OEM, and even filter OEM to see what possible solutions they offer for varnish mitigation. Our overall goal is to ensure we are providing customers with the root cause of the formation of varnish and a better understanding of the condition of the machine's health.

LINK
www.polarislabs.com