



MEASURING AND TREATING VARNISH FORMATION IN TURBINE OILS

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In this Technical Bulletin we discuss the treatment of varnish deposits in turbine oil, control valves and other machinery parts. We also look at what information can be gleaned from the varnish deposits, and how the data can be used to optimise turbine uptime and reduce maintenance costs.

Laboratory test methods have now been developed to measure the varnish potential of turbine oils. The test method is colorimetric – it measures the total colour intensity of a patch to determine the varnish potential of the oil. It also can determine certain colour components of the patch which can help to

pin-point the stress mode taking place in the oil that is leading to varnish formation.

Once the varnish-forming potential of the lubricant becomes too high, the oil must be treated to remove residues from the oil and the machine's internal surfaces – simply replacing the oil will leave residues behind which will act as a catalyst and poison the new oil charge and varnish rapidly reforms.

Specialist varnish treatment and filtration systems have been developed to remove varnish from oil, as well as dedicated flushing fluids for severe cases.

Once the varnish has been removed from the oil and machine, the oil suitability for continued use must be determined by some traditional turbine oil test methods such as air release ability and water separability, as well as newer methods, such as RULER, to determine the remaining anti-oxidant levels in the oil.

RULER determines the remaining anti-oxidant levels present in the oil compared with the levels measured in the new oil. For this test, a sample of the new oil of the same type and, ideally, from the same batch is required.

Varnish formation in lubricating oil systems is an old problem, but there is new interest in this problem due to the increase in varnish-related machine failures. It is now recognised that varnish formation is a different phenomenon from sludge and the increase in varnish formation is blamed mainly on the

move from Group I to Group II and III base oils with their lower solvency, as well as higher stresses placed on the oil by higher oil operating temperatures and smaller machine sump capacities. Another reason offered is changes in additive chemistry.

Some useful abbreviations	
ASTM	ASTM International, formerly the American Society for Testing and Materials
EHC	Electrohydraulic control system
FTIR	Fourier Transform Infrared spectroscopy
MPC	Membrane Patch Colorimetry
RPVOT	Rotating Pressure Vessel Oxidation Test
RUL	Remaining Useful Life
RULER™	Remaining Useful Life Evaluation Routine

There is now a standard method to measure the varnish potential of oil and several methods available to remove the varnish from the oil and machine. Oil analysis traditionally focused on machine condition monitoring, but, with the increased cost of oil and of used oil disposal, there is now increasing interest in oil condition monitoring to extend oil service life.

WHAT IS VARNISH IN LUBRICATING OIL SYSTEMS?

Varnish starts off initially as a mainly soluble organic contaminant comprised of oil degradation by-products and sometimes depleted additive molecules. Normal oil degradation and ultimately varnish formation is caused by the normal stress factors such as heat, air and moisture. Increases in these stress levels as well as additive depletion, contamination by dirt, solids and foreign chemical products can contribute to varnish formation. The presence of catalytic wear metal particles such as iron and copper can also accelerate varnish formation. Varnish problems occur mainly in steam and gas turbines, compressors, hydraulics, circulating systems, large pumps and even gear systems.

Varnish is different to sludge, although sludge can become a precursor to varnish. Sludge is normally soft and sticky and easy to wipe off with a cloth. Sludge moves around the system and eventually settles in the low points in the system or restrictive passages. Varnish also starts as

soft and sticky deposits, but varnish settles on all internal machine surfaces particularly in cooler parts of the system. Varnish may also plate onto hot surfaces and eventually cure to a hard shiny glaze which becomes oil-insoluble and difficult to remove by physical methods.

The deposits are initially a yellow-brown colour, then may obtain a red tinge and progress to eventually become dark brown and shiny on wear surfaces and even black if there is soot present.

WHY IS VARNISH IN OIL A PROBLEM?

Varnish deposits can become thin, hard shiny coatings on wearing parts such as journal bearings, control valves and gears. On journal bearings, the varnish build-up causes a loss of operating clearance, which causes increased bearing wear and eventual failure. Hard particles such as dirt and wear metals trapped in the varnish can increase the wear. Varnish coatings can reduce the heat transfer efficiency of heat exchangers. Control valves in turbines and hydraulics are a particular problem. Varnish deposits reduce clearances and cause sticky operation and seizure. Varnish can plug filters, screens and small orifices. It also accelerates additive depletion. Varnish will form on all interior machine surfaces, including gears, tanks and pipework. Varnish can also form crusts on mechanical seals and disrupt their function.



Figure 1: Varnish on centrifugal compressor gears [picture courtesy Higrotek]

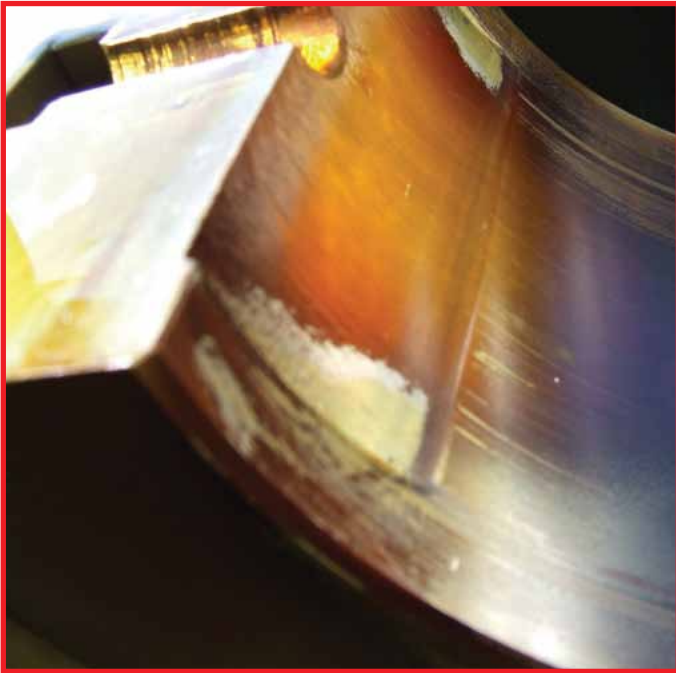


Figure 2: Varnish on a pinion bearing [picture courtesy Fluitec]

MEASURING THE VARNISH-FORMING POTENTIAL OF OIL

Both the oil analysis and condition monitoring communities have long placed their trust in acid number test results to indicate oil fitness for further use. Acid number will increase as the oil degrades, but it cannot predict the oil's tendency to cause varnish formation. The ultra-centrifuge test rates sediment formation, but is not a direct measure of varnish-forming potential. FTIR provides information on the degradation processes taking place, while RPVOT and RUL tests provide information on the remaining anti-oxidant additive levels, but none can detect varnish formation. Some of these tests have also not found great favour in routine oil analysis, either due to high cost or the logistic difficulty of obtaining new oil reference samples for comparison.

ASTM published standard D7843 in 2012, which describes how varnish potential of an oil sample is determined by Membrane Patch Colorimetry (MPC). This technique was known as Varnish Potential Rating (VPR) during the early development period.

The oil is diluted with solvent and filtered through a very fine membrane by gravimetric method and the residue washed with more solvent. The colour spectrum of the resulting stain is then analysed with a spectrophotometer. The overall index is a measure of intensity and varnish-forming potential. The obtained value is compared with general guidelines:

MPC value	Action
<15	Normal – none
16 to 30	Monitor – more regular testing
31 to 40	Abnormal – possible varnish deposit and malfunction – remove varnish
>40	Critical – varnish deposit, possible malfunction – remove varnish

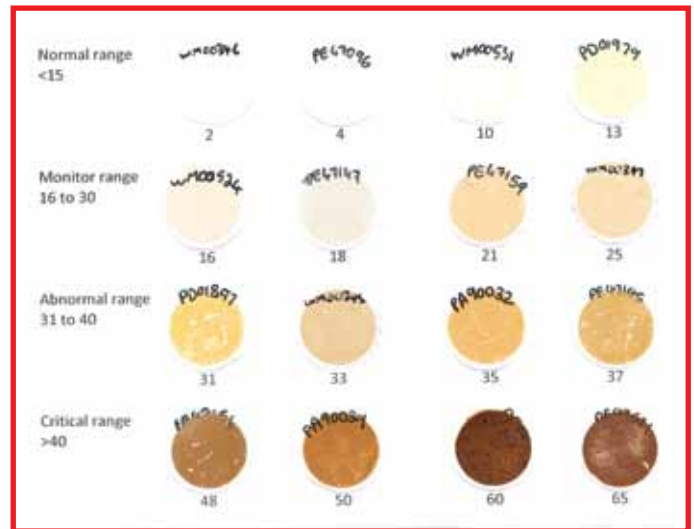


Figure 3: A range of MPC patches with ratings

VARNISH REMOVAL

The oil cannot simply be changed – the oil that remains behind in the system and the varnish already formed on the interior surfaces of the system will act as a catalyst and in effect “poison” the new oil which will then degrade rapidly.

The oil in the system needs to be treated to remove dissolved varnish before the new oil is introduced. As the level of varnish in the oil reduces, the oil's ability to re-dissolve varnish clinging to the machine surfaces increases and more varnish is brought into solution in the oil, from where it can be removed by filtration or other methods of separation. This process is then continued until all varnish is cleaned from the oil and the machine surfaces, confirmed by a MPC value that has reduced to an acceptable level, ideally below 10. If the oil is cleaned of varnish but the cleaning process is terminated before the whole system is clean, the newly-cleaned oil will rapidly accumulate varnish again.

The process can take from days to months, depending on the severity of the varnish deposits and the flow rate and efficiency of the varnish removal equipment.

VARNISH REMOVAL METHODS

Most methods listed here will be carried out in an off-line bypass mode at low flow rates. In these cases, varnish is not removed from machine surfaces directly – the oil is cleaned of varnish and the solvent action of the cleaned oil then removes varnish deposits. The oil transports the re-dissolved varnish to filters or separators where it can be removed from the system.

Depth Filtration

This method involves fine conventional cellulose oil filters. They only remove soft suspended contaminants if the oil temperature is below 40 °C. This method is not very effective alone, as it only removes degradation products in suspension but not in solution. If combined with another technique such as electric charge filtration, it can perform well with minimal capital outlay and maintenance. Specialised varnish removal cellulose filters also have physical adsorption properties that improve their varnish retention abilities.

Electrostatic Oil Cleaning

A high-voltage, no-current electrostatic field is maintained across electrodes. When polar varnish and hard particles pass through this field, they are attracted to the negative or positive electrodes, whichever is the opposite charge to the particle's own charge. The accumulated varnish is then removed from the electrodes. This method removes degradation products in suspension only. The efficiency can be increased if combined with another technique. Electrostatic separators are sensitive to water and conductive contaminants.

Charged Agglomeration Cleaning

Particles are charged positive or negative in separate flow streams. When the charged particles are recombined downstream, they form neutral and larger particles which can be filtered out by conventional mechanical means. This method is very efficient at removing suspended contaminants, but these separators are also sensitive to water and conductive contaminants.

Resin-based Chemical Absorption

These elements remove soft contaminants in suspension and solution over a wide temperature range. The oil passes over a resin bed and the contaminants are absorbed via ion exchange. The

process is also known as electrophysical separation and is very effective. As varnish is removed from the oil, it increases the oil's ability to re-dissolve and suspend more varnish. These elements do not perform filtration – they remove varnish by chemically bonding the varnish to the adsorption media surface. High levels of chemical contaminants in the oil can coat the resin bed and render the element ineffective.

Chemical Cleaning

Cleaning chemicals containing detergents and dispersants are used to flush the system during planned plant outage. These cleaners can be very effective at removing varnish deposits from internal surfaces but it is important to flush out all traces of the chemical cleaners before the system is refilled with fresh oil.

Solvency Improvers

Adding a solvency enhancer to the oil will increase the oil's ability to re-dissolve varnish coatings and bring them back into solution. Ideally, the chemical should be left in for a few months and the varnish then removed by one of the methods already mentioned, or in the case of smaller systems, the oil can be changed at a future planned outage. These products cannot be used with phosphate ester fire-resistant control fluids.

VARNISH TREATMENT CONSIDERATIONS

The approach to varnish removal differs at each facility. The options are: purchase portable or fixed equipment, rent equipment, contract the service, perform chemical cleaning or add a solvency-enhancing product. Other considerations are the cost of oil replacement, the severity of the varnish deposits and the consequences of plant malfunction.

On small systems (under 200 litres) with mineral oil such as large pumps, it will be more cost effective to add a solvency enhancer and change the oil at a future date. If the oil is an expensive synthetic product, a different approach may be considered. The varnish-treating equipment size must be matched to the machine size and varnish severity to ensure cost and varnish removal efficiency.

Resin adsorption elements are very efficient varnish removers, but due to high cost, they need to be used to best effect. The element size must be selected

so that the element varnish retention capacity is almost exhausted by the time the varnish is removed, otherwise the capacity is wasted unless it can be deployed elsewhere on the same plant. If the element will be re-used, oil compatibility must be ensured – if you cannot use oil A to top up oil B, it's not compatible and the element should not be re-used.

Electric charge filters can be installed for long-term varnish and solid contaminant filtration. With all systems, excess dirt and water must first be removed prior to varnish treatment. Centrifuges work best in such cases, despite their high initial cost.

AFTER VARNISH REMOVAL

Once the varnish deposits have been removed from the oil and the machine internal surfaces, the oil condition needs to be re-assessed to determine if the oil is still fit for further use. Several tests are required.

Firstly, the remaining antioxidant levels need to be determined. The antioxidant levels may have been very low before commencing cleaning, or some of the antioxidants may have agglomerated with the varnish and removed during the cleaning procedure.

The antioxidant level may be determined by performing the Rotating Pressure Vessel Oxidation Test (RPVOT) which measures oxidation resistance or by measuring the remaining amine and phenol antioxidant levels with cyclic voltammetry (RULER). If the remaining levels are below 25%, the oil must be discarded.

Some additional tests such as air release, water separability and foaming characteristics should also be considered at this time. If the oil fails any of the above-mentioned property tests before oil treatment for varnish commences, the cleaning process must still be completed with the old oil, after which the oil may be discarded. If the antioxidants are depleted but the oil still meets certain other criteria, the antioxidant levels may be restored by the addition of a formulation of antioxidants – a process commonly known as 'sweetening the oil'.

The cleaning process takes time and may be accelerated by the addition of proprietary solvency additives. It may not be possible to remove tenacious varnish deposits with the machine online. That would

require the machine to be removed from service, the oil drained and solvent cleaning to be carried out. As a last resort, physical abrasion can be performed on reachable surfaces. In extreme cases, varnish may form a hard glazed layer on bearing surfaces which cannot be removed without damaging the underlying surface.

ROOT CAUSE ANALYSIS

If the oil service life prior to varnish formation is considered unsatisfactory, root cause analysis should be attempted in order to identify, find and correct problems in the system to prevent a rapid recurrence of varnish formation.

The spectrophotometer - which measures the colour intensity of the membrane patch that is translated into the varnish forming potential of the oil - can also provide the three main values that represent the visual colour space. These values can indicate some of the stress modes taking place in the oil system. The CIELAB colour scales L^* , a^* and b^* are used.

The L^* value represents the shade of the patch. The lower the L^* value the higher the concentration of black particles in the oil. A black colour may be due to soot particles caused by micro-dieseling, spark discharge or hot spots in the system. A hot spot is a localised area of high temperature.

The a^* value represents the green to red scale. A high a^* value indicates an increase in sludge-forming potential, or a reduction in extreme pressure additives in certain oil types.

The b^* value represents the colour measured on the blue to yellow scale. A b^* value increasing towards yellow indicates the presence of degraded antioxidant additives which can form varnish.

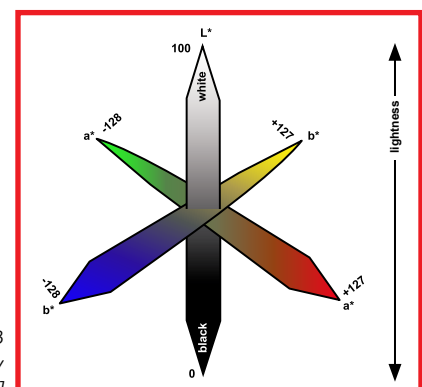


Figure 4: The CIELAB Colour Model [courtesy of Phil Cruse GQC]

FTIR spectroscopy can provide a wealth of information on how the oil degradation is taking place. FTIR measures oil degradation by-products. High nitration levels would indicate thermal degradation due to hot spots, the effects of micro-dieseling due to excessive oil-entrained air bubbles, or fluid friction-induced electrostatic discharge in filters and elsewhere. Thermal degradation takes place at high temperature without the presence of oxygen. High oxidation levels indicate oxidative degradation which is a chemical reaction with oxygen and increases with temperature. FTIR can also compare the remaining levels of oxidation inhibitors with the levels in fresh oil.

CONCLUSION

The future for machine owners lies in regular oil testing and early treatment when signs of varnish formation are detected. For large system operators such as power generation utilities, the future lies in the permanent installation oil treatment equipment, preferably at the plant construction stage. This will take the form of kidney loop bypass filtration and treatment systems that can be brought into operation to treat specific symptoms such as dirt, water, varnish or acid in the oil. The oil treatment equipment may be any combination of depth filters, resin elements, clay filters, electrostatic filters, centrifuges or vacuum dehydrators which can be used individually, simultaneously or in sequence.

For smaller operations where mobile filters and/or centrifuges are used, varnish removal filters can be incorporated into the equipment or used separately.

The RULER test can be used on phosphate ester fire-resistant EHC fluids. The use of the D-7843 test method for determining the varnish potential in phosphate ester systems is still under debate, but for varnish treatment there are customised adsorption media available.

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