RESOLVING VARNISH CHALLENGES

Varnish Removal Technology in Turbine Oil

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Varnish is an organic residue produced by irreversible chemical degradation of mineral oil lubricants. It can lead to filter plugging, restricted oil flow, poor heat transfer, valve sticking, fail-to-start conditions, and unit trips.

During rotating equipment operation, heat generated due to friction degrades the oil and produces very small byproduct particles that settle throughout the system as varnish. Spark discharges from static charge buildup in the lubricating oil filters play a key role in its formation. Over time, these particles attach themselves to surfaces throughout the turbine, producing a sticky film. As varnish builds up, performance of rotating equipment suffers.

A variety of varnish removal systems are available in the market. As the conversion between soluble and insoluble varnish is a physical equilibrium process dependent upon temperature, Varnish Removal Units (VRU) are equipped with a cooler to reduce the oil temperature and convert soluble into insoluble varnish. Special filter media inside the VRU capture dissolved and suspended soft contaminants from the oil.

VARNISH FORMATION

Varnish is a sub-micron-sized soft contaminant that is polar in nature. Oxidation and thermal breakdown are among the causes of varnish formation. But the two major reasons are micro-dieseling and static electric discharge.

In micro-dieseling, the implosion of entrained air bubbles as they migrate from low-pressure zones to high-pressure zones creates a local oil temperature in excess of 1,800ºF. This is enough to cause severe oxidation of oil molecules and generates carbonaceous byproducts. As system pressures increase, the potential for micro-dieseling rises.

The industry's shift to synthetic and glass filter media has created unexpected side effects due to the combination of tighter filter pore sizes to remove fine sediment with very high filter flux rates to reduce capital cost. The result is significant static charge buildup within the oil system. These spontaneous discharges can generate sparks of static electricity with temperatures greater than 18,000ºF. This "cooks" the oil, creating molecule fragments that deplete antioxidant additives. The oil circuit where there is metal-on-metal contact can also generate a static charge.

The conversion between soluble and insoluble varnish is a physical equilibrium process dependent upon temperature.

Oil-degraded soft contaminants are dissolved in the oil at operation temperature which are polar in nature and get absorbed onto dipolar (colder) metallic surfaces. The varnish is formed by soft contaminants agglomerating and hardening into a lacquer-like coating on valve spools and sleeves, bearing surfaces, gears and other internal surfaces of the lubrication system.

The sticky nature of varnish captures hard contaminants as they flow within the system, forming an abrasive finish that accelerates component wear. Furthermore, varnish is an efficient insulator that provokes bearing surfaces to run hotter, and heat exchangers to have lower efficiency.

VARNISH DETECTION METHOD

In Saudi Aramco, all critical rotating machines are monitored by a lubricant condition monitoring (LCM) system. The scheduled samples are tested inhouse. Test slates are decided based on oil type and equipment. However, color and acid number are checked for all industrial lube oils. When color and acid number are high, the RULER (Remaining Useful Life Evaluation Routine)/ RPVOT (Rotating Pressure Vessel Oxidation Test), and UC (Ultracentrifuge)/ MPC (Membrane Patch Colorimetric Test) are checked to understand the condition of the oil and design the corrective action to prevent unscheduled equipment downtime.

The MPC test has been used for many years in oil analysis as a qualitative test to assess the condition of oil. Recently, several commercial laboratories have developed quantifiable scales to trend the varnish potential of oil. For example, on Analyst Inc.'s scale from 0 to 100, a varnish potential rating of 0 to 15 is considered normal. The range 15 to 30 means monitoring is required. Readings greater than 30 are considered actionable and should trigger rapid remediation.

GAS COMPRESSOR EXAMPLE

Delaval make a 5-stage centrifugal low-pressure (LP) gas compressor driven by a 3,500 hp electric motor. It is a critical asset, operating throughout the year with no standby equipment. The compressor takes gas from the LP suction drum and discharges it to the high-pressure (HP) gas compressor. The compressor runs at 10,295 RPM and delivers 19.27 - 21.55 MMSCFD of gas, with the amount varying from summer to winter. The set alarm and trip temperature of the compressor bearings are 235°F and 250°F respectively.

The compressor train is lubricated through a forced feed system to provide lubrication to the motor, gearbox and compressor bearings. The lube oil reservoir capacity is more than 3,000 gallons of ISO VG 46 turbine oil.

The bearing temperature trend of the LP compressor showed a gradual increase at the inboard (I/B) bearing. It reached above the limit of 250°F and resulted in a trip. The bearing was dismantled, and varnish was found on the bearing. This lowered the oil flow rate because of reduced clearance and a reduced heat dissipation rate (Figure 1 and 2).

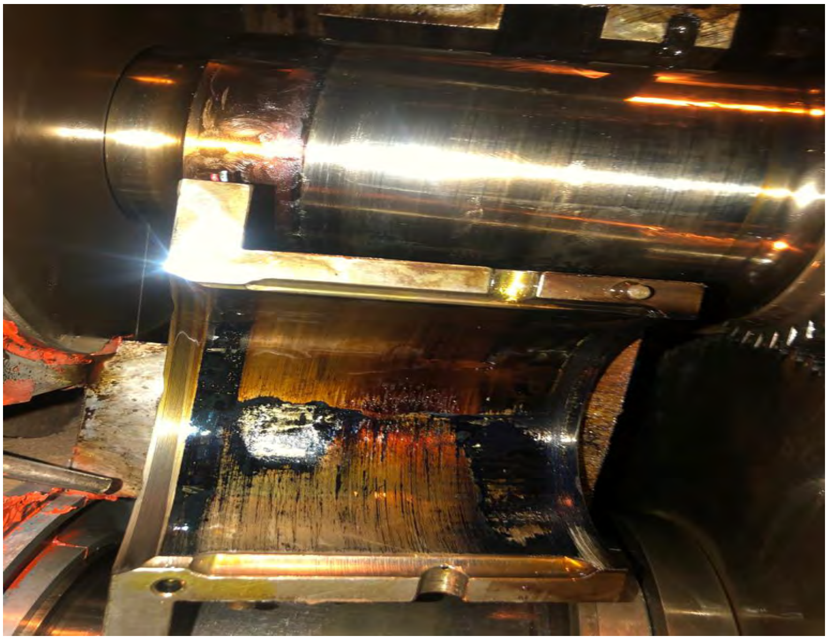


Figure 1: Varnish was found in the compressor gearbox, bearing, and shaft.

VARNISH REMOVAL TECHNOLOGY

An offline Varnish Removal Unit (VRU) was connected to the LP gas compressor lube oil system while the machine was running. The VRU suction is taken from the lube oil reservoir drain valve. The VRU discharge is returned back to reservoir through a one-inch socket welded on the reservoir inspection manway.

The VRU utilizes filter media optimized for varnish removal. The warm oil is drawn from the system tank to the VRU by means of the transfer pump. The oil first passes through a blast cooler, then a heat exchanger, and finally a chiller system before reaching the filter housing. The oil temperature comes down to approximately 50°F before reaching the filter media that captures dissolved and suspended soft contaminants.

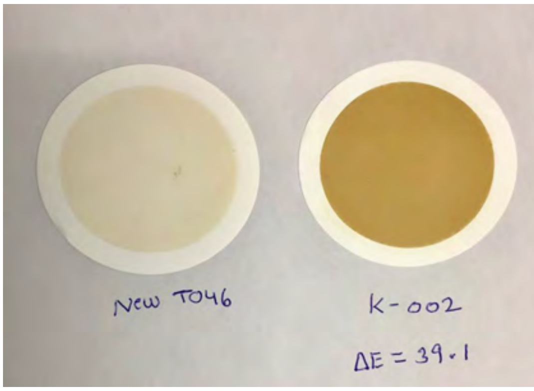


Figure 2: The lube oil sample testing revealed a very high level of varnish presence; the test result for new (left) and in-service lube oil (right).

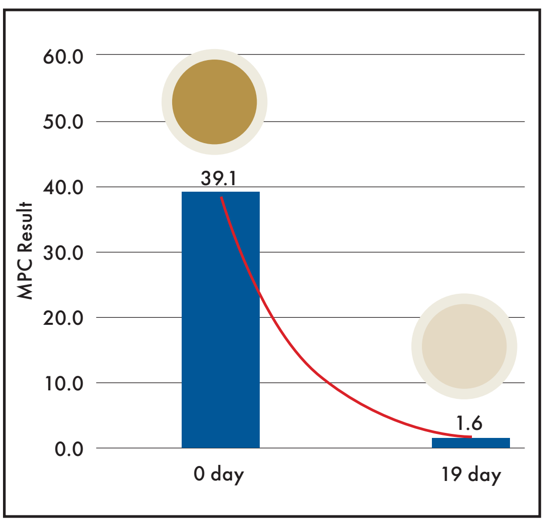


Figure 3: MPC Results Trend.

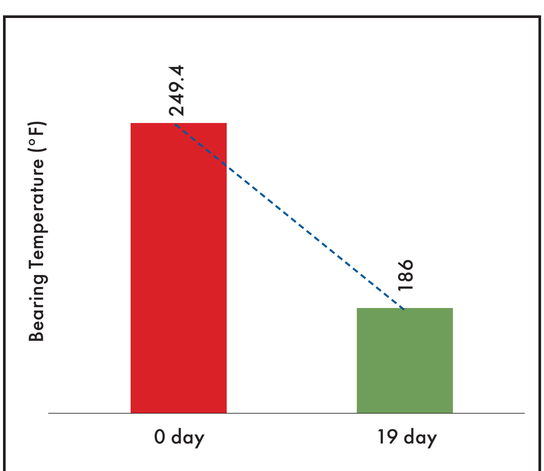


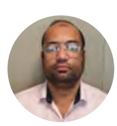
Figure 4: Bearing Tempt Trend.

Varnish has traditionally been defined as an insoluble deposit. However, it also exists in soluble state. The conversion between soluble and insoluble varnish is a physical equilibrium process dependent upon temperature. The soluble varnish becomes insoluble by reducing the lube oil temperature and can then be removed easily from the lube oil system.

After extracting the varnish from the lube oil, it is returned to the main lube oil system. Varnish-free oil now starts to clean system components in contact with oil, resulting in a varnish-free system for up to a few months depending on system condition.

After utilizing the VRU for a few weeks on the LP gas compressor, bearing temperatures and the condition of the lube/seal oil were improved. Oil samples subjected to MPC tests showed a drop from 39.1 to 1.4 within 19 days of operation. Bearing temperatures dropped from 249.4°F to 186°F within 19 days due to the removal of varnish and better heat dissipation as well as increased oil flow.

The usage of the VRU in combination with MPC testing of the lube oil system reduced the bearing temperature by detecting and cleaning varnish deposits. This improved heat dissipation and prevented any equipment trips due to high bearing temperatures. It also eliminated the immediate need for oil replacement, system flushing, and chemical cleaning. ■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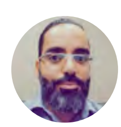
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The varnish removal unit utilized by Saudi Aramco. Courtesy: CJC

Clean turbine fluids promote trouble-free operation

Brent Converse, the plant engineer at Old Dominion Electric Cooperative's Wildcat Point Generation Facility (Sidebar 1), has three decades of experience in the operation and maintenance of powerplant equipment—including advanced-class gas and steam turbines. Among the most important lessons Converse has learned over his career: "Stay ahead of the curve" on things having a significant impact on reliability and performance, and pay close attention to detail.

The editors asked Converse to share an example during a telephone interview. He chose the lube- and hydraulic-oil conditioning systems for his plant's three turbine/generators. Background: Wildcat Point's Mitsubishi Power 501GAC gas turbines have separate sumps for control and lube oil—the former 150 gal, the latter about 6900. Both systems are charged with Idemitsu's Daphne Super Turbine Oil MG32.

The Alstom steamer has a nominal 6600-gal combination sump for control and lube oil; the Alstom hydrogen-cooled generator a separate sump for seal oil. The fluid common to both systems is Mobil DTE 746.

Converse, who has been at Wildcat Point since before commissioning, said the first oil conditioning systems installed were C.C.Jensen Inc's off-line (a/k/a kidney loop) HDU fine-filter solution for the gas-turbine control-oil sumps (Fig 1).

The plant engineer monitors control oil quarterly, judging its condition primarily based on the results of RPVOT, RULER, and acid-number tests. The HDU can mitigate fluid degradation conducive to the formation of acids and insoluble oxidation products that could impede the operation of components critical to turbine control.

However, antioxidant depletion makes it necessary to replace control oil every two years, or so. "Having had no unit trips attributed to control/lube-oil issues since commissioning, such attention to detail has paid dividends," said Converse.

The plant engineer's familiarity with the Jensen system was a catalyst for a discussion with the company's technical manager, Axel Wegner, at a user group meeting. The result was two-fold: Installation of Jensen's varnish removal unit (VRU) on both gas turbines and its PTU-type Filter Separator on the steam turbine.

More recently an HDU-type Fine Filter, similar to that serving the gas-turbine control-oil system, was installed on the ST generator seal oil system. The major difference between the two is that the latter is explosion-proof.

Why kidney loop

Kidney loop or offline filters benefit users because they are independent of the fluid system and always in service at an optimal flow rate—thereby avoiding pressure fluctuations and other disturbances that might otherwise negatively impact rotating equipment. Plus, they achieve very fine filtration. As Fig 1 shows, turbine fluids are withdrawn from the lowest point in

1. Wildcat Point

Wildcat Point Generation Facility, located in Rising Sun, Md, and owned by Old Dominion Electric Cooperative (ODEC), is a nominal 1000-MW 2 × 1 combined cycle. The gas turbine/generators are Mitsubishi Power 501Gs (air cooled); the supplementary-fired heat-recovery steam generators and steam turbine were supplied by Alstom.

The oil/gas-fired project began commercial operation in April 2018. Transcontinental Gas Pipe Line Co, a subsidiary of Williams Partners, supplies gas to Wildcat Point via its 11-mile Rock Springs expansion project.

Cycle heat rejection is via a 16-cell counterflow mechanical-draft tower. Cooling water is supplied via a 5-mile supply/discharge pipeline connected to the Susquehanna River.

Plant site is near the Maryland/Pennsylvania border and adjacent to The Carlyle Group's Rock Springs Generation Facility, which is equipped with four GE 7F peakers. Power is delivered to the PJM Interconnection via a 500-kV switchyard at the Rock Springs site.

2. How to determine the ISO fluid cleanliness rating

Fit the counts in the right-hand column of the sample lab analysis (table at left) to the appropriate range of particles per milliliter (ml) in the table at the right to determine the Range Number defined in ISO 4406.

Example: The sample has 1752 particles larger than 4 microns (the first number in the series), 517 larger than 6 microns, and 55 larger than 14 microns. The Range Numbers from the right-hand table expressed in ISO convention are 18/16/13.

Keep in mind that turbine journal bearing and hydraulic servo-valve clearances dictate the need for clean oil. Excessive bearing wear and servo-valve sticking can result if tight cleanliness standards are not maintained. Turbine OEMs offer specific guidelines on recommended cleanliness levels, typically 16/14/11. Best practices suggest that ISO cleanliness testing be conducted quarterly or more frequently depending on service duty.

Sample particle count

Particle size, microns	No. of particles larger than size at left
4	1752
6	517
10	144
14	55
20	25
50	1.3

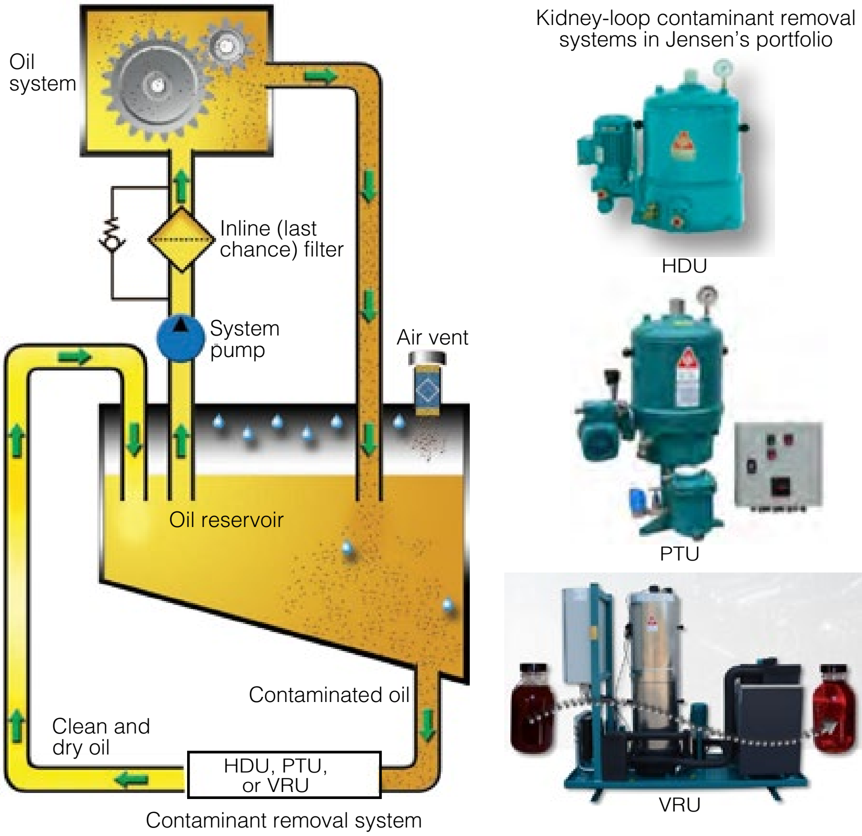
1752 particles per ml larger than 4 microns → 1300 (Range Number 18)

517 particles per ml larger than 6 microns → 320 (Range Number 16)

55 particles per ml larger than 14 microns → 40 (Range Number 13)

ISO cleanliness rating (Range Number)

More than this no. of particles per ml	Up to an including this no. of particles per ml	Range Number
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5000	10,000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8



1. Kidney-loop contaminant removal systems from C.C.Jensen Inc rely on a stack of filter disks to eliminate particulate matter, water, acidity, and degradation products from lube, hydraulic, gear, transformer, diesel, and other oils used in powerplants. Composition of the filtration medium varies depending on the duty

2. Filter disks are effective in removing varnish

the oil reservoir, removing sediment in the process.

All of the Jensen offline filters installed at Wildcat Point—HDU, PTU, and VRU—are arranged in this manner. Likewise, all are designed to (1) remove particles 3 microns absolute and larger, (2) absorb up to 1 gal of water per filter insert, and (3) remove insoluble varnish. This performance is achieved by a stack of two or more filter inserts, such as those shown in Fig 2, made primarily of compressed wood cellulose and cotton linters.

Composition of the filter inserts may vary from the standard Jensen offering where special requirements warrant. This has not been necessary at Wildcat Point. Wegner notes that independent laboratory tests show the Jensen filter inserts do not affect the phenolic and aminic antioxidant additive packages typically used in hydraulic/lube oil formulations for powerplants.

Applications. The HDU and its standard filter insert are designed for use in applications except where water ingress is expected. Special inserts are available for acidity reduction, dissolved-water removal, and soluble-

3. Varnish factoids and turbine-fluids best practices

MPC value: 1 UC value: 4

A. That some varnishes are colorless is in evidence here with the MPC test showing pristine lube oil (MPC value of 1) and the ultra-centrifuge result on the same sample having a UC value of 4 (scale is 0 to 8)—a varnish level of some concern

B. Same turbine oil in the left and center bottles. At 140F (left), varnish is dissolved in the base oil. At 40F (center), it is insoluble—meaning the saturation level of the varnish in the oil exceeds its solubility at the fluid temperature. Varnish is "cured" and no longer soluble in the base fluid when "baked on" hot surfaces (thrust bearing shoe at right)

- There are more than 30 different kinds of varnish; some are colorless. When in doubt, add an ultra-centrifuge (UC) test to your MPC (membrane colorimetric patch) analysis (Fig A). Recall that the MPC patch is made by isolating and agglomerating insoluble by-products associated with varnish, the color of the patch being a measure of varnish potential. By contrast, the "g" forces imposed on the oil sample in the UC test extract insoluble contaminants too small for normal particle counting.
- Varnish can be dissolved, insoluble, or cured, and its state depends on temperature and contact with air (Fig B). Varnish can cover surfaces immediately when it becomes insoluble.
- Hundreds of machine inspections and oil analyses have shown that (1) critical concentrations of varnish can be present with generally acceptable antioxidant levels, and (2) oil can be varnish-free with completely depleted antioxidant levels. Oil cleanliness is the determining factor.
- To assure accurate test analyses for varnish, take oil samples when the machine is running and in thermal equilibrium. Testing of cool oil will give lower-than-actual concentrations of varnish.
- Testing for particulate contamination can be by the optical or pore-blockage methods. In the former, the oil sample is passed through a beam of light. Anything that interrupts that beam is counted as a "particle." The calibrated mesh screen used in the pore-blockage method captures only hard particulates. Thus, there can be a significant difference between the two results, depending on the presence of water, soft contaminants, and/or insolubles.
- A sudden high-pressure alarm from your kidney-loop filtration system likely is caused by water ingress.
- When using a C.C.Jensen Inc kidney loop system, the company recommends scheduling your annual filter insert changes when the oil is coolest–for example, at the end of an outage–before the system is returned to service and the oil heats up again.

varnish removal.

The PTU is used mostly with steam-turbine lube-oil systems (and diesel-oil filtration systems) because of its ability to remove large quantities of water from the turbine fluid and discharge it automatically.

Wegner says the PTU has advantages over dehydrators often used in ST control and lube-oil systems for this application—including lower capital and operating costs, ability to remove particulates and varnish, and faster water removal. However, dehydrators may be beneficial in systems charged with fluids having poor demulsibility (don't shed water easily). Centrifuges, a third alternative for water removal, are limited in their ability to work reliably over long periods and to reduce moisture levels to the 20 ppm often recommended today.

Jensen's VRU typically serves on large gas and steam turbines where large amounts of soluble varnish must be removed from lube oil. A specially designed filter insert removes dissolved and suspended soft contaminants by polar attraction and alerts on varnish saturation by high pressure. The varnish-free oil produced cleans all system components it comes in contact with, ultimately reducing the level of varnish in the full charge of fluid to near zero.

Jensen recommends that its filtration systems run 24/7/365 and that the filter inserts be changed annually, when the pressure drop across the filter exceeds the recommended limit, or when oil analysis requires a change—whichever comes first.

A high pressure drop requiring new filter inserts can be caused by a leak exceeding the water holding capacity of the filter or by a high concentration of particulates in the turbine fluid. Wear and tear of mating parts and rusting of carbon steel components—such as the oil reservoir—contribute to the latter. Wildcat Point avoids rust to the degree possible with oil sumps made of stainless steel.

Regarding control of particulates,

Wegner says that begins when the oil is purchased. He urges filtering new oil or specifying a required ISO cleanliness level at that time to avoid receiving a fluid that may be dirtier than that called for by manufacturers of servos and other hydraulic control components.

Based on his experience, you can expect an average contamination level of about 19/17/14 unless you write a tighter spec. Go to Sidebar 2 to refresh your knowledge of ISO cleanliness ratings.

Sidebar 3 offers best practices on turbine fluid systems and varnish.

Extended warranties and service. There's only so much plant personnel can handle today given busy schedules, new operating regimes, etc. Converse said Wildcat Point opted for Jensen's extended warranties and service to keep equipment running the way it should, maintaining turbine fluids within recommended specifications.

Jensen changes out filter elements annually and performs all PMs called for in its O&M instructions. Any interim issues are responded to in timely fashion and there have been no delays in service and in the receipt of necessary parts. As noted earlier, "no failed starts" is the objective and the fluid systems for the principal rotating equipment at Wildcat Point continue to meet these expectations. CCJ