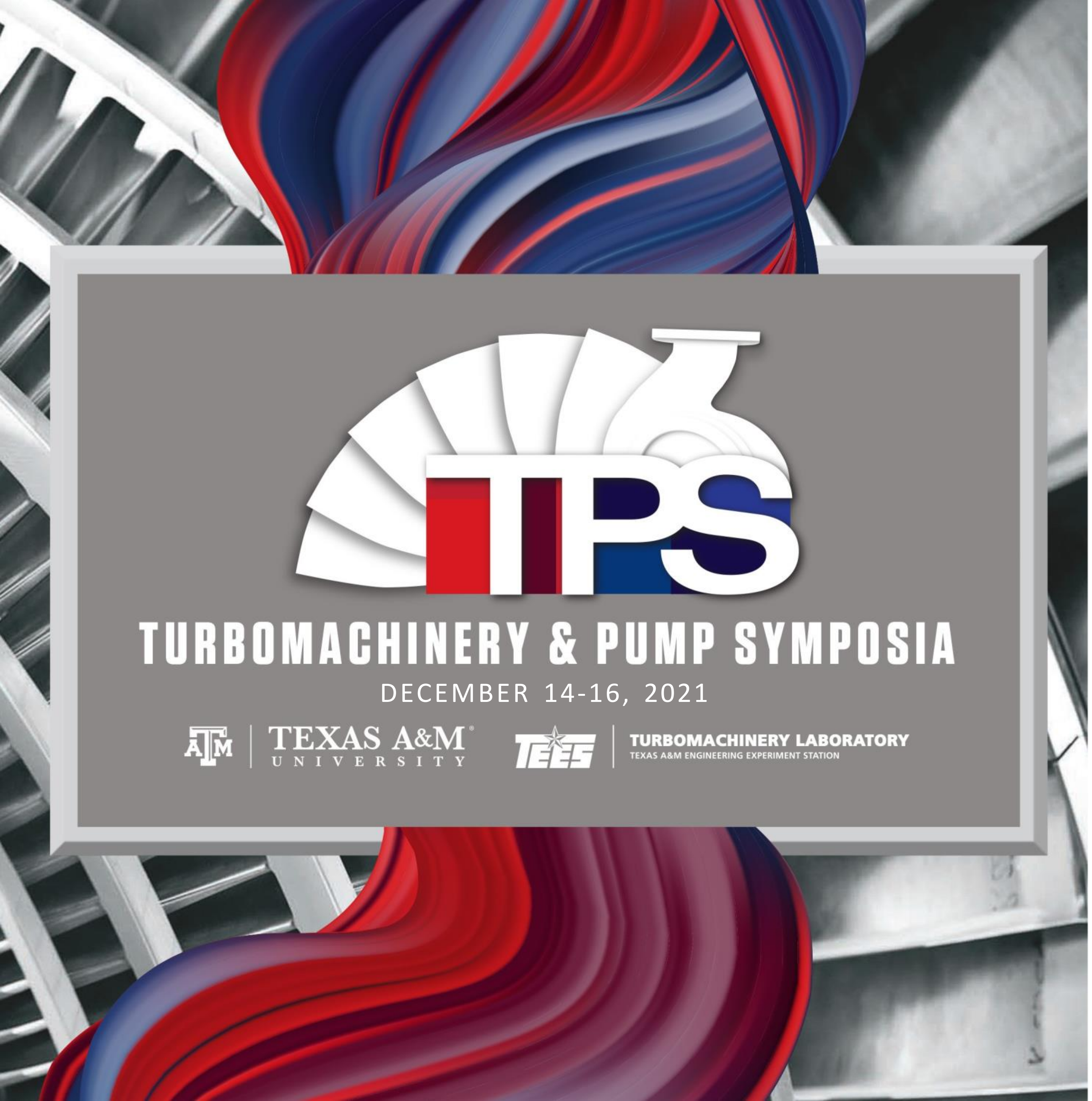

MODERN RISKS OF VARNISH AND DEFLAGRATIONS IN COMPRESSOR AND TURBINE LUBRICATION OIL SYSTEMS

CASE STUDY: MAIN AIR COMPRESSOR IN NETHERLANDS

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TURBOMACHINERY & PUMP SYMPOSIA

SUMMARY

This presentation looks at a case study of a main air compressor that developed severe varnish ultimately linked to change in modern oil chemistry.

It reviews actions that can be taken to minimize oil degradation resulting in varnish formation and reduce the risk of deflagrations in compressor and turbine oil systems.

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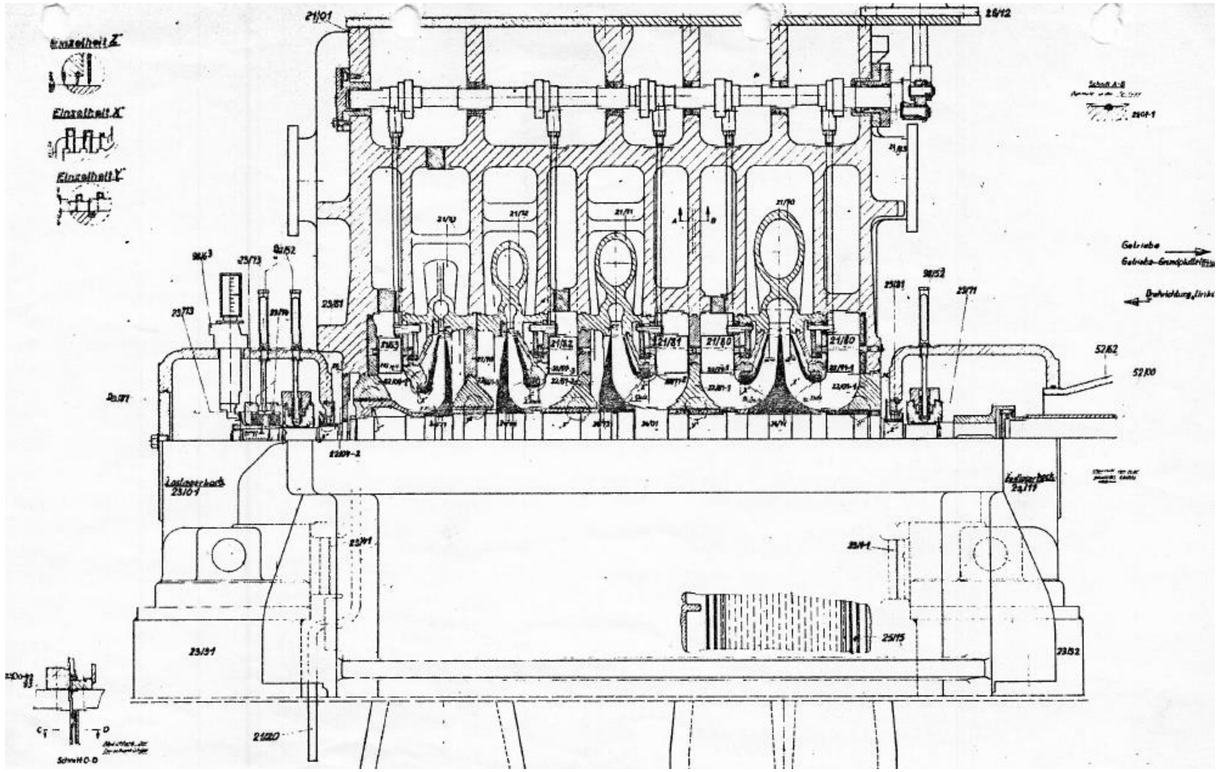
COMPRESSOR DETAILS

4-stage main air compressor in service since 1970

- 80,400 m3/h (47,322 cfm) flow rate
- 7,500 kW (10,058 hp) motor drive
- Suction pressure 1.02 bara (14.79 psia) / Discharge pressure 7.7 bara (111.68 psia)
- Control oil filter
    - Hydraulic load 0.061 $L/min/cm^2$
- Lube oil filter
    - Hydraulic load 0.059 $L/min/cm^2$



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THE PROBLEM

- Compressor was operating in standby service with oil system running continuously
- On attempt to start compressor, start permission was not achieved due to insufficient lube oil pressure
- The lubrication oil filter and control oil filter were found coated in black sludge and deposits, therefore causing the high DP and insufficient oil pressure to prevent machine from starting

FINDINGS

- The sample from the filter appeared to be thermoplastic (solid at 18°C (64°F) but melted to liquid at 60°C (140°F))
  - High viscosity at higher temperature means movement in the system very limited – generation source at filter where it was found suspected
- The varnish was soluble in a polar solvent
  - Determined to be methylene chloride -> hydrocarbon, not containing any inorganic material or soot.
- Infrared spectroscopy was done to analyze the sample further to understand the chemistry of the varnish and deposits

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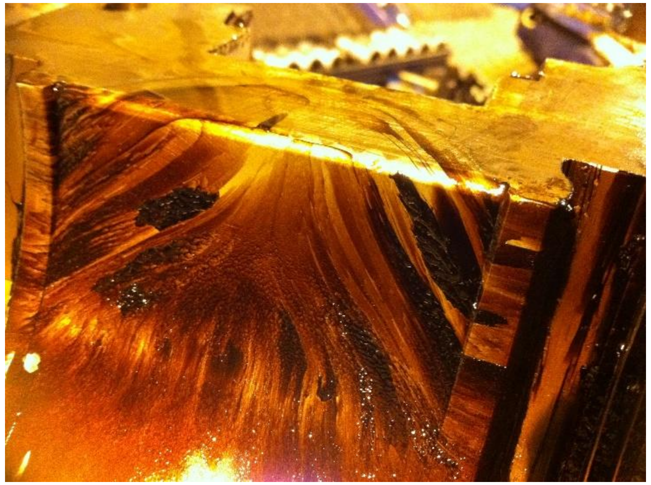
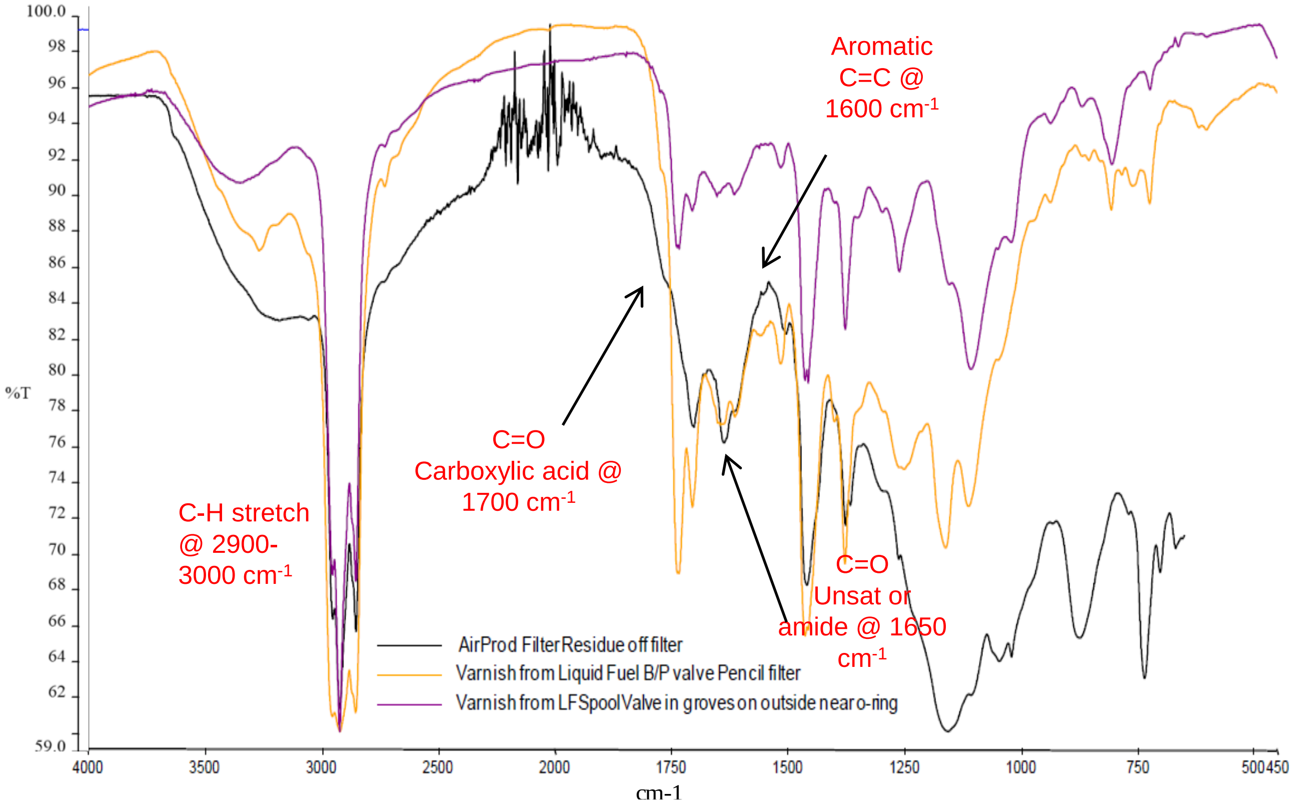
FINDINGS

- A thin layer of varnish was identified on the gearbox, surfaces of the bearings, and in the piping system.
- No metal or foreign debris was noted.
- An oil sample taken 3 months prior indicated acceptable water content (<70 ppm), a slight decrease in viscosity by 3%, but no other major issues.
    - MPC (membrane patch colorimetry), oil conductivity, flash point was not measured routinely at this time



FINDINGS



This chemistry is indicative of samples produced by sparking of lubrication oil (high temperature reaction >300°C (572°F), with high acid formation but little ester formation. **Was a change in base oil causing reaction leading to by-product and filter damage?**

ROOT CAUSE ELIMINATION

- Oil aging products dropping out of solution (sludge, varnish, deposits) have several root causes with many reaction pathways:
  - Oxidation of oil at temperatures > 60°C (140°F)
  - Accelerated oil degradation due to contamination (water, wear metals, dirt)
  - Additive depletion / hydrolysis
  - Thermal Degradation (thermal cracking > 300°C (572°F)
    - ➢ Micro-dieseling (Adiabatic compression)
      - ➢ Ruled out, lack of soot in analyzed samples
    - ➢ Electrostatic discharge
      - ➢ **Supported by spectra findings**

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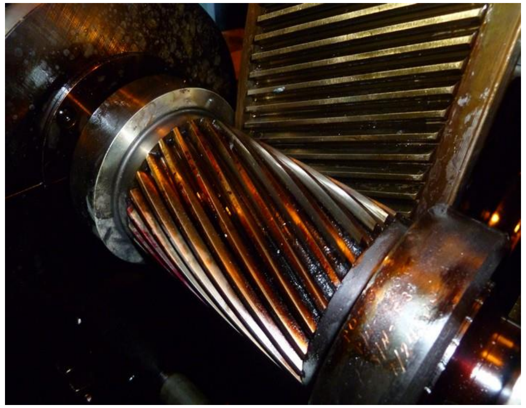
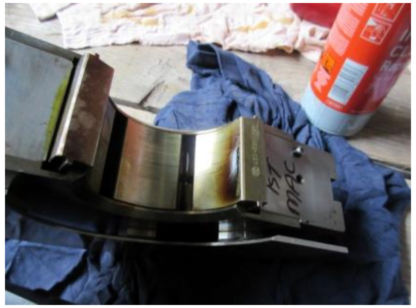
ACTIONS TAKEN

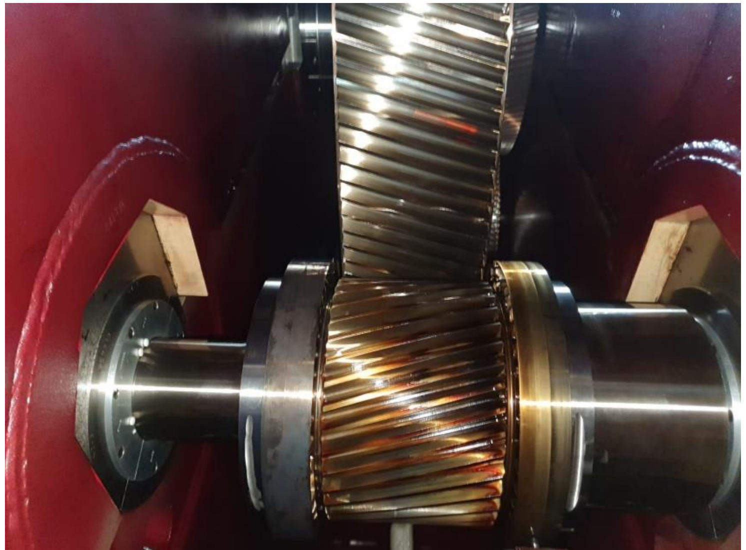
- The oil system was flushed to remove all varnish and deposits from the system
- New oil filters and oil type installed
- Oil heaters were inspected and found no malfunctions
- No RCA was done, considered a one-off issue at the time.
- More frequent oil analysis is now done and use of varnish removal unit when MPC (membrane patch colorimetry) rises.
- Oil system shut off when compressor offline.

VARNISH PREVALENCE

- Noted in recent years an increase in varnish and deposits in turbo-compressors – both detected by rising MPC in used oil analysis, but also visually during routine maintenance on bearings, gearing
- Mitigations to **treat** varnish have been established, but root causes of varnish origin still relatively unclear when inspecting a machine.
- In the past 5-10 years, more analysis of the chemistry of varnish sources has been undertaken, but not yet possible to conclude in a system what % of varnish comes from what specific source.

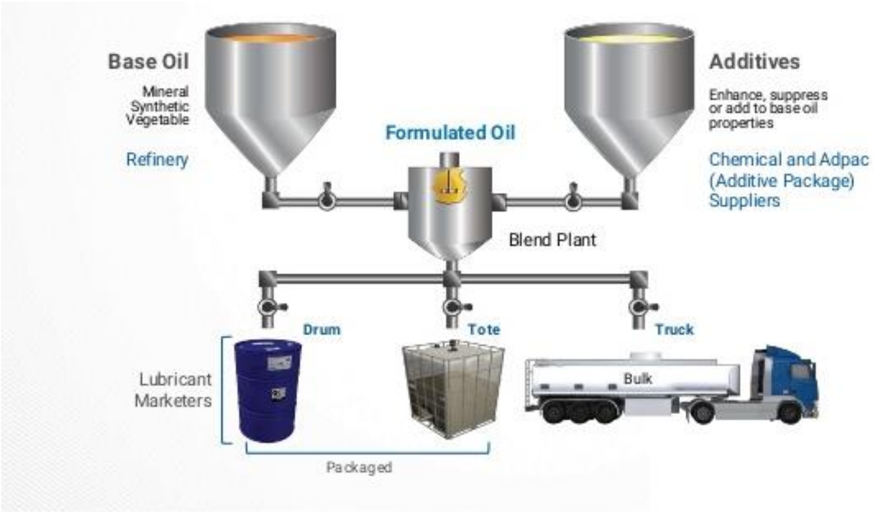






LUBRICATION OIL CHANGE

- Over the past decade, distilled crude oils (Group I) are rapidly being displaced by more refined base oils (Group II, III) and synthetic alternatives (Group IV) in to enhance performance and meet environmental regulations.
- Better refining processes such as hydrotreatment or hydrocracking result in base oils better purity and uniformity.
- As a result, base oils now have a lower amount of unsaturated (polar) hydrocarbons and are virtually sulfur-free with low aromatics



API BASE OIL CATEGORIES

	Base Oil Category	Sulfur (%)		Saturates (%)	Viscosity Index
Mineral	Group I (solvent refined)	>0.03	and/or	<90	80 to 120
Mineral	Group II (hydrotreated)	<0.03	and	>90	80 to 120
Mineral	Group III (hydrocracked)	<0.03	and	>90	>120
Synthetic	Group IV	PAO Synthetic Lubricants			
Synthetic	Group V	All other base oils not included in Groups I, II, III or IV			

Source: Machinery Lubrication, Noria Corporation

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BASE OIL DIFFERENCES

GP I base oils have **better solvency** than GP II / III base oils

- Production of GP II/ III base oils by hydrotreating or hydrocracking result in lower levels of unsaturated polar hydrocarbons. Varnish has a polar structure. Polar substances dissolve more easily in polar substances.
- When the proportion of polar hydrocarbons in oil is reduced, oil aging products / varnish cannot dissolve as easily.

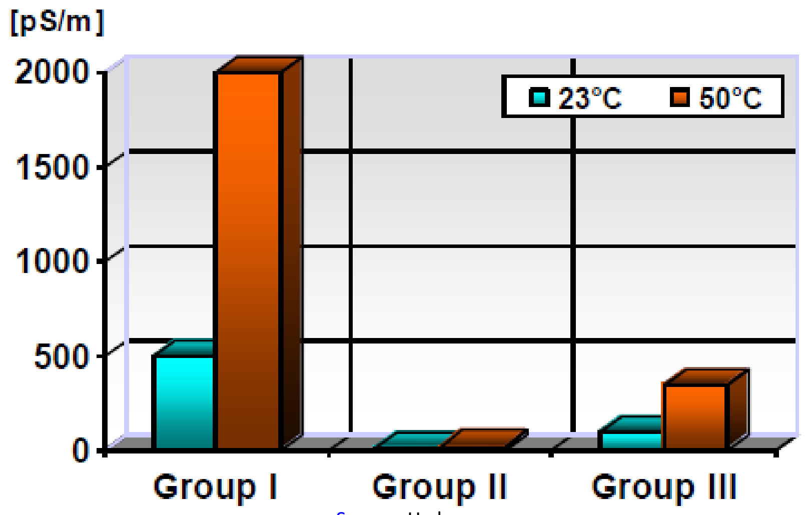
GP II base oils have **more oxidation resistance** than GP I base oils

- GP II base oils have less antioxidant additives and therefore less deposits to drop out.

GP II turbine oils contain very little sulfur and very few metal-organic additives, as these contribute to corrosion and deposits.

CONDUCTIVITY OF OIL

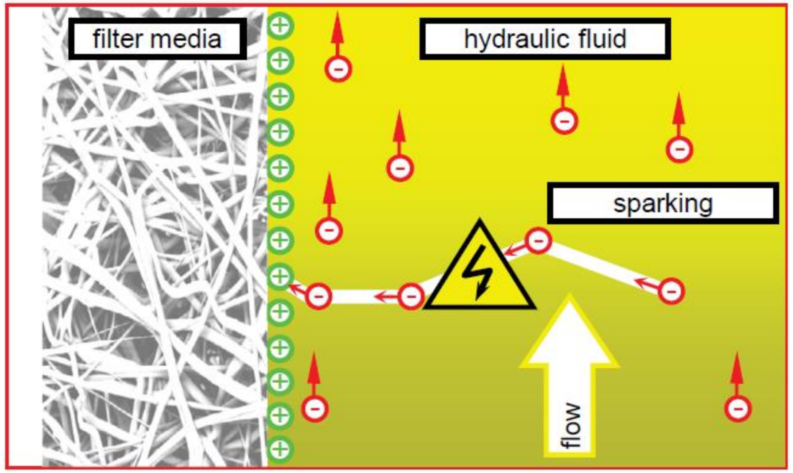
- Conductivities of liquids are classified as high (>1,000 pS/m), medium (1,000-50 pS/m), low (50-2 pS/m), or ultra-low (<2 pS/m).
  - Generally, liquids with conductivity greater than 50 pS/m do not accumulate static charges provided the system is properly grounded, as charges relax as fast as they are generated.



Source: Hydac

ELECTROSTATIC CHARGING

- Electrostatic charge generation occurs in fluid as a result of friction between fluid and system components, such as through a pipe or porous structure.
- Electrostatic discharge factors
  - Temperature -> charge generation and accumulation increases with lower oil temperature
  - Flow velocity -> charge generation increases with increased flow velocity
  - The lower the conductivity, the higher the charge generation



Sparking Source: Hydac

KEY FINDINGS

Research suggests 2 key risk factors for ESD occurring which are common in our operations:

‘The typical oil formulations employed in turbine lube systems are known to exhibit relatively low electrical conductivities, typically **<10 pS*m^{-1} at 25°C**. At typical flow rates employed in those systems (6000 L*min^{-1}) and the effective hydraulic loads (**0.027 L*min^{-1}*cm^{-2}**), ESD can be expected to occur under normal operating conditions.
FROM JOHN DUCHOWSKI, TRIBOLOGIA 4-2014

For subject compressor, changing to a (slightly) higher conductivity oil from 1 pS/m to 10 pS/m, upgrading oil filter, and reducing standby runtime has prevented further degradation of lube oil.

	Base Oil Group	Conductivity @ 25C
A: ISO 46 Turbine Oil	3	0.8 pS/m
B; ISO 32, 46 Turbine Oil	2	1 pS/m
C; ISO 32, 46 Turbine Oil	2	5 pS/m
D; ISO 32, 46 Turbine Oil	2	7 pS/m
E; ISO 32, 68 Hydraulic Fluid	2	10 pS/m
F; ISO 32, 46 Turbine Oil	5	14 pS/m
H; ISO 32 Turbine Oil	1	>500 pS/m

IMPLICATIONS

- For low conductivity fluids, the advised residence time (between charge generator and oil tank) is 3x relaxation time
  - Can easily exceed the traditional design by OEMs and API-614 guidance of oil systems of 30 seconds.
  - Larger oil piping volume would require a significant footprint and cost increase.
    - Lube oil volumes are being minimized to save cost, which means more fluid turnover and higher filter flow rates
    - Filtration ratings improving, resulting in higher hydraulic loads across filters.

- ESD is an ignition source risk, if flammable atmosphere exists in or around oil system

Fluid Conductivity (pS/m)	Charge Relaxation Time Constant (seconds)	Time for 99% Charge Relaxation (seconds)
0.1	150	200
1	15	69
5	3	14
10	1.5	6.9
50	0.3	1.4
450	0.033	0.15
600	0.0025	0.012

CONCLUSIONS

End users aren't always aware of base oil composition or formulation changes - Oil data sheets do not indicate base oils, ad-pacs, conductivity.

Reduced filter life, risk of mechanical damage, oil degradation due to ESD was identified on subject compressor that was resolved by changing to slightly higher conductivity oil, upgrading oil filter, and becoming more pro-active in monitoring lube oil quality and taking action to replace or treat oil when degradation is identified.

Address root causes of varnish generation – infrared spectroscopy can be an effective tool in analyzing varnish/deposit materials to understand possible contribution of oil degradation by electrostatic discharge.

Questions?