Non-Varnishing PAG-based Turbine Fluid and GEK Spec 32568h Recommendations

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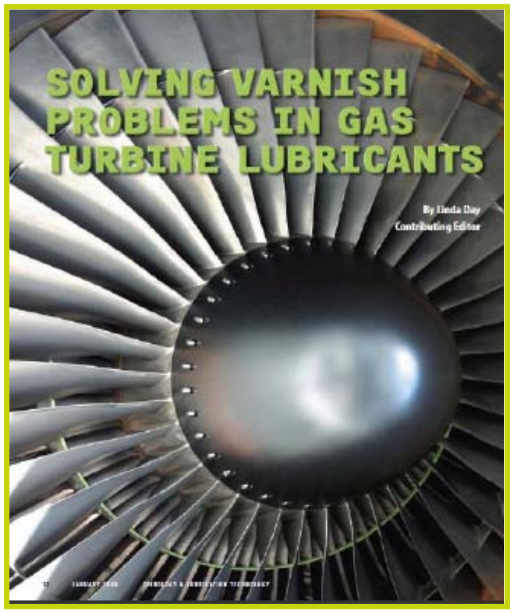
Presentation Objectives

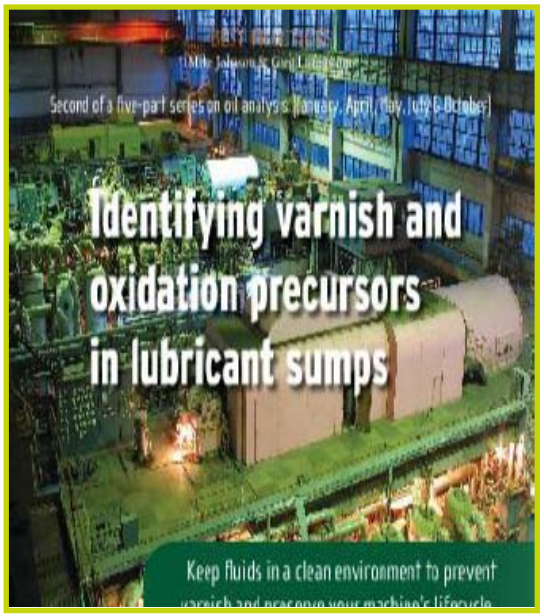
- Polyalkylene Glycols(PAGs) – Chemistry and Varnish Free Technology
- Characteristics – PAG-based Turbine Fluid
- In-Service Monitoring of PAG-based Turbine Oils
- Inclusion of PAG-based Synthetic Turbine Fluid in GEK 32568h

Varnish, Varnish, Varnish



TLT Magazine, January 2008

Varying degrees of varnished servo valve filters



TLT Magazine, April 2011

Defining the Opportunity Year 2007

- Heavy Duty Gas and Steam Turbines
- Common sump - lube oil & hydraulic system varnishing
- IGV's and/or GCV's are driving trips
- Significant cost due to varnish related trips (lost revenue & maintenance)
- Standard lube oil tests incapable of varnish detection
- Degradation of hydrocarbon turbine oils continue to persist

Why should a gas turbine operator evaluate and specify PAG-based turbine fluid technology?

- End Users will have *less trips* and *longer service-life* by using PAG-based turbine fluids with outstanding *varnish-free* performance

- End Users can implement a varnish-free solution faster by leveraging DOW's experience and data in turbo machinery applications

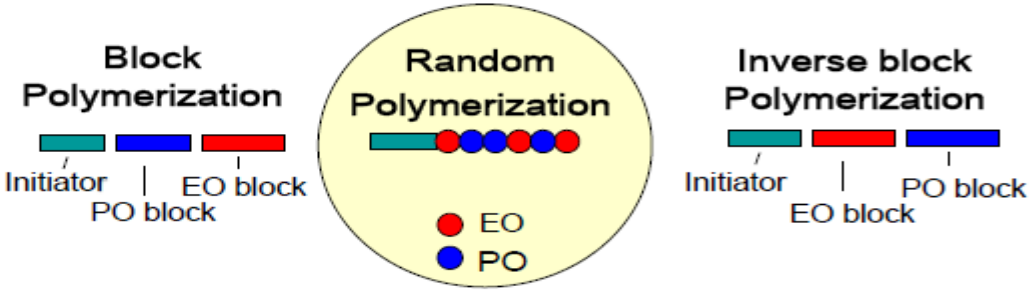
PAG Technology: Designed to Refined

Typical Synthesis Route to Polyalkylene Glycols

Ethylene oxide (EO) Propylene oxide (PO)

- High performance synthetic lubricants
- Solve problems that mineral oils can not.
- Synthesized from ethylene oxide and propylene oxide
- Flexible chemistry – polymers can be tailor designed to meet many requirements
- Extensively researched to provide energy efficient solutions

CLASSICAL POLYMER STRUCTURES BASED ON EO & PO



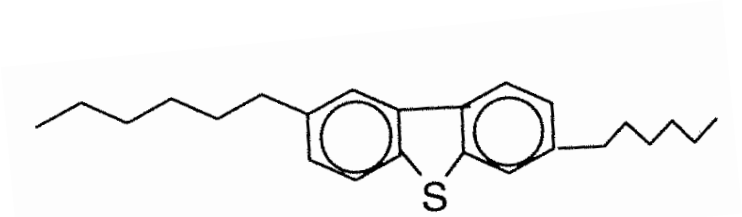
Initiators are typically monols, diols or triols
(for example butanol, propylene glycol, glycerol).

PAGs can be designed to have a wide range of molecular weights, viscosities and functional performance

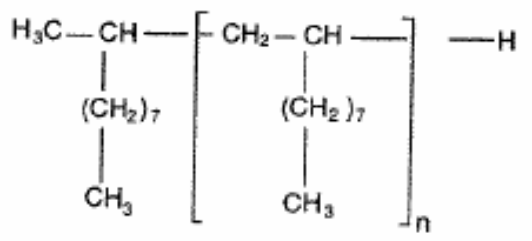
What is different?

Degradation by-products of hydrocarbon oils are polar compounds – but not soluble in non-polar base oil

Mineral Oil – Petroleum- based Hydrocarbon Group I Base stock

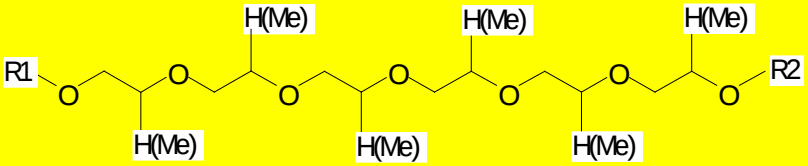


PAO- Poly Alpha Olefin- Synthetic Hydrocarbon Oil Group IV



Non-Polar

Heavily additized for oxidation stability and has poor solvency



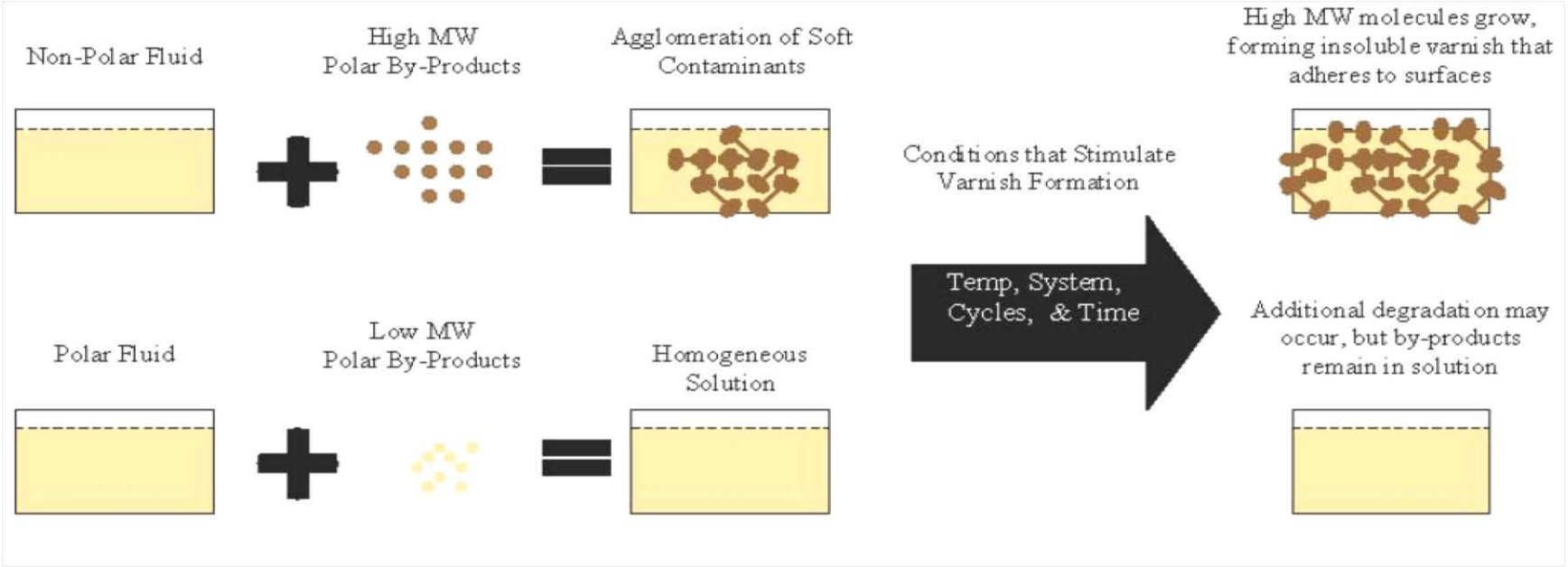
Polar

Inherently thermo-oxidatively stable with high VI

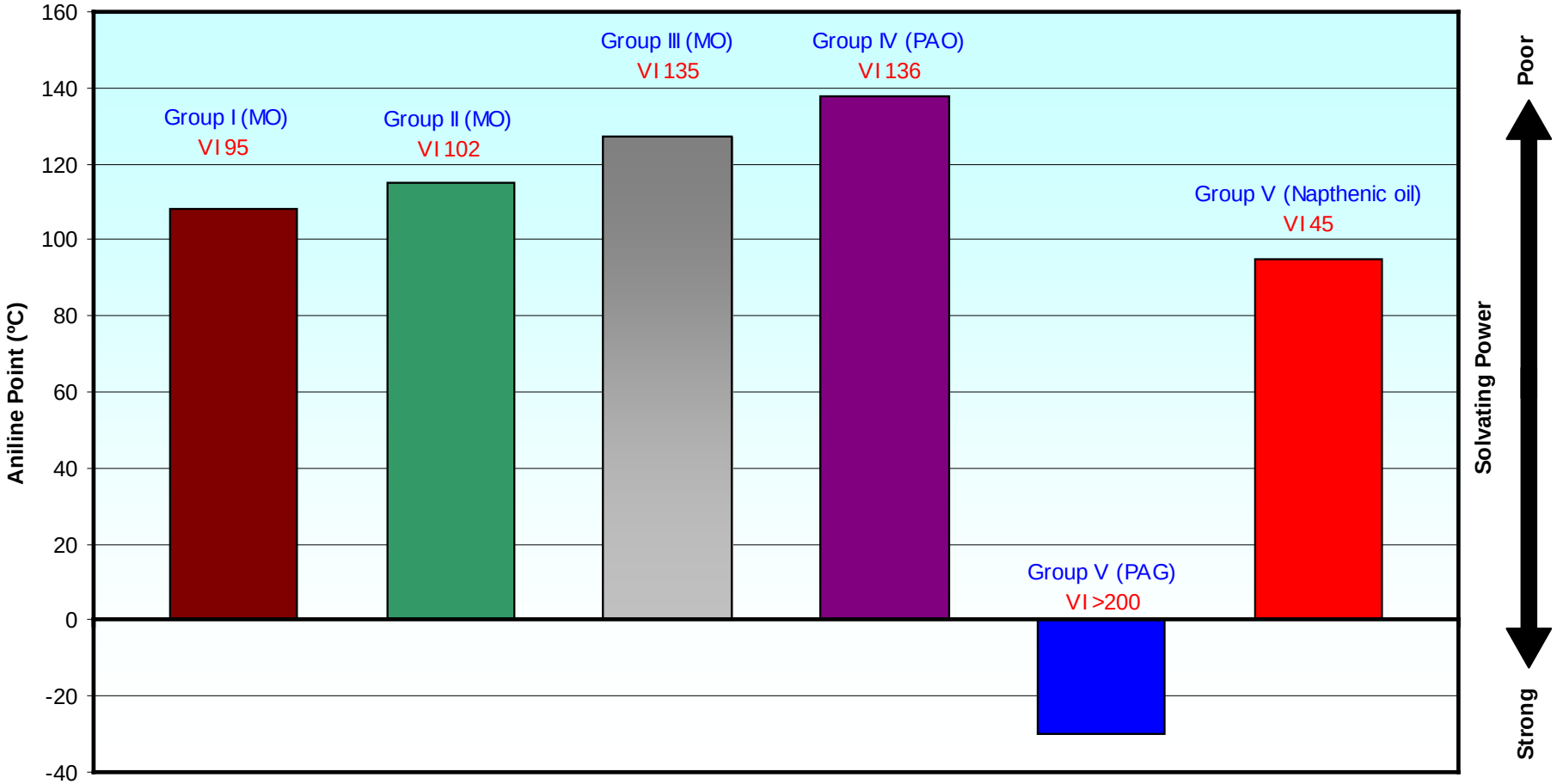
Degradation by-products of PAGs are polar compounds – soluble in polar parent base oil

Equipment Reliability - Varnish Elimination

Oxidation of hydrocarbon oils and PAGs



Aniline Point for Various Base stocks



TURBO COMPRESSORS - Varnish Elimination

Recommended Service Life 2000 hours

10+ Years Experience – Over 100,000 Installations

Group I-III Produce Heavy Sludge and Varnish

Group IV's Produce Hard Yellow Varnish

Minimum service life 8000 hours

PAG Technology is Non-Varnishing

Polyalkylene Glycol Chemistry
Produces **NO SLUDGE**

These Applications Are More Challenging Than Typical Turbine Conditions

Leveraged experience to solve varnish problems in gas turbines that used hydrocarbon based fluids

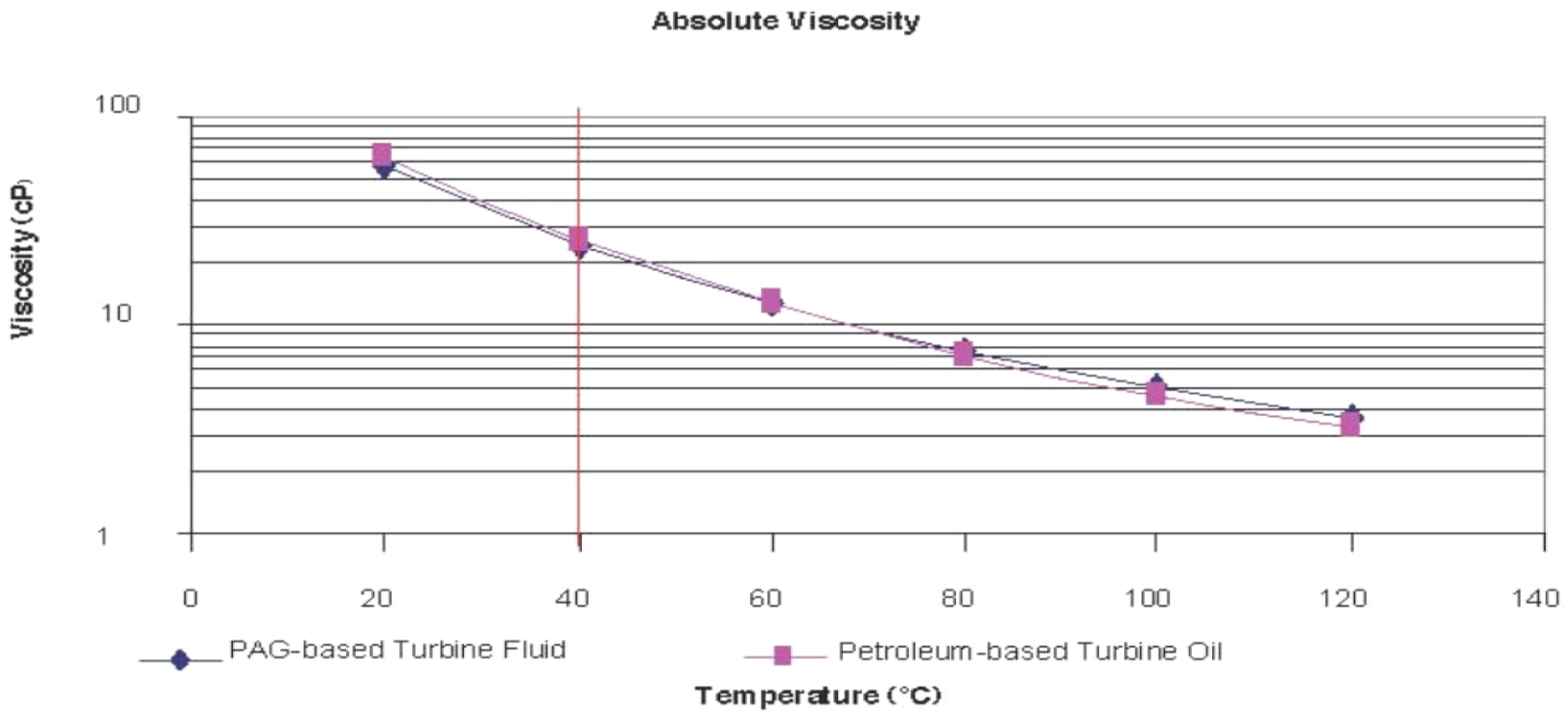
Comparative Properties

PAG-Based Synthetic Turbine Fluid Vs. A Petroleum-Based Turbine Oil

	Polyalkylene Glycol	Petroleum-Based
Typical Properties ISO Viscosity Grade	25	32
@40° C (104° F) cSt	26.23	32.44
@100° C (212° F) cSt	5.19	5.56
Viscosity Index	132	109
Thermal Conductivity @40C watts/m °K	0.145	0.1
Four Ball Wear Scar mm	0.63	0.65
Air release Results ASTM D 3427 Minutes to 0.2% Entrained Air volume	0.4	4.0 - 5.0
Biodegradable	Yes	----
Hydrolytic Stability	No Reaction With Water	Forms Acids, Degrades

Evidence of Technical Solution

VISCOSITY COMPARISON

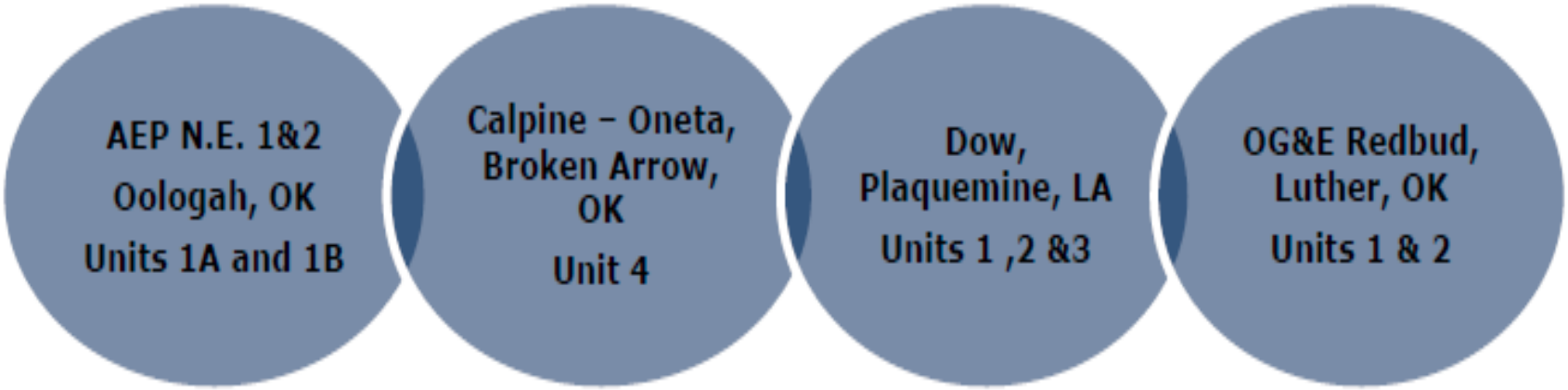


Evidence of Technical Solution

TURBINE FLUID CONVERSONS, HOURS

Converted 41 gas turbines since November ’07

- All fluid conditions track well
- Consistent measurements of TAN, Particle Count, Metals, AO, Water Content

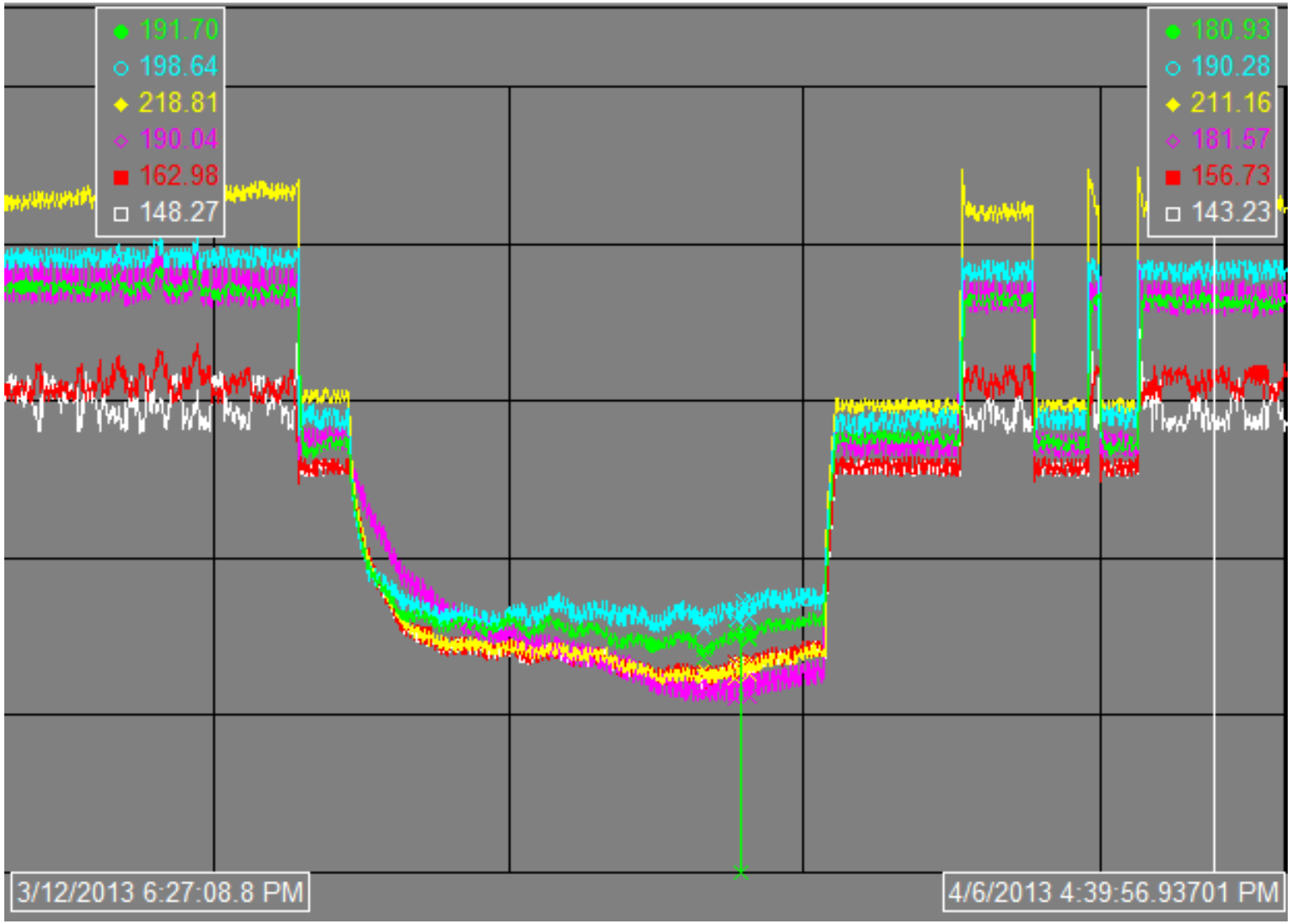


DOW PAG-based Turbine Fluid: Monitoring Tests

Sample	Base Line PAG-based-Turbine Fluid	7 Years, Peaker 21000 Hours	7 Years Base Load >50000 Hours	GE Specs GEK 32568G
ASTM D 445 Viscosity	26	27.1	26.2	28-35
ASTM D 972 mg KOH/g	0.08	0.2	0.16	0.4 Max
ASTM D 6971 Ruler	100	91	85	25% Min NOV
ASTM D 2272 Minutes	750	509	490	25% Min NOV
ASTM D 7843 (MPC Test)	3	11	9	Trend Monitor
Particle Count ISO 4406	12/11/9	14/13/11	15/12/10	-
ICP ASTM D 6595				-
Sodium	3	6	4	---
Calcium	2	3	2	-
Zinc	-	1		
Phosphorous	1	5	4	

PAG-based Turbine Fluid: Cooler Bearings

- Bearing Metal Temp - Generator Bearing # — °F
- Bearing Metal Temp – Generator Bearing # — 192-181
- Bearing Metal Temp – Turbine Bearing #1 — 199-190
- Bearing Metal Temp – Turbine Bearing #2 — 219-211
- Bearing Metal Temp – Thrust Active — 190-182
- Bearing Metal Temp – Thrust Inactive — 163-157 / 148-143


191.70
198.64
218.81
190.04
162.98
148.27
180.93
190.28
211.16
181.57
156.73
143.23
-10.77
- 8.36
- 7.65
- 8.47
- 6.25
- 5.04
3/12/2013 6:27:08.8 PM
4/6/2013 4:39:56.93701 PM

Foaming & Air release

Specification	PAG-based Turbine Fluid	PAG-based Turbine Fluid After 5 years use in Peaker Turbine
Foam Tendency, ASTM D892, ml		
Seq. 1	10/0	10/0
Seq. II	0/0	0/0
Seq. III	0/0	5/0
Air Release, ASTM D3427 (Minutes @ 50° C)	0.4	0.7**

- Excellent air release for both neat fluid and fluid after five years in peaking Turbine, ** 7 year Peaker sample
- Lower air release times than those typical of petroleum and hydrocarbon-based turbine fluids 4.0 to 5.0 recently tested)
  - GEK 32568G Spec requires 5.0 max
- Prolonged air release times can lead to pump cavitations, micro dieseling, premature oxidation, and component wear.

Corrosion Characteristics

Sample	Base Line PAG-based-Turbine Fluid	7 Years, Cyclic 21,000, Hrs	7 Years Base Load >50,000 Hrs	AST M D 4378 & 6224
ASTM D 665 A Rust Prevention	Pass	No Corrosion	No Corrosion	Light Fail
ASTM D 130 24 Hours @100^{0}C Copper Corrosion	1A	1B	1B	-

1B Max is GE New Fluid Spec

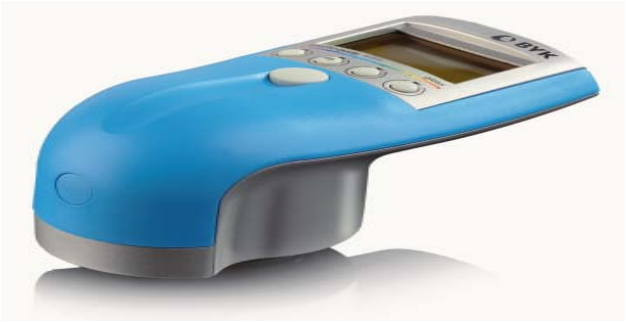
PAINT COMPATIBILITY TEST: P23E-AL-0204 REV. E

Experimental
Paint: A8B95 1-part Gold Phenolic-Epoxy Primer (GE approved paint).
Thinner: D5E11 n-Butyl Acetate
Oils: Dow Turbine Fluid TF-25 and Texaco R&O 32
Surface Preparation Sec 4.5 : Sand blasted steel panels
Paint Preparation Sec 4.6
Coating Application Sec 4.7
30 days Immersion testing @ 200 ° F
Delta E is defined as total color difference between sample and the standard

Oil Type	Delta E
Dow Turbine Fluid TF-25	11.81
Dow Turbine Fluid TF-25	11.42
Dow Turbine Fluid TF-25	12.12
Texaco R&O 32	21.30
Texaco R&O 32	20.46
Texaco R&O 32	20.49

BYK Colorimeter

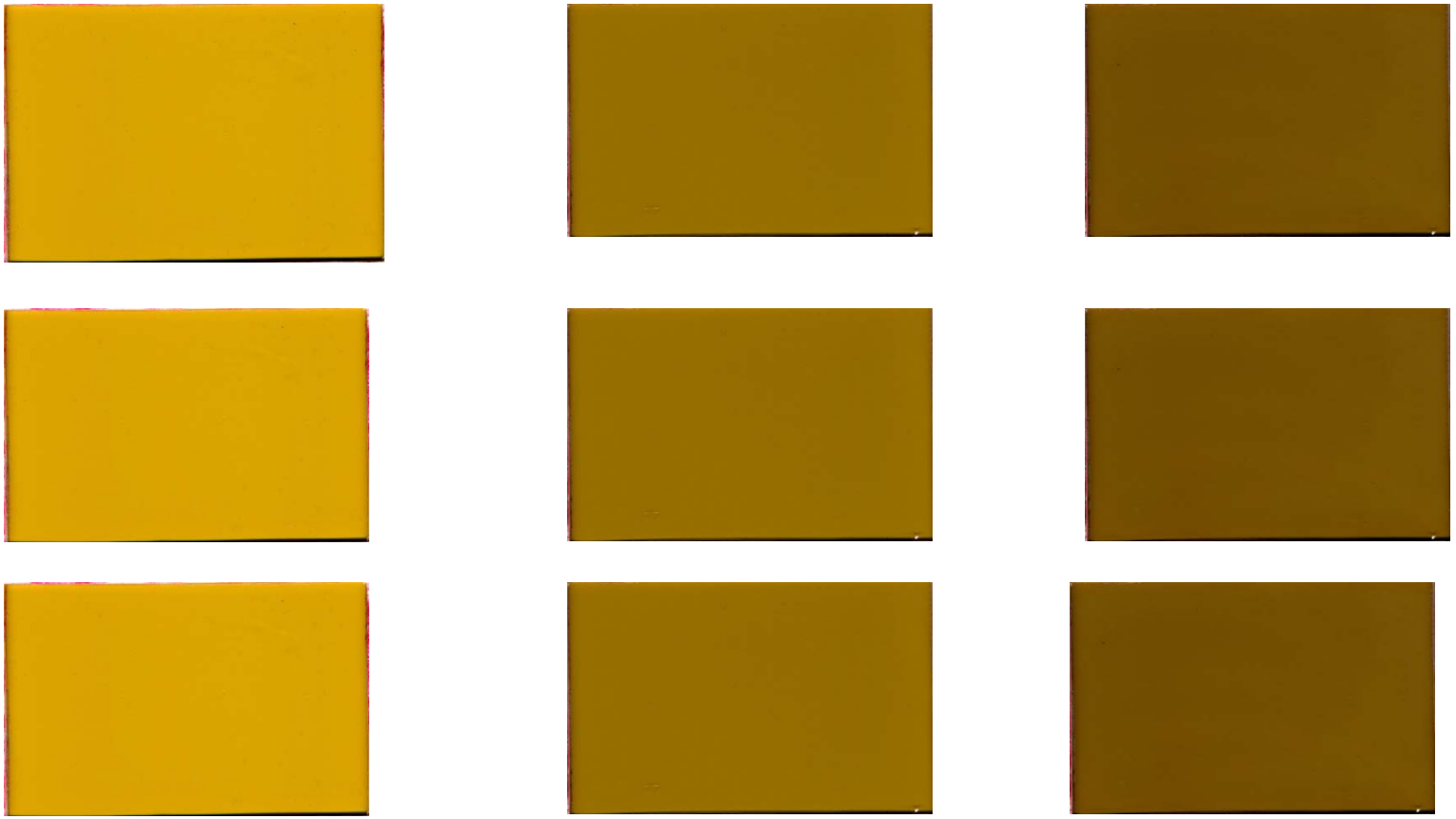
S 124026 A.



GE Paint Coated Panels: 30 days immersed in @ 200F

No Sign of wrinkling, blistering, or peeling, Texaco 32 darker in color vs. Dow TF-25

Standard	Dow Turbine Fluid TF-25	Texaco R&O 32



Base Load Turbine - Filter Analysis

Experimental: Filter Analysis

Method: Oblique reflected light microscopy (LM)

Instrument: Leica WILD MZ-16 stereo-zoom light microscope equipped with a Nikon DXM 1200 digital camera and ACT-1 image acquisition software

Sample Preparation: samples were imaged using oblique reflected light (fiber optic light and ring lamp)

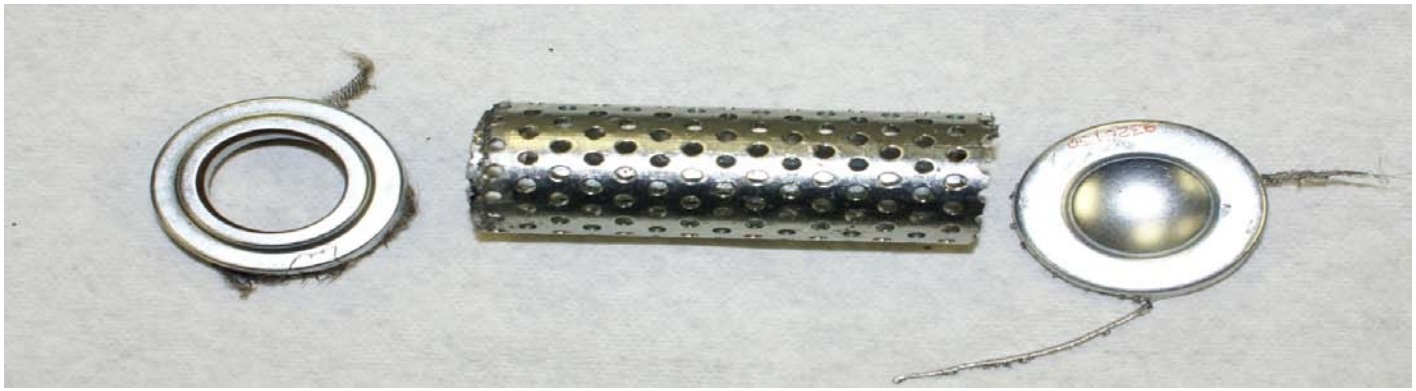
Extracted Oil subjected to ICP analysis

All metals were <1 ppm (Fe, Ni,Al,Sn,Ag,Cr, Pb,Si,B)

K, Ca were <10ppm

Base Load Turbine - Filter Analysis

Four Years Used Last Chance Filter Tear Down



Filter Body/Baffle with ends

Stainless Steel Mesh

Paper Filter

Wire screen

GEK32568h
Revised April 2013

GE Power & Water

Lubricating Oil Recommendations for Gas Turbines
With Bearing Ambients above 500°F (260°C)

http://www.ge-energy.com/tools_and_training/tools/technical_manuals_gas_and_steam_turbine_generator_units.jsp

Conclusions

- In-service monitoring of PAG based Turbine Fluid track well after 48 thousand hours of use in GE Heavy Duty 7 FA Gas Turbines

- Polyalkylene Glycols(PAGs) Technology eliminates varnish and deposits in Heavy Duty Gas Turbine applications

Thank You

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