GTEN 2019 Symposium

October 21-23, 2019 | Banff, Alberta

A Paradigm Shift in Gas Turbine Lubricant Maintenance

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EPT

Presented at the Gas Turbines Energy Network (GTEN) 2019 Symposium

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Banff, AB, Canada
Photo: Matt Hobbs

Introduction

- EPT: Specialize in ion exchange-based lubricant treatments.
  - 25 years experience.
  - > 1,000 installations.
  - 50,000,000 operating hours.
  - > $100,000,000 proven cost savings.

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Agenda

- Existing approach to turbine lubricant maintenance.
- Varnish introduction.
- Tools for GT oil maintenance:
  - Varnish measurement.
  - Impact on fluid formulation.
  - Aftermarket additives.
  - Fluid treatments.
- A paradigm shift in fluid maintenance.

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Current Approach

- Maintenance programs focus: particulate removal.
- Oil replacement criteria based on combination of low antioxidants and high acid number.
- Typical turbine oil life is 2-5 years (ASTM D4378-13).
  - 20-50% antioxidant consumption/year.
- Flushing often required at time of replacement.
- And that's if it goes by the book…
  - Normal to have fail-to-starts and production losses of >24hrs/year (and in many cases much worse).

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>97% Availability Hides the Problem

Source: ICIS/ €58 MW/h (01/04/2018)

- Frame 7E GT (60 Hz)/9E (50 Hz)
  - 84 MW (@ $40/MW) = $80,640/day.
  - + $12,000 steam/hour (oil & gas).
  - Production value:

    $80,640 – $368,640/day.
- Rate of failure relating to varnish:
  - 2 incidents/year totaling 24 hours downtime/year.
- $80,640 annual Loss = $2,016,000 over the life of the turbine in power gen.
- $368,640 annual Loss = $9,216,000 over the life of the turbine in oil & gas.

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1.0 Varnish Introduction

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Oxidation

- Attacks all molecules:
  - Oil hydrocarbons, additives, etc.
- O_2 initiates free-radical chain reaction.
- Oxidation by-products:
  - Alcohols, esters, acids etc.
  - Normally all SOLUBLE.

INITIATION

C-H + ·O_2 → C· + H-O_2

PROPAGATION

C· + O_2 → C-O-O·

C-O-O· + C-H → C-O-O-H + C·

C-O-O-H → C-O· + ·O-H

TERMINATION

C-O-O-H → O=C-O-H

C· + C· → C-C

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What Causes Varnish?

- Lubricants are non-polar while their breakdown products are polar.
  - "Like dissolves like."
  - There is a tendency for these to separate.

- Once oxidation products accumulate past the point of saturation, they convert from a soluble form to an insoluble form creating deposits referred to as *varnish*.

- The saturation point is temperature-dependent.
  - When the oil is near saturation, varnish can be insoluble at low temperatures and soluble at elevated temperatures.

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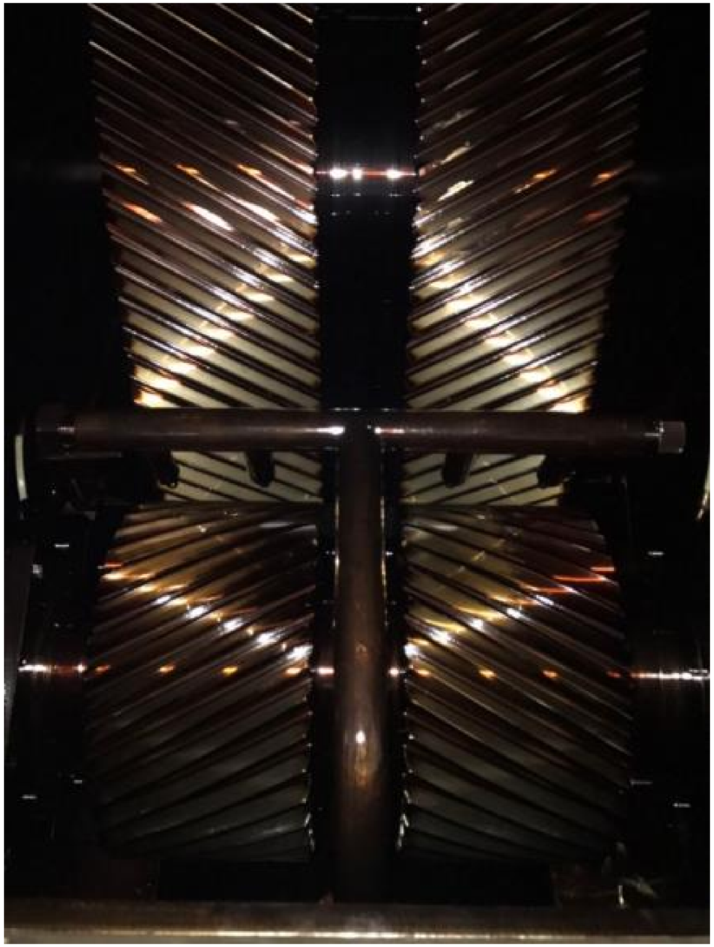
Varnish Impacts All Gas Turbines

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2.0 Varnish Measurement

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Measuring Varnish Potential: MPC

ASTM D7843-16

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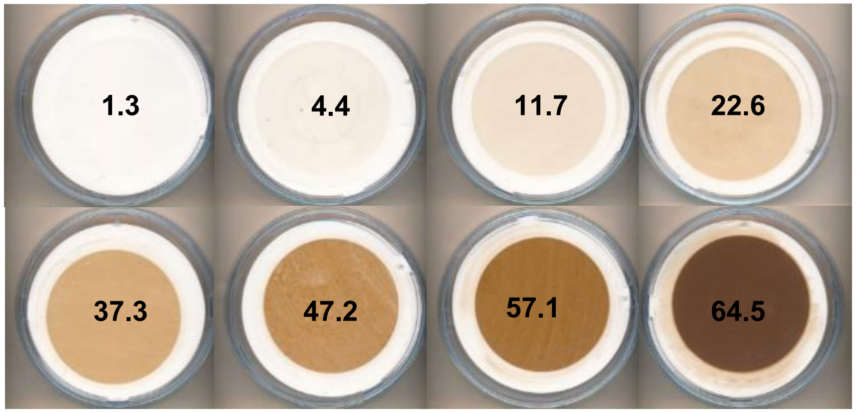
Measuring Varnish Potential: MPC

ASTM D7843-16



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MPC Test Key Points

- ASTM D7843-16:
- Prior to testing:
  - Heat sample to 60C for 24hrs.
  - After heating, hold sample for 72 ± 4 hrs.
  - “Resets” sample and allows soluble varnish to be detected.

Designation: D7843 – 16

Standard Test Method for Measurement of Lubricant Generated Insoluble Color Bodies in In-Service Turbine Oils using Membrane Patch Colorimetry[1]

This standard is issued under the fixed designation D7843; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This test method extracts insoluble contaminants from a sample of in-service turbine oil onto a patch and the color of the membrane patch is analyzed by a spectrophotometer. The results are reported as a ΔE value, within the CIE LAB scale.

1.2 This test method is not appropriate for turbine oils with dyes.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products
D4378 Practice for In-Service Monitoring of Mineral Turbine Oils for Steam, Gas, and Combined Cycle Turbines
E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 *Definitions:*

3.1.1 *CIELAB color scales, n*—CIE 1976 L^*, a^*, b^* opponent-color scales, in which a^* is positive in the red direction and negative in the green direction; b^* is positive in the yellow direction and negative in the blue direction; and L^* is positive in the lightness direction and negative in the darkness direction. **E308**

3.1.2 *colorimetry, n*—the science of color measurement. **E284**

3.1.3 *in-service oil, n*—lubricating oil that is present in a machine that has been at operating temperature for at least one hour (for example, an engine, gearbox, transformer, or turbine).

3.1.4 *membrane color, n*—a visual rating of particulate on a filter membrane against ASTM Color Standards.

3.1.5 *membrane filter, n*—a porous article of closely controlled pore size through which a liquid is passed to separate matter in suspension.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *varnish, n*—a thin, hard, lustrous, oil-insoluble deposit, composed primarily of organic residue, and most readily definable by color intensity. It is not easily removed by wiping with a clean, dry, soft, lint-free wiping material and is resistant to saturated solvents. Its color may vary, but it usually appears in gray, brown, or amber hues.

4. Summary of Test Method

4.1 Insoluble deposits are extracted from an in-service turbine oil sample using a 47 mm, 0.45 µm membrane nitrocellulose patch. The color of the patch is then analyzed using a spectrophotometer and the results are reported as a ΔE value in the CIE LAB scale.

5. Significance and Use

5.1 This test can be a guide to end-users on the formation of lubricant-generated, insoluble deposits.

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.C0.01 on Turbine Oil Monitoring, Problems and Systems.

Current edition approved June 1, 2016. Published August 2016. Originally approved in 2012. Last previous edition approved in 2012 as D7843 – 12. DOI: 10.1520/D7843-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

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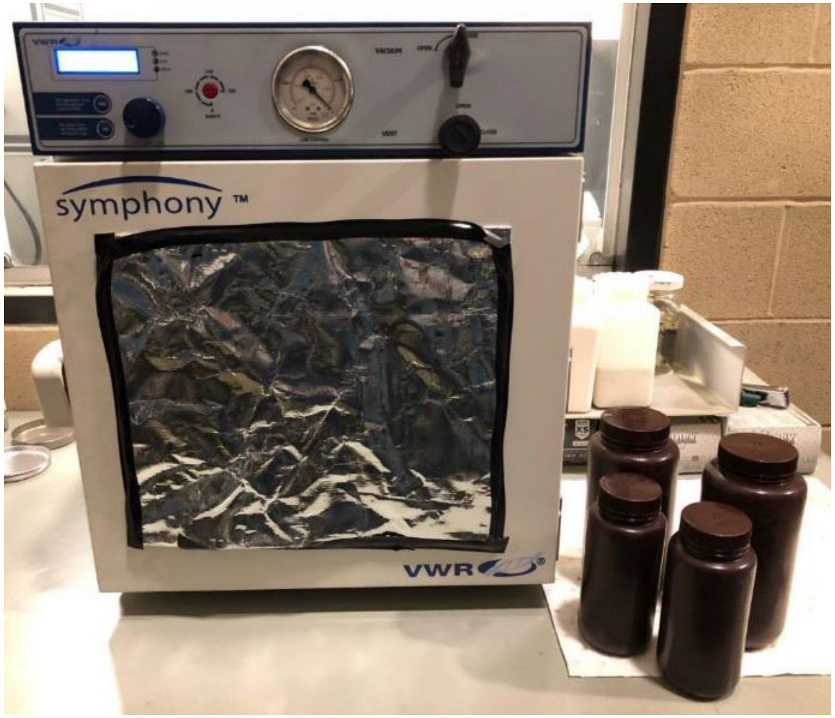
MPC Test Key Points

ASTM D7843-16:

- Updated in 2016.
  - Light must be excluded between sampling and testing.



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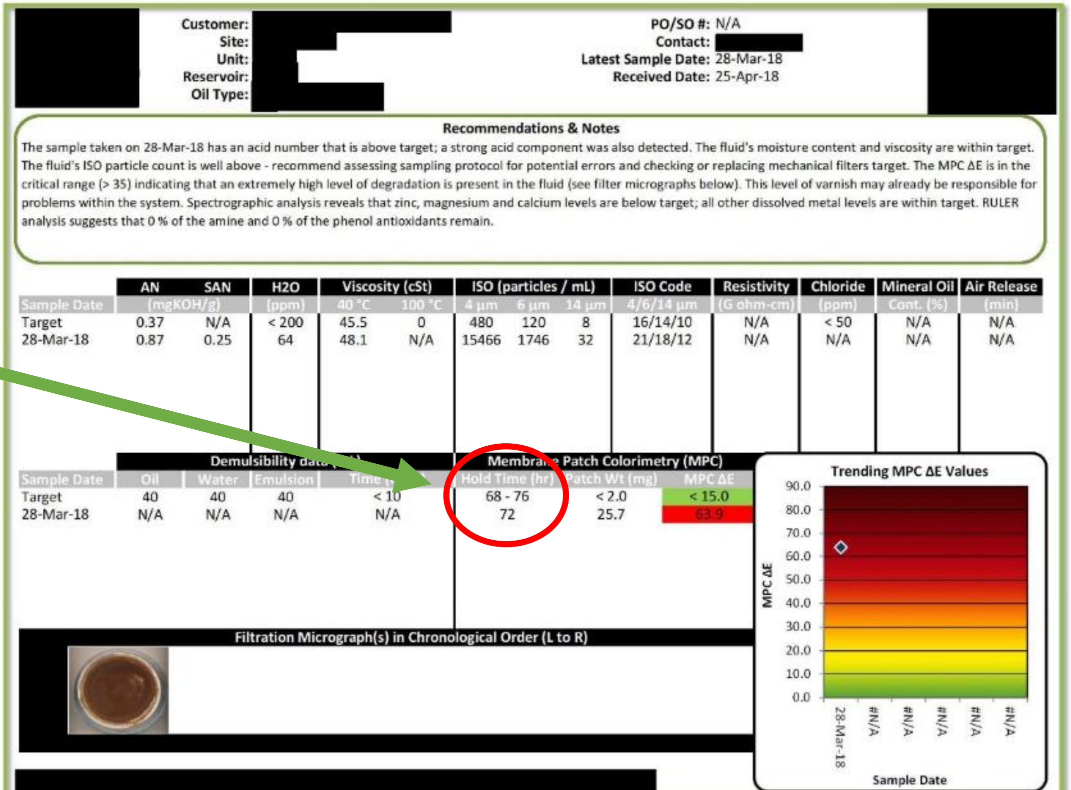
MPC Test Key Points

ASTM D7843-16:

- 72 ± 4 hour hold time *must* be reported with the MPC result.



[redacted]

Customer: [redacted]
Site: [redacted]
Unit: [redacted]
Reservoir: [redacted]
Oil Type: [redacted]

PO/SO #: N/A
Contact: [redacted]
Latest Sample Date: 28-Mar-18
Received Date: 25-Apr-18

[redacted]

Recommendations & Notes

The sample taken on 28-Mar-18 has an acid number that is above target; a strong acid component was also detected. The fluid's moisture content and viscosity are within target. The fluid's ISO particle count is well above - recommend assessing sampling protocol for potential errors and checking or replacing mechanical filters target. The MPC ΔE is in the critical range (> 35) indicating that an extremely high level of degradation is present in the fluid (see filter micrographs below). This level of varnish may already be responsible for problems within the system. Spectrographic analysis reveals that zinc, magnesium and calcium levels are below target; all other dissolved metal levels are within target. RULER analysis suggests that 0 % of the amine and 0 % of the phenol antioxidants remain.

	AN	SAN	H2O	Viscosity (cSt)		ISO (particles / mL)			ISO Code	Resistivity	Chloride	Mineral Oil	Air Release
Sample Date	(mgKOH/g)		(ppm)	40 °C	100 °C	4 µm	6 µm	14 µm	4/6/14 µm	(G ohm-cm)	(ppm)	Cont. (%)	(min)
Target	0.37	N/A	< 200	45.5	0	480	120	8	16/14/10	N/A	< 50	N/A	N/A
28-Mar-18	0.87	0.25	64	48.1	N/A	15466	1746	32	21/18/12	N/A	N/A	N/A	N/A

	Demulsibility data				Membrane Patch Colorimetry (MPC)		
Sample Date	Oil	Water	Emulsion	Time	Hold Time (hr)	Patch Wt (mg)	MPC ΔE
Target	40	40	40	< 10	68 - 76	< 2.0	< 15.0
28-Mar-18	N/A	N/A	N/A	N/A	72	25.7	63.9

Trending MPC ΔE Values
MPC ΔE
90.0 80.0 70.0 60.0 50.0 40.0 30.0 20.0 10.0 0.0
28-Mar-18 #N/A #N/A #N/A #N/A #N/A
Sample Date

Filtration Micrograph(s) in Chronological Order (L to R)

[redacted]

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MPC Test Results

- Filtration without the 72 hour hold period:

MPC Method	Test Location	60°C Heating Period (hours)	20°C Incubation Period (hours)	Initial Patch Photo	Filtered Patch Photo	Initial MPC ΔE	Filtered MPC ΔE	Change
Real Time	On-Site	0	0			36.0	3.0	- 92%

- 1µm /99.5% efficient filter used to clean fluid with on-site MPC testing.
    - Omitted key 24 hours heating + 72 hours incubation periods.
- Real-time MPC results suggest that varnish has been removed.
- User sent duplicate samples to lab for proper MPC testing to confirm.

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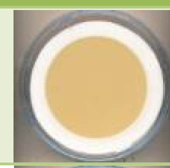
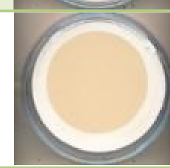
MPC Test Results

- Filtration without the 72 hour hold period:

MPC Method	Test Location	60°C Heating Period (hours)	20°C Incubation Period (hours)	Initial Patch Photo	Filtered Patch Photo	Initial MPC ΔE	Filtered MPC ΔE	Change
Real Time	On-Site	0	0			36.0	3.0	- 92%
ASTM D7843-16	Lab	24	72			22.1	22.1	- 0%

- Lab MPC test reveals filters only removed insoluble varnish!
- Improved filtration led to 0% MPC ↓.
- Soluble varnish remained and re-established equilibrium after standard 4 days.
- Demonstrates the critically of removing soluble material.

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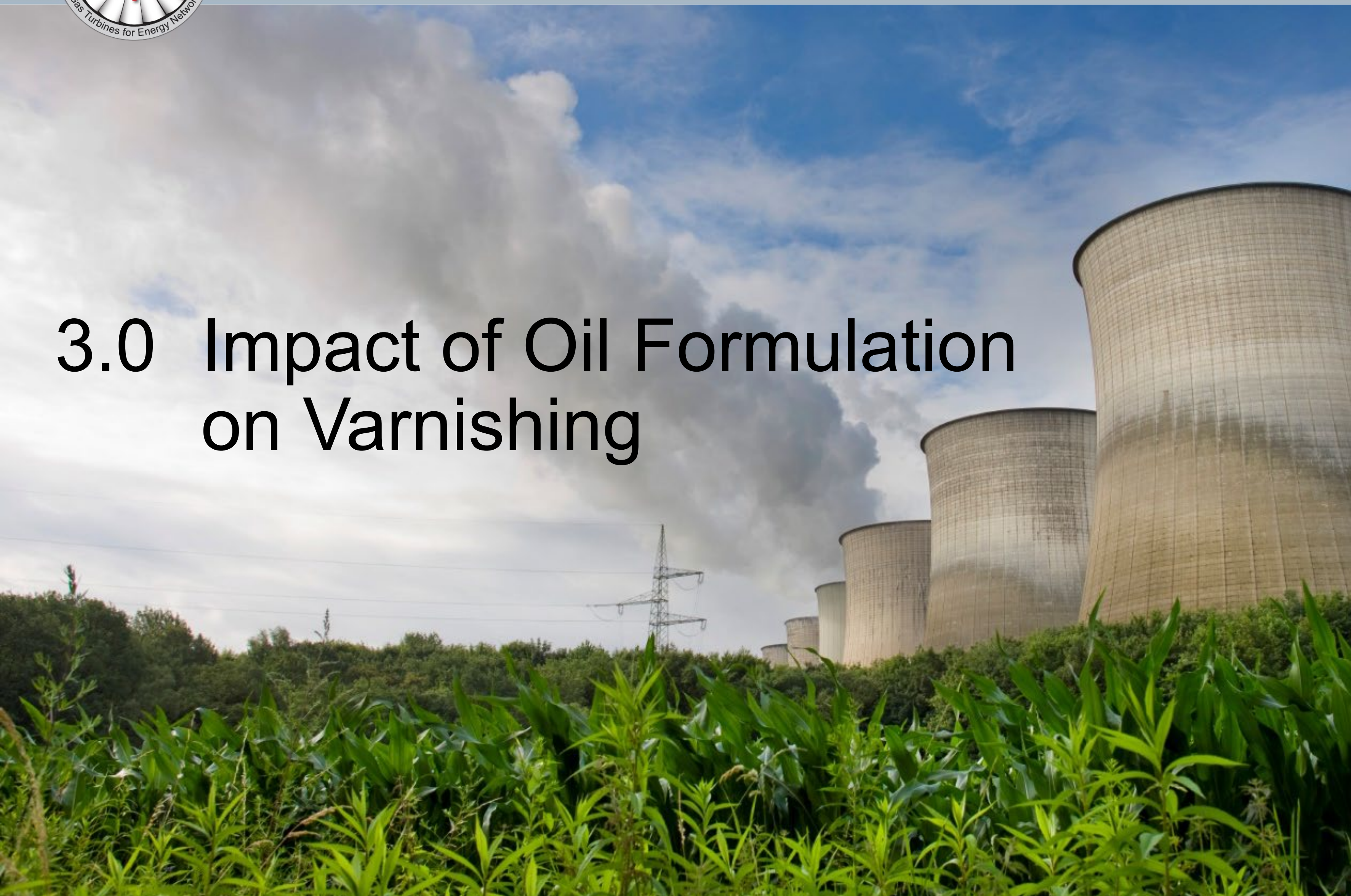

3.0 Impact of Oil Formulation on Varnishing

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New Oil Breakdown Testing

- Reproducible lubricant breakdown compared Group I, Group II turbine oils:
  - Heated to 150°C.
  - Dry air bubbled through.
  - Copper catalyst present.
  - Monitor condition by oil analysis.

    (more test data than TOST)

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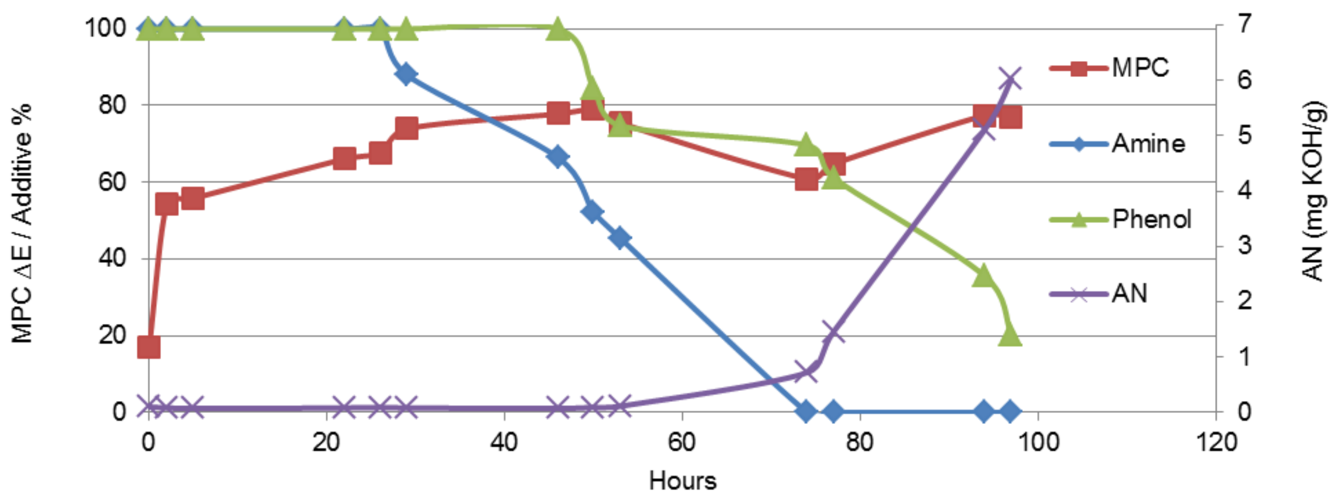
Group I Breakdown

- Oil analysis data plotted against breakdown time.
- Least oxidatively stable:
  - Critical MPC after only 2 hours.
    - No antioxidant consumption during this period.
  - Rapid AN ↑ after antioxidant amine exhaustion.



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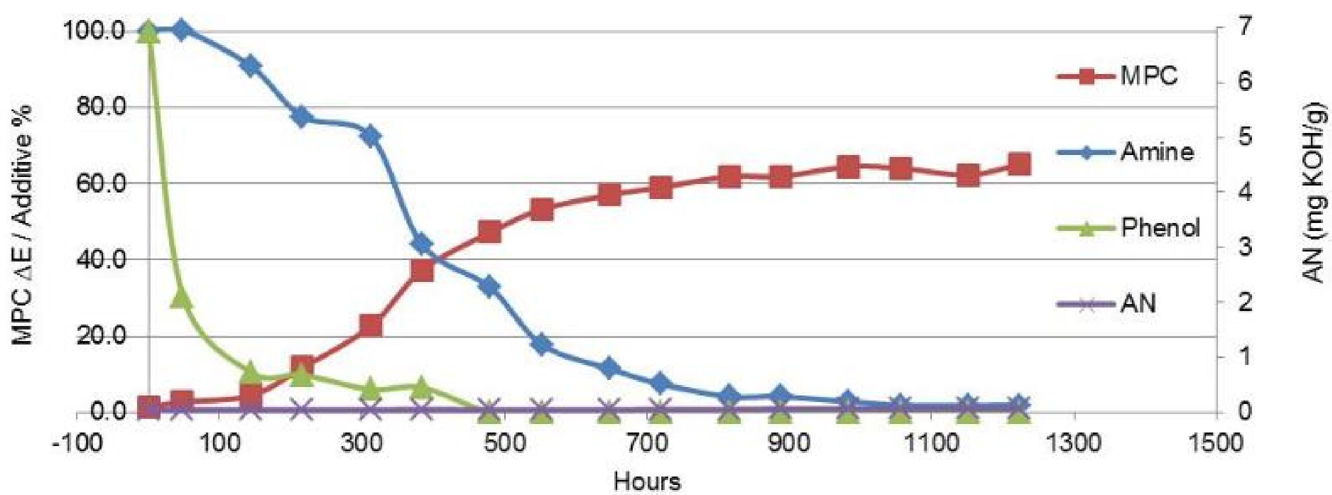
Group II Breakdown

- Very robust: oxidatively stable base stock with effective antioxidants.
  - Critical MPC after 384 hours.
  - No significant AN ↑ over entire test duration (1,224 hours).
  - Antioxidants work as intended.



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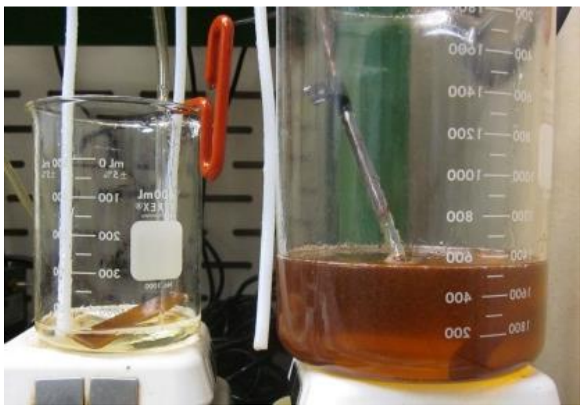
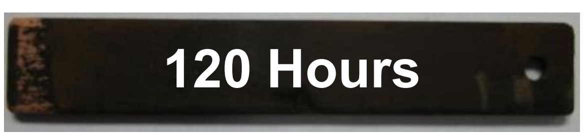
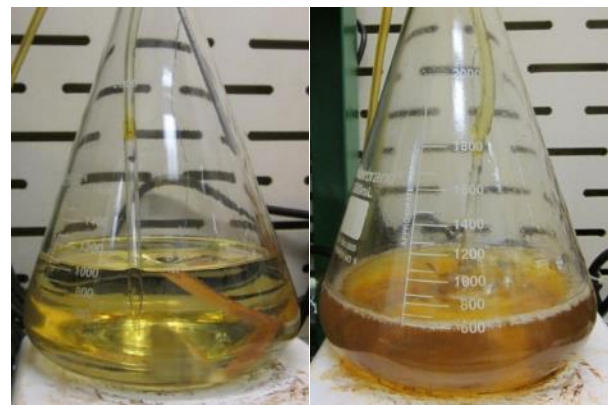
Group I *vs.* II Breakdown

Group I (New Left; Degraded Right)





Group II (New Left; Degraded Right)



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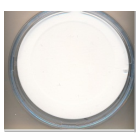
Breakdown Repeated with ICB™

- Degraded 2 identical beakers of turbine oil side-by-side.
  - LEFT: without ICB™ Ion Exchange treatment.
  - RIGHT: with ICB™ Ion Exchange treatment.
  - Temperature: 90 C for 53 days.

0 days 3 days 17 days 31 days 53 days

Untreated:



: ICB™-treated

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4.0 Aftermarket Additives

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Aftermarket Additives

- Added at 10% level to pre-existing turbine fluids.
- Marketed as…
  - “The End of Varnish.”
  - “Significantly reduces soft particle contamination.”
  - “Significantly reduces MPC results.”
  - “Reduces reliance on expensive varnish removal equipment.”
  - “improves (existing antioxidants) by adding premium antioxidants that specifically target varnish formation.”

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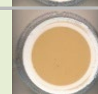
Aftermarket Additive Use Results

Sample	ISO Particle Counts	MPC ΔE	MPC Patch Picture	AN (mg KOH/g)	FTIR Oxidation (%)	Additives		
						Amine (%)	Phenol (%)	AW P (ppm)
Target	<16/14/10	< 15.0	-	< 0.10	< 35	100	100	5
GT 1	22/19/13	50.1		0.28	208	11	28	252
GT 2	22/20/14	35.9		0.24	161	12	51	168
GT 3	22/20/16	41.1		0.17	129	17	98	158
GT 4	25/22/13	40.5		0.18	123	15	66	103

- By using you are creating a new brand of oil.
  - Who is responsible and providing assurance to end-user?
  - Will oil supplier support installation?
  - What are the base lines and condemning limits?
  - What is the cost of top up over life of oil?

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5.0 Oil Treatment and Filtration

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Reversing Varnish

- Varnish formation is a physical change of contamination from one form to another (dissolved to solid).
  - The process can be reversed.
- Equilibrium chemistry dictates that if you return the oil to an unsaturated condition by removing the dissolved contamination using ion exchange resins you will <u>force</u> varnish deposits back into solution
- STRATEGY:
  - If you can prevent the oil from getting saturated you can prevent varnish under all operating conditions.

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MPC Test Results

- Filtration *vs* Ion Exchange with Proper MPC Prodedure:

MPC Method	Test Location	60°C Heating Period (hours)	20°C Incubation Period (hours)	Initial Patch Photo	Filtered Patch Photo	Initial MPC ΔE	Filtered MPC ΔE	Change
High-Efficiency Filtration	Lab	24	72			22.1	22.1	- 0%
Ion Exchange (ICB™)	Lab	24	72			22.1	3.2	- 86%

- ICB™ removes soluble varnish component that filtration could not.
  - ICB™ led to 86% MPC ↓.

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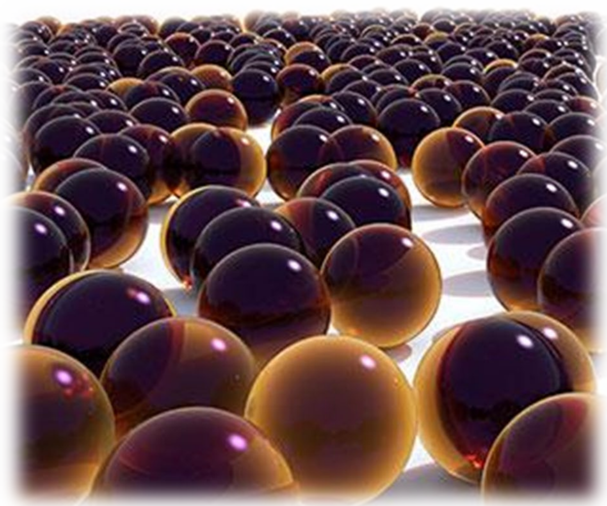
ICB™ Ion Exchange Technology

ICB™



ICB™ is a trademark of EPT.

Benefits:

- Engineered ion exchange product.
- Precise chemistry.
- Quality control.
- High capacity:
  - 2 sets of filters to clean up.
  - Annual filter changes thereafter.

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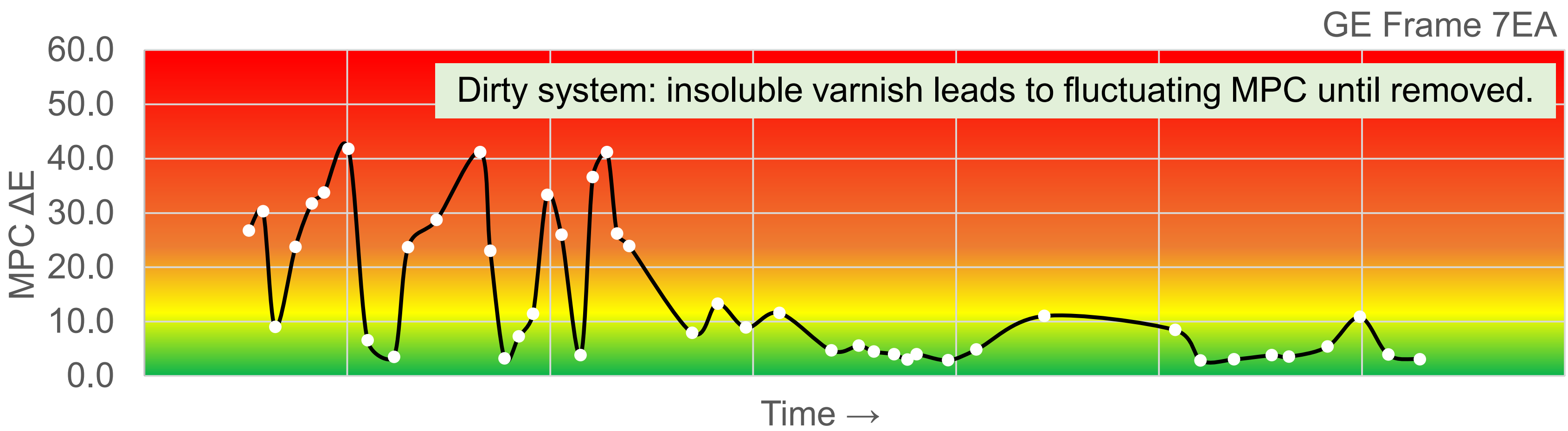
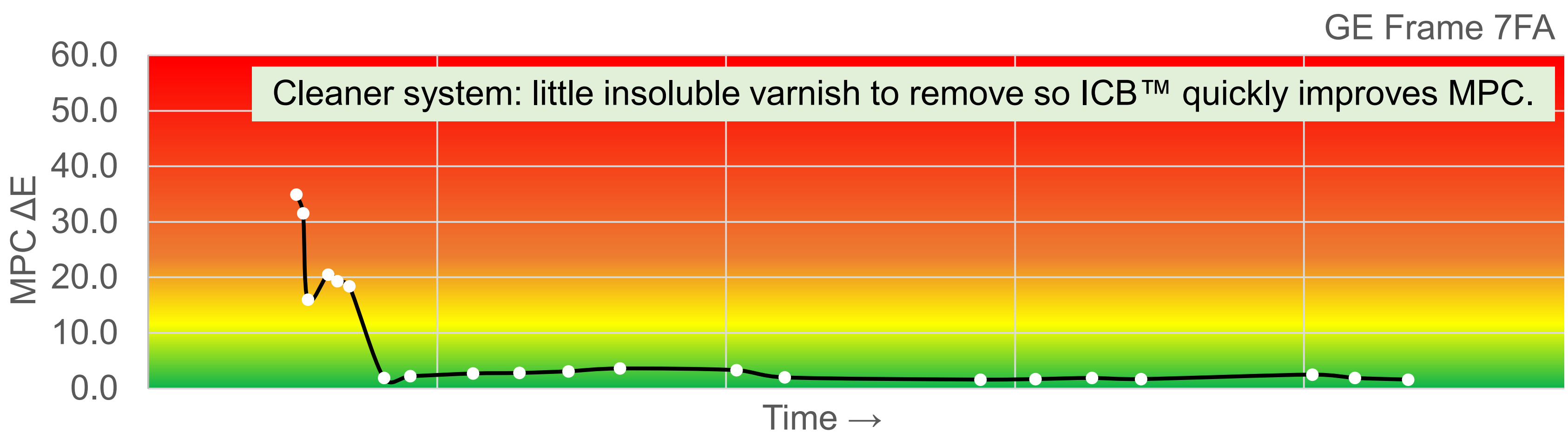
ICB™ Cleanup *vs.* Stability





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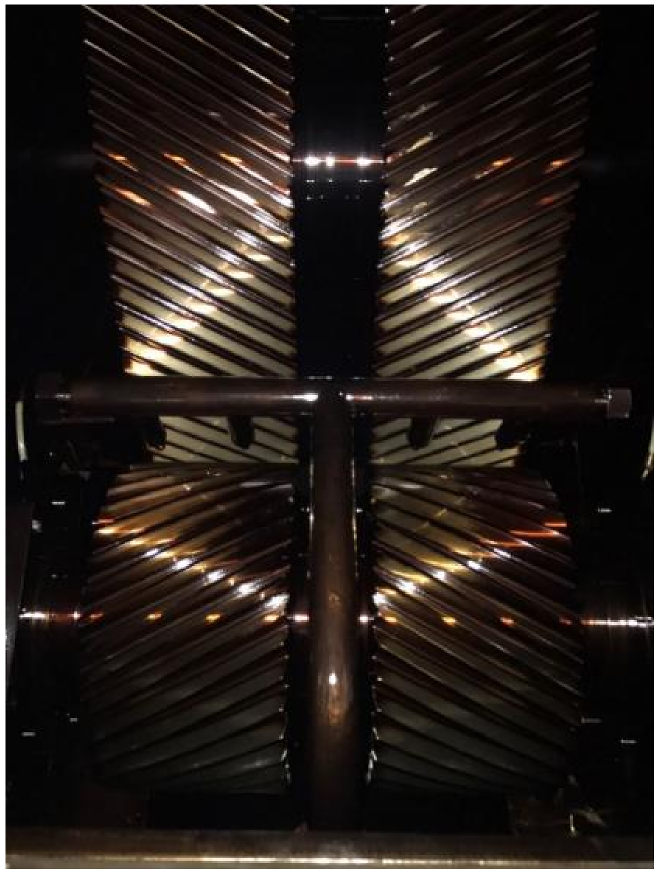
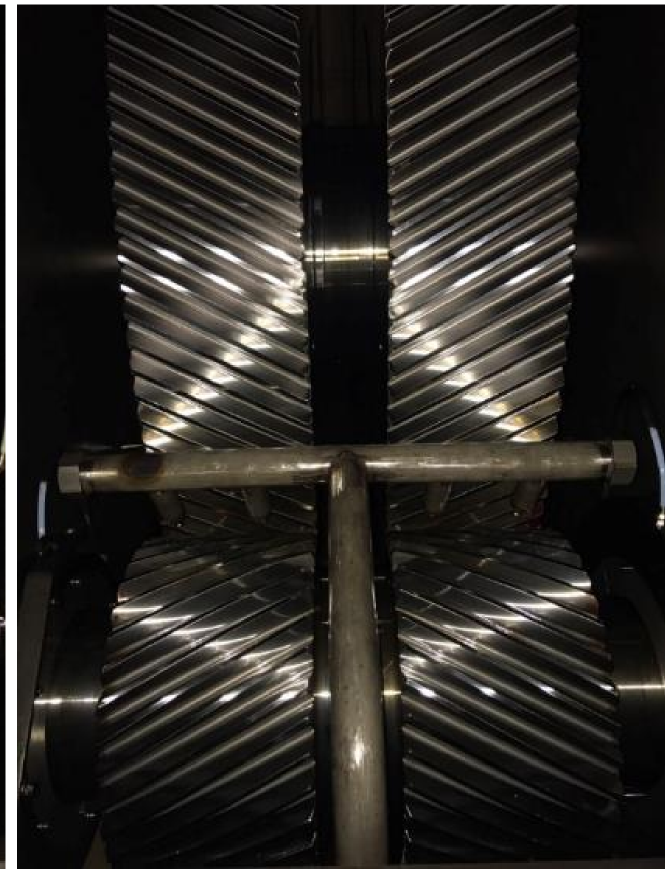
Before & After ICB™ Cleanup





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6.0 A Paradigm Shift in Oil Maintenance

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Long-Term Oil Management

- Paradigm shift: view GT oil as an asset not a consumable!
- Fluid replacement based on combination of low additives and high acid number.
  - What tools allow you to manage these?
- Full time ICB™ fluid conditioning from a new oil condition:
  - Leads to fundamental change in oil quality and additive performance.
- In conjunction with a 5% annual top-up strategy, oil life can be managed to levels never before observed.

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Case Study

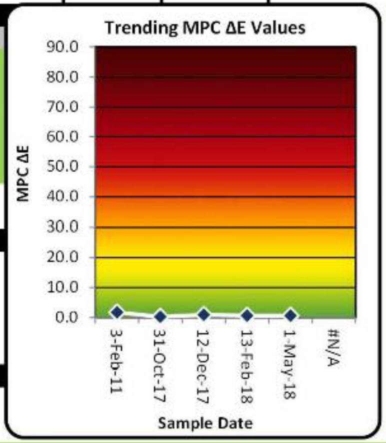
9-year-old GT oil with ICB™ conditioning system installed from Day 1:

- Greatest AN observed: 0.04 mg KOH/g.
- Greatest MPC observed: ΔE = 1.8.

Sample Date	AN (mgKOH/g)	SAN (mgKOH/g)	H2O (ppm)	Viscosity (cSt) 40 °C	Viscosity (cSt) 100 °C	ISO (particles / mL) 4 µm	ISO (particles / mL) 6 µm	ISO (particles / mL) 14 µm	ISO Code 4/6/14 µm	Resistivity (G ohm-cm)	Chloride (ppm)	Mineral Oil Cont. (%)	Air Release (min)
Target	0.04	N/A	< 200	33.9	5.57	480	120	8	16/14/10	N/A	< 50	N/A	3
3-Feb-11	0.03		2	33.1	N/A	1046	280	19	17/15/11	N/A	N/A	N/A	N/A
31-Oct-17	0.04		1.3	N/A	N/A	156	55	9	14/13/10	N/A	N/A	N/A	N/A
12-Dec-17	0.05		5.4	N/A	N/A	48	11	2	13/11/8	N/A	N/A	N/A	N/A
13-Feb-18	0.04		4.5	N/A	N/A	190	60	6	15/13/10	N/A	N/A	N/A	N/A
1-May-18	0.03		6.5	N/A	N/A	37	7	0	12/10/6	N/A	N/A	N/A	N/A

Sample Date	Demulsibility data (mL) Oil	Water	Emulsion	Time (mins)	Membrane Patch Colorimetry (MPC) Hold Time (hr)	Patch Wt (mg)	MPC ΔE
Target	40	40	40	< 10	68 - 76	< 2.0	< 15.0
3-Feb-11	N/A	N/A	N/A	N/A		2.0	1.8
31-Oct-17	N/A	N/A	N/A	N/A	70	3.3	0.3
12-Dec-17	N/A	N/A	N/A	N/A	69	1.8	1.0
13-Feb-18	N/A	N/A	N/A	N/A	71	2.8	0.7
1-May-18	N/A	N/A	N/A	N/A	69	1.6	0.7

Filtration Micrograph(s) in Chronological Order (L to R)



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Case Study

9-year-old GT oil with ICB™ conditioning system installed from Day 1:

- 8% antioxidant consumption over 9 years (< 1%/year).
- With 5% annual top-up, oil life projected to > 25 years (life of turbine).

Sample Date	Sulphur (ppm)	RPVOT (min)	Rust Inhibition	Density (g / mL)	Fluid Colour	Cu Corr. (class.)	TOST (hours)	Foaming Tendency (After 5 min/10 min) Seq I (mL / mL)	Seq II	Seq III	Seq IV
Target	316	2700	PASS	0.86	1	1a	10000	0/0	15/0	0/0	N/A
3-Feb-11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
31-Oct-17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12-Dec-17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
13-Feb-18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1-May-18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Sample	Dissolved Gas Analysis (ppm) Total*	H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	CO	CO_2	O_2	N_2	RULER (%) Amine	Phenol
Target	0	0	0	0	0	0	<25	< 200	N/A	N/A	100	100
3-Feb-11												
31-Oct-17											81	100
12-Dec-17											84	82
13-Feb-18											94	100
1-May-18											92	100

*Total combustible gases, which are highlighted in red

[redacted] [redacted]

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ICB™ ROI Calculations

TURBINE	TITAN 130 (25 YEAR LIFE)		7FA (25 YEAR LIFE)	
CAPACITY	17.5 MW ($40/MW)		171 MW ($40/MW)	
OIL VOLUME	5125 L ($7.53/L)		22800 L ($7.53/L)	
ONE-TIME FLUSHING COST	$50,000		$125,000	
CONDITIONING SYSTEM	**NO**	**YES**	**NO**	**YES**
OIL LIFE	8 YRS (3 FILLS)	25 YRS (1 FILL)	8 YRS (3 FILLS)	25 YRS (1 FILL)
CONDITIONING SYSTEM CAPEX	$0	$15,000	$0	$30,000
CONDITIONING CONSUMMABLES/YEAR	$0	$2,250	$0	$4,500
LIFETIME CONSUMMABLES COSTS	$0	$56,250	$0	$112,500
LIFETIME FILL COSTS	$115,774	$38,591	$515,052	$171,684
LIFETIME FLUSH COSTS (2 FLUSHES)	$100,000	$0	$250,000	$0
LIFETIME MAKE UP COSTS (5%/YEAR)	$48,239	$48,239	$214,605	$214,605
LIFETIME OIL-COSTS	$264,013	$158,080	$979,657	$528,789
LIFETIME CONDITIONING COSTS	$0	$71,250	$0	$142,500
TOTAL LIFETIME COSTS	**$264,013**	**$229,330**	**$979,657**	**$671,289**
LOST PRODUCTION HOURS/YEAR	24	0	24	0
ANNUAL PRODUCTION LOSSES	$16,800	$0	$164,160	$0
TOTAL LIFETIME PRODUCTION LOSSES	**$420,000**	**$0**	**$4,104,000**	**$0**
SAVINGS (EXCLUDING PRODUCTION LOSSES)	N/A	$105,933	N/A	$450,868
SAVINGS (INCLUDING PRODUCTION LOSSES)	N/A	$525,933	N/A	$4,554,868
ROI (EXCLUDING PRODUCTION LOSSES)	**N/A**	**149%**	**N/A**	**316%**
ROI (INCLUDING 1 x 24 HOUR PRODUCTION LOSS)	**N/A**	**172%**	**N/A**	**432%**
ROI (INCLUDING 1 x 24 HOUR PRODUCTION LOSS/YR)	**N/A**	**738%**	**N/A**	**3196%**

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EPT Summary

- Paradigm Shift: Treat your fluid like an asset not a consumable.

- Understand and use tools at your disposal to manage that asset:
  - High quality oils from reputable manufacturer/supplier.
  - If you're not an oil-formulator, don't try to be one.
  - Reliable oil analysis data.
  - Use conditioning to remove varnish-precursors as they form.
  - Clean your oil so it can clean your system.

- Prudent investment:
  - Significant ROI.
  - Predictable costs.
  - Eliminate unpredictable oil-related failures.

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Thank you!

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