stle*Nashville*
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Evaluation of Turbine Oil Performance

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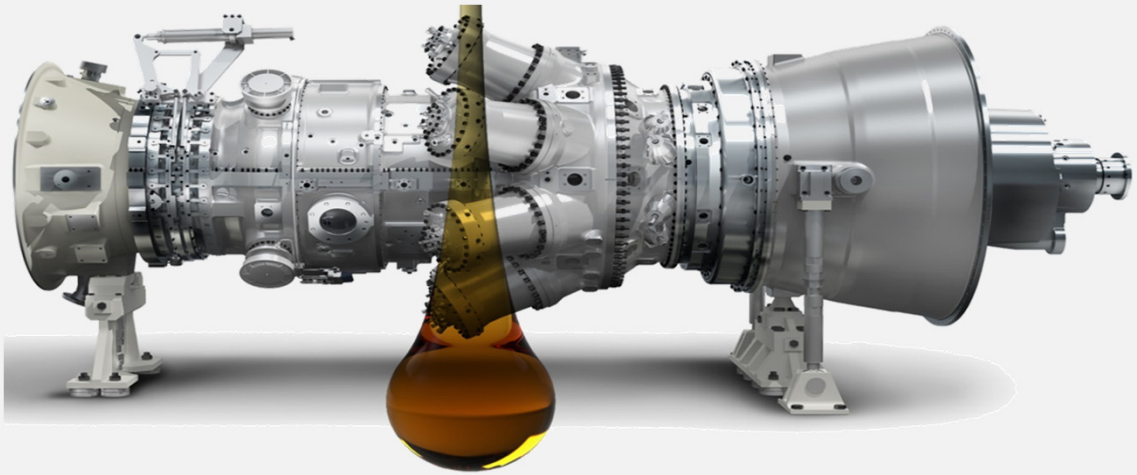
23rd May 2019, Power Generation Committee



Summary

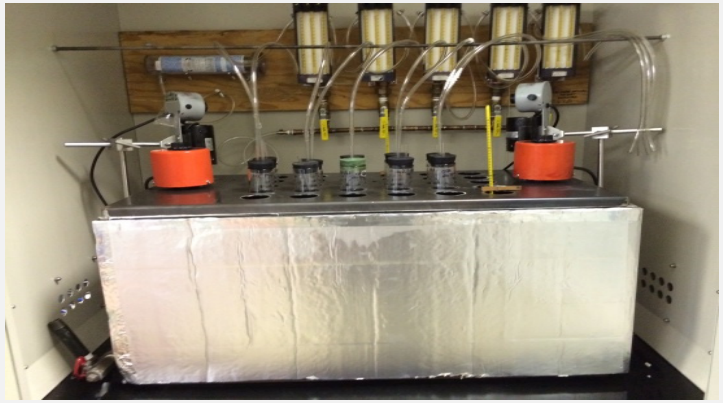
- Comparison of Turbine Oil Oxidation Tests
- TOPP Test Parameters & Experimental Setup
- Commercial Turbine Oil Performance
- Antioxidant Performance
- Base Oil Performance
- TOPP Tests Observations
- Next Generation Turbine Oil
- TOPP Findings

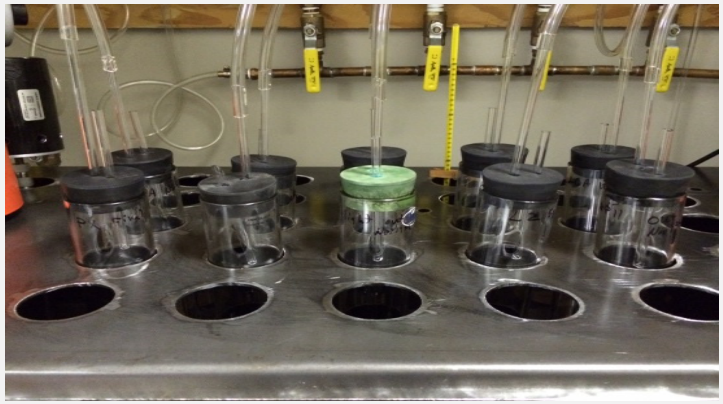
Turbine Oil Oxidation Test Comparison

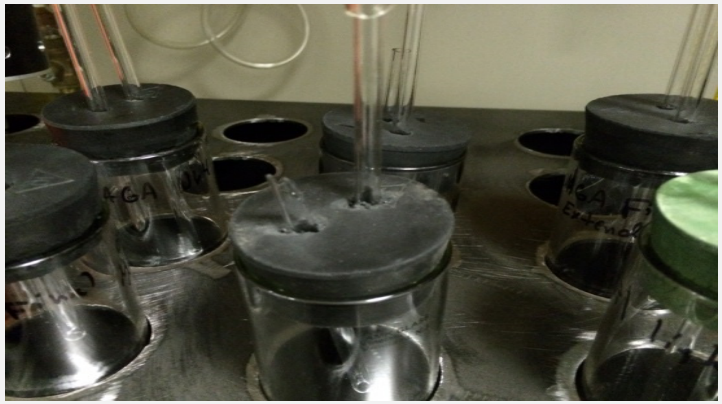
Parameter	D943 (TOST) Turbine Oil Oxidation Stability	D7873 (Dry TOST)	TOPP Turbine Oil Performance Prediction
Gas (L/hrs.)	Oxygen - 3	Oxygen - 3	Dry Air - 3
Temperature (°C)	**95**	120	120
Water (ml)	60 (17%)	No	No
Oil Sample (ml)	300	360	350
Acid Number (mg KOH/gm)	**2.0**	No	No
Insoluble	No	Yes	Yes
Insoluble Method	No	**Residue weight 100 ml sludge /kg of Oil at 25% RPVOT , 1 micron patch**	Membrane patch Colorimetry (MPC) color measurement, 0.45 micron patch
Reaction Conditions	Oxidation, Hydrolysis and Catalytic	Oxidation and Catalytic	Oxidation and Catalytic
Hours	>10,000	1008	1008

Additive manufacturers and OEM such as Siemens and Solar Turbines has expressed interest in TOPP, also proposed to ASTM

TOPP Experimental Setup

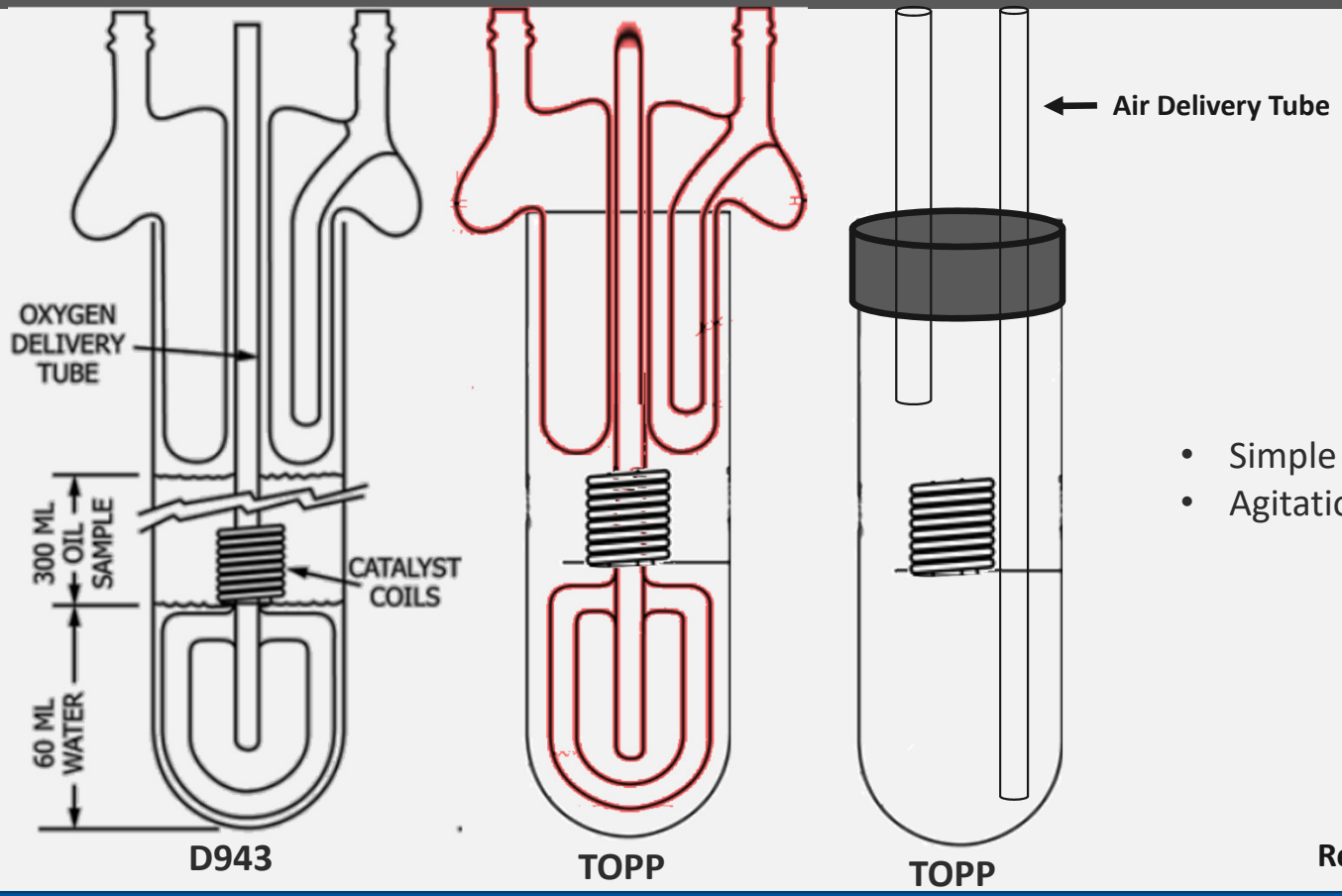






TOPP: Turbine Oil Performance Prediction

Sample Tubes



- Simple and easy setup
- Agitation provided by air

Reference: ASTM D943

TOPP Test Procedure & Sampling

- Ruler
- MPC
- Demulsibility
- Foam
- Viscosity
- TAN
- RPVOT
- FTIR
- Air release
- Particle Count
- Clarity
- Elemental Analysis

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- Temperature: 120 ^{0}C, Dry Air: 3L/Hrs, Steel/Copper Catalyst: ASTM D5846, Six Tubes, 6 Weeks
- Samples collected every week for 6 weeks and full oil analysis is performed.
- Additional test may be added based on application and operational conditions

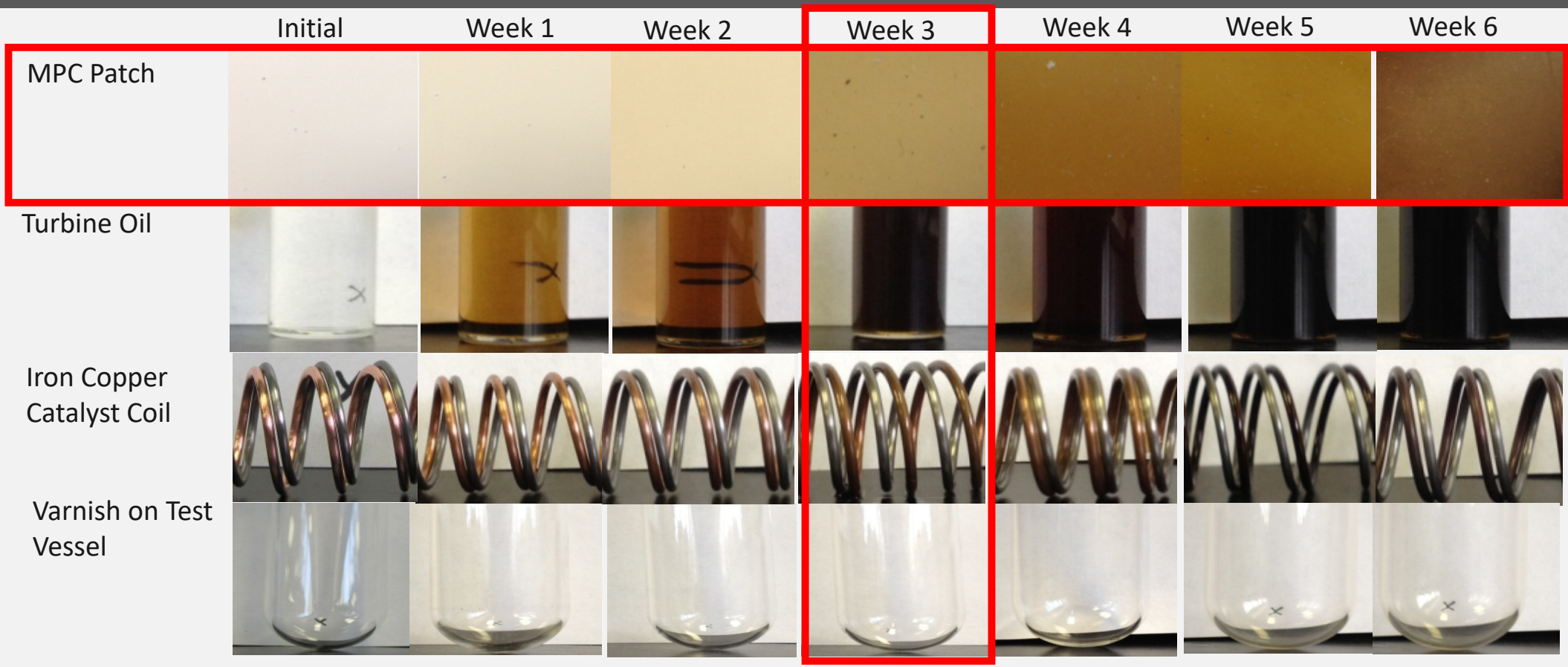
Observation

- Oxidation stability and resistance
- Acid generation
- Deposit resistance
- Sample clarity
- Performance properties
- Deposit on the tubes
- Deposit on the catalyst
- Other physical properties

TOPP of Turbine Oil 1

Test	Baseline	Turbine Oil (1 week)	Turbine Oil (2 weeks)	Turbine Oil (3 weeks)	Turbine Oil (4 weeks)	Turbine Oil (5 weeks)	Turbine Oil (6 weeks)
TAN, ASTM D664, mg/KOH	0.16	0.16	0.16	0.26	0.29	0.33	0.34
Ruler, ASTM D6971, RUL%	100	89	88	55	48	6	12
Ruler, ASTM D6971, % Aminic:	100%	91	79	66	36	12	16
Ruler, ASTM D6971, % Phenolic:	100%	119.6	144.4	63.2	0	0	0
RPVOT, ASTM D2272, minutes	1332	1056	1275	777	851	281	299
Membrane Patch Colorimetry ΔE	2	11	25	47	66	62	70
Weight of Residue, mg/L	137	202	264	152	530	368	445

TOPP of Turbine Oil 1

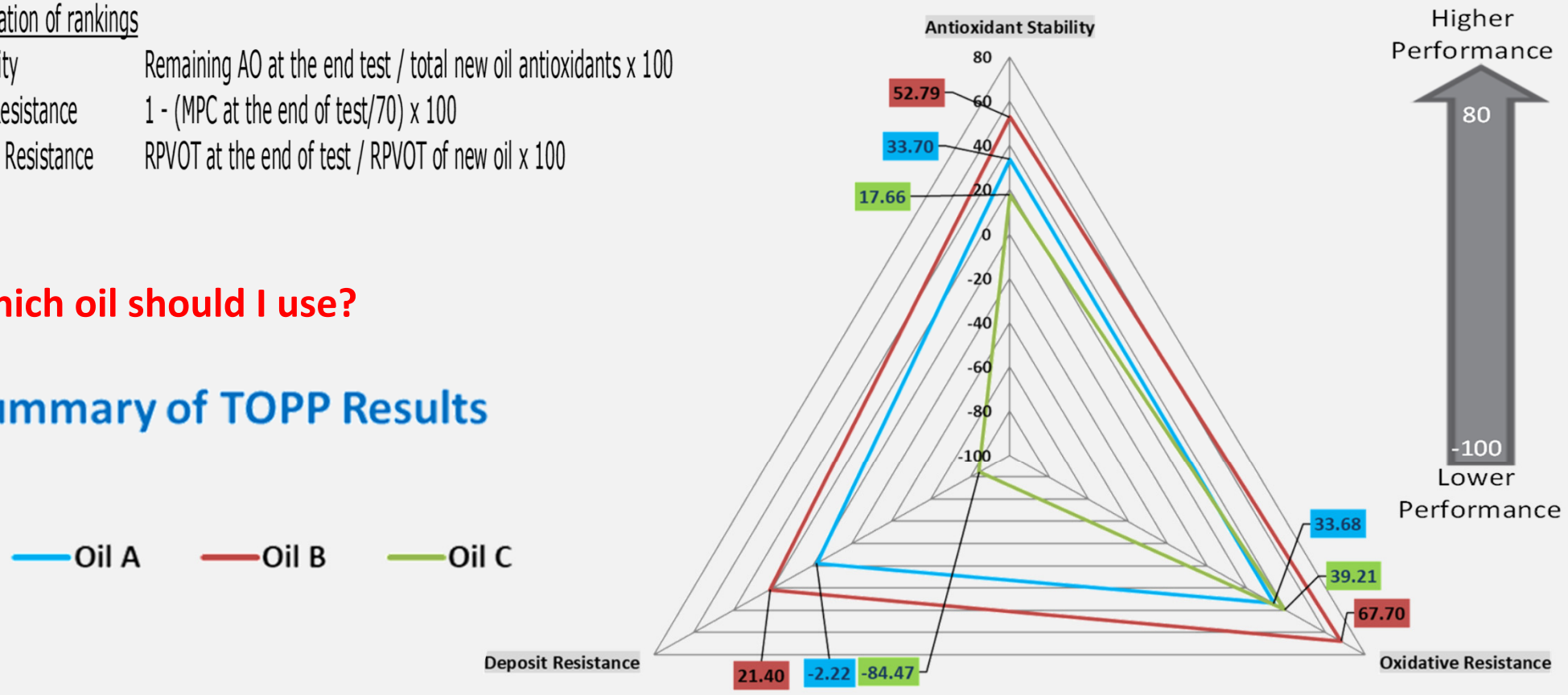


Summary of TOPP Results

Determination of rankings

AO Stability	Remaining AO at the end test / total new oil antioxidants x 100
Deposit Resistance	1 - (MPC at the end of test/70) x 100
Oxidative Resistance	RPVOT at the end of test / RPVOT of new oil x 100

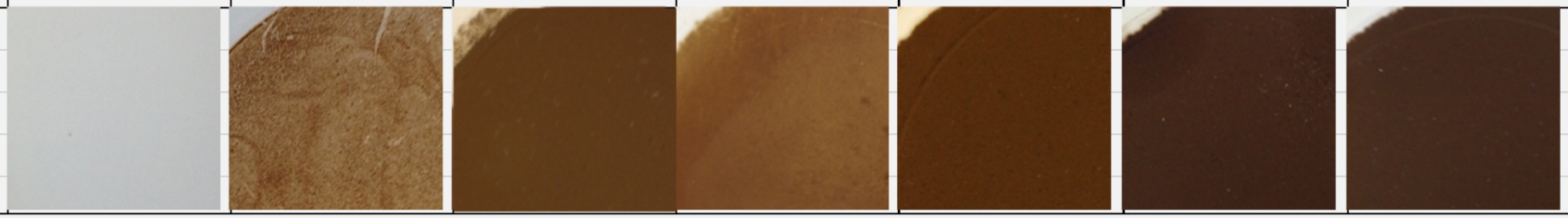
Which oil should I use?



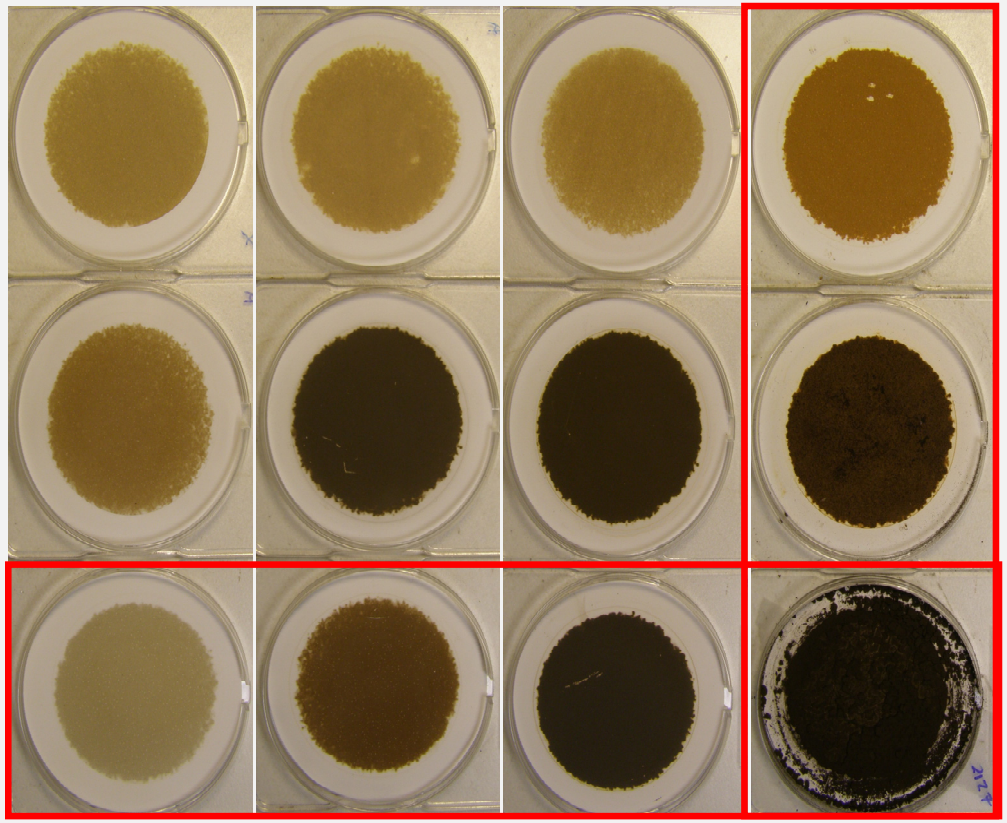
Summary of TOPP Results

ΔE	3.477	18.854	51.329	40.313	48.403	55.101	71.554
MPC Pictures							
Oil A							

ΔE	3.276	21.311	35.009	31.246	31.999	36.33	55.022
MPC Photo							
Oil B							

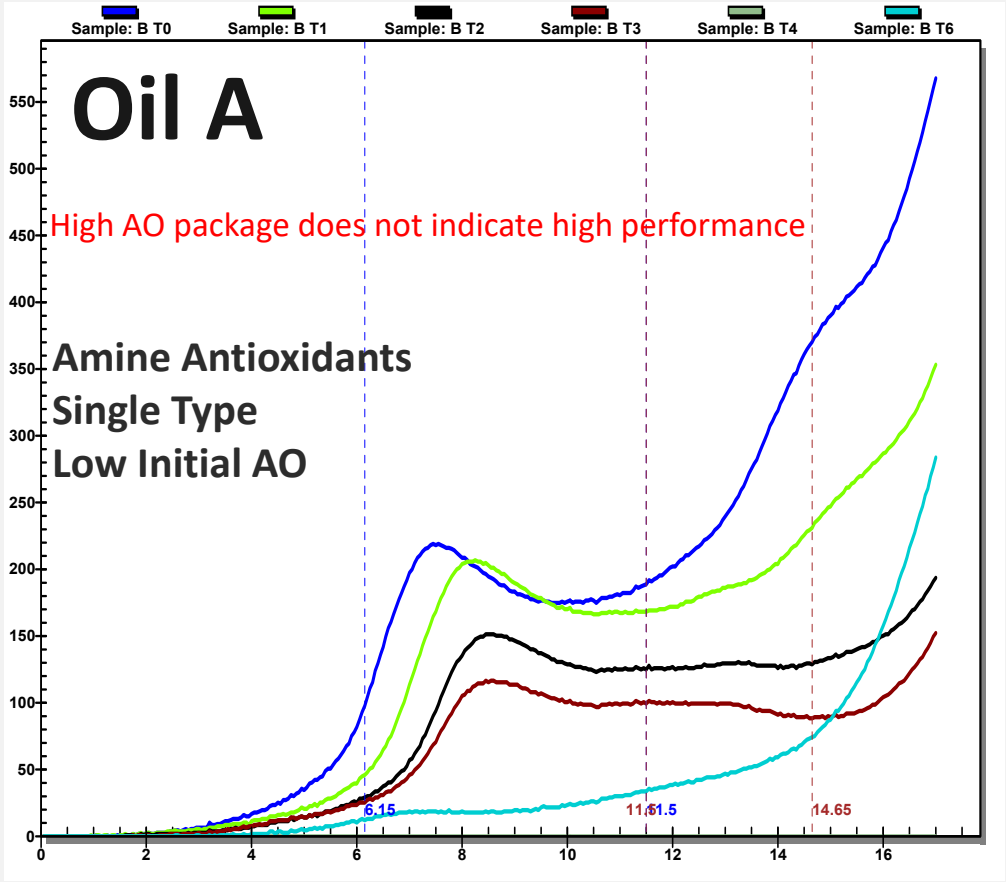
ΔE	3.588	53.728	122.978	126.25	126.19	130.87	129.127
MPC Photo							
Oil C							

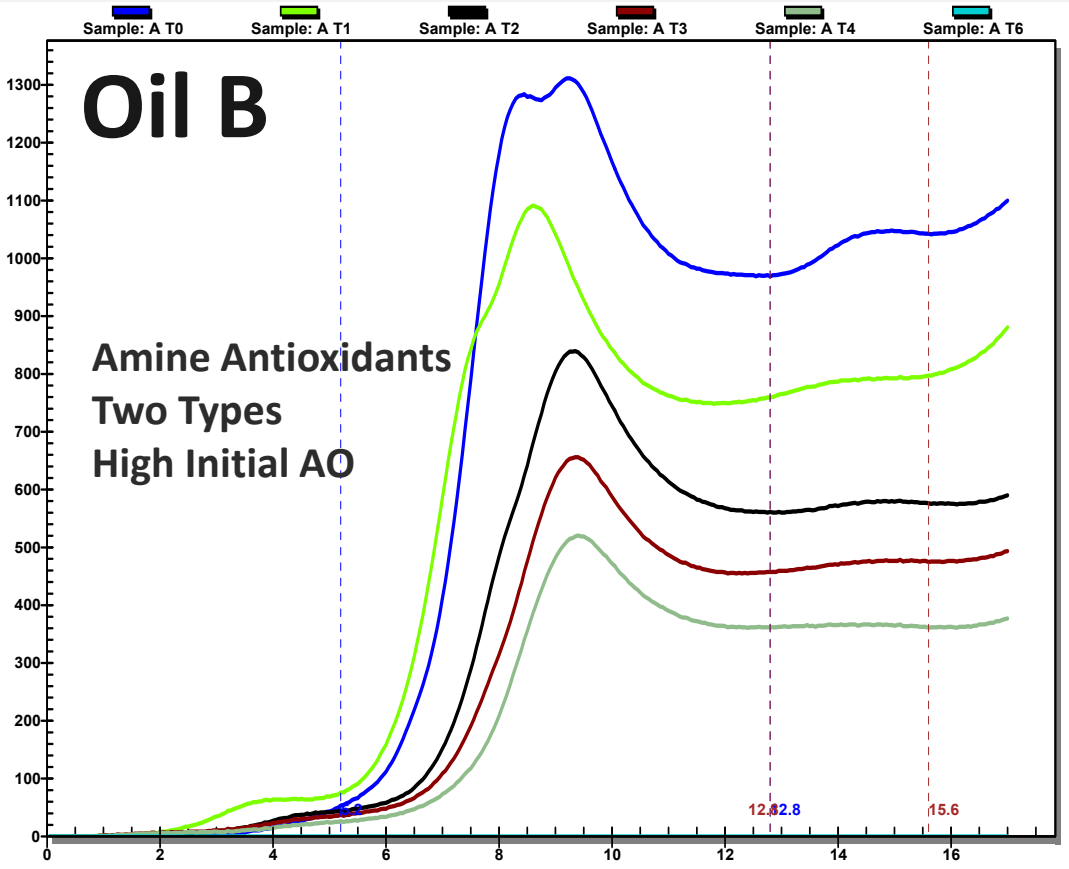
TOPP Formulated Oil Antioxidants Deposits



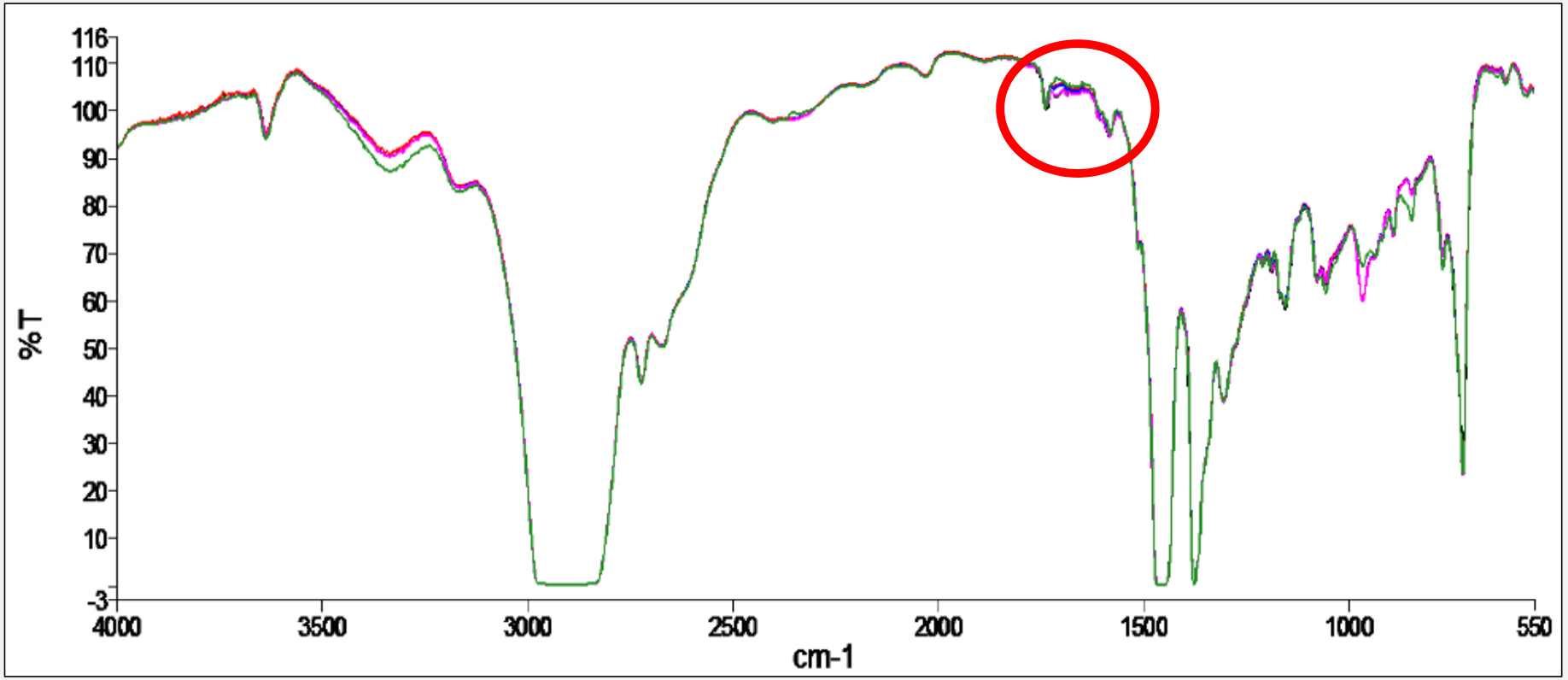
Would you like this in your system?

TOPP Formulated Oil Antioxidants Depletion



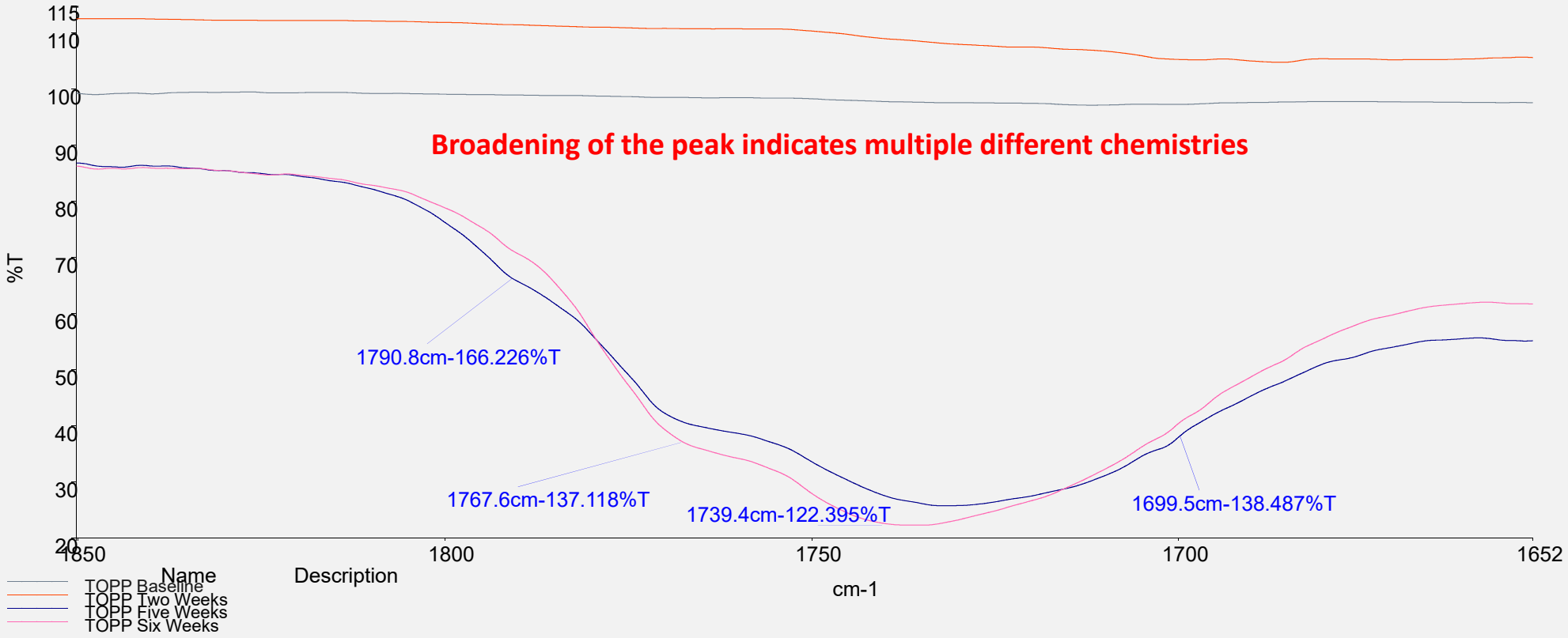


TOPP Formulated Oxidation FTIR Region



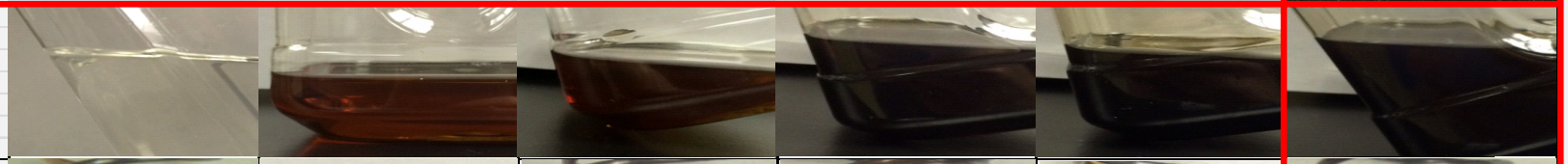
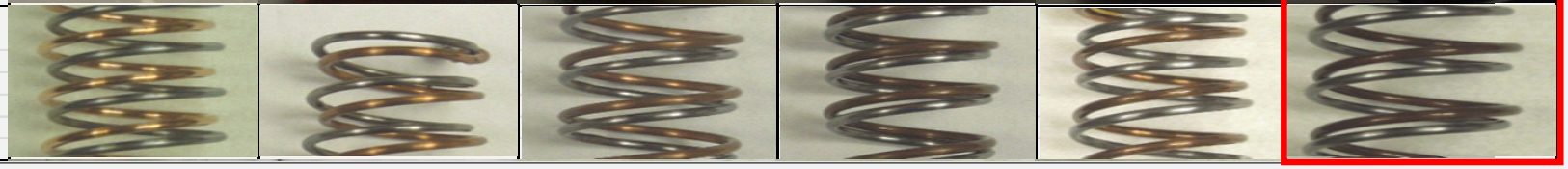
Monitoring depletion of oxidation and thermal degradation species during the TOPP test

TOPP Formulated Oxidation FTIR Region

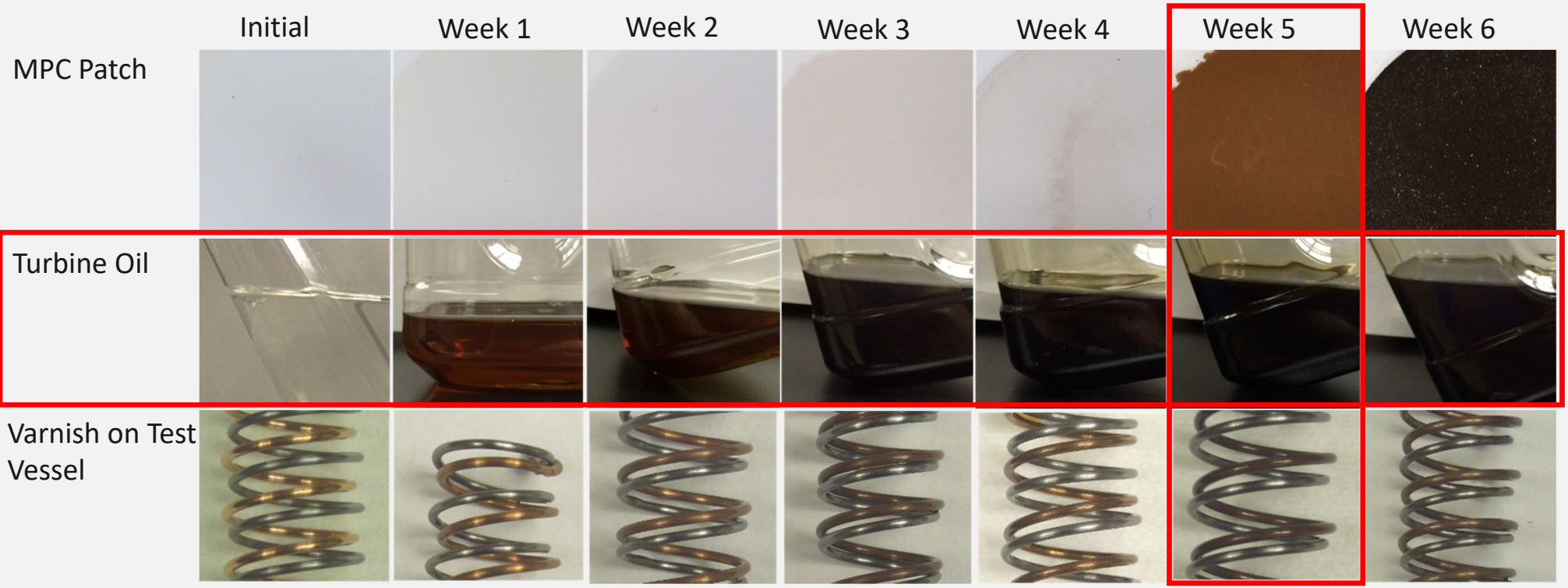


Measure thermal, hydrolysis and oxidative reaction products using FTIR spectroscopy

TOPP of Turbine Oil 2

Test	Sample A - Baseline	Sample A - 168hr (1 week)	Sample A - 336hr (2 weeks)	Sample A - 504hr (3 weeks)	Sample A - 672hr (4 weeks)	Sample A -1008hr (6 weeks)
Color, ASTM D1500	L 0.5	3.0	4.5	7.5	8.0	8.0
TAN, ASTM D664, mg/KOH	0.11	0.15	0.19	0.18	0.24	0.32
Ruler, ASTM D6971						
% Amminic:	9010.5 (100)	7840 (87.0)	7333.5 (81.4)	6444 (71.5)	4176 (46.3)	5571 (61.8)
% Phenolic:	463 (100)	350 (75.6)	295 (63.7)	337.3 (72.9)	201 (43.4)	329 (71.1)
RPVOT, ASTM D2272, minutes	866	835	801	747	607	722
Membrane Patch Colorimetry						
ΔE	2.0	6.4	13.2	8.7	9.2	73.8
Weight of Residue, mg/L	143.0	22.8	32.2	37.6	35.4	242.4
MPC Photo						
Turbine Oil Photo						
Iron/Copper Catalyst Coil Photo						

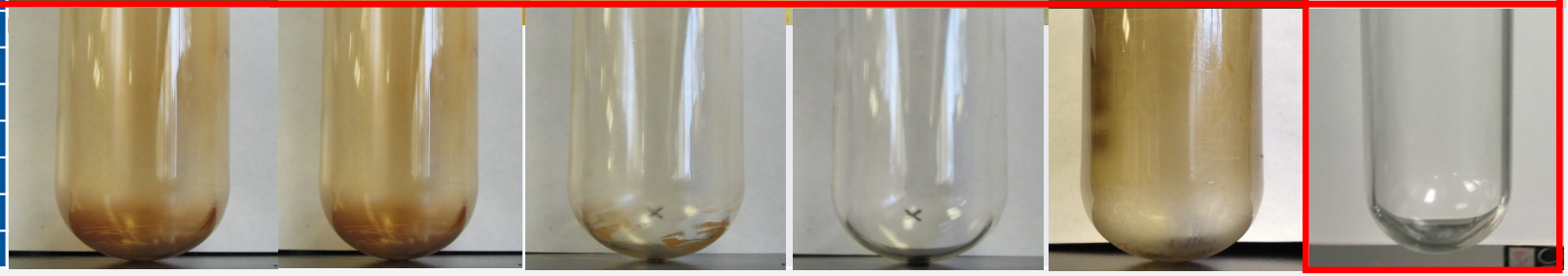
TOPP Of Turbine Oil 2



TOPP of Turbine Oil 3

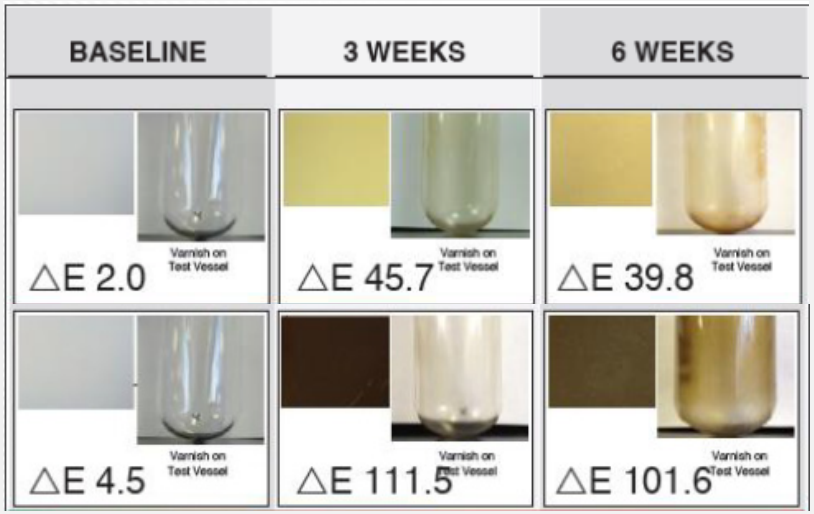
Test	Turbine Oil - Baseline	Turbine Oil - 168 hr (1 week)	Turbine Oil - 336 hr (2 weeks)	Turbine Oil - 504 hr (3 weeks)	Turbine Oil - 672 hr (4 weeks)	Turbine Oil - 840 hr (5 weeks)	Turbine Oil -1008 hr (6 weeks)
TAN, ASTM D664, mg/KOH	0.1	0.07	0.06	0.09	0.08	0.07	0.06
Ruler, ASTM D6971							
Area Amminic (%):	854 (100)	345 (40.4)	416 (48.7)	495 (58)	540 (63.2)	382 (44.7)	436.5 (51.1)
Area Phenolic (%):	137.5 (100)	73 (53.1)	155 (100)	118 (85.8)	49.5 (36)	80 (58.2)	24 (17.5)
RPVOT, ASTM D2272, minutes	611	220	158	140	128	111	107
Membrane Patch Colorimetry							
ΔE	0.9	20.1	39.1	39.1	40.6	39.8	51.2
MPC Photo							
Turbine Oil Photo							
Iron/Copper Catalyst Coil Photo							
Varnish on Test Vessel Photo							

TOPP of Commercial Turbine Oils

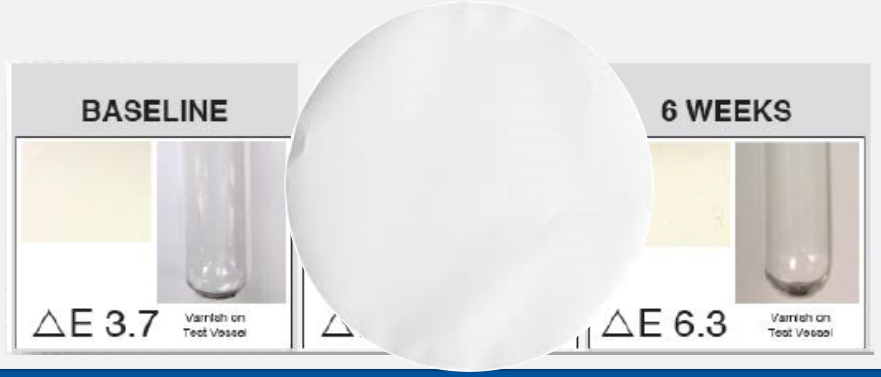
Test	Competitor Oil 1 - 1008 hr (6 weeks)	Competitor Oil 2 - 1008 hr (6 weeks)	Competitor Oil 3 - 1008 hr (6 weeks)	Competitor Oil 4 - 1008 hr (6 weeks)	Competitor Oil 4 - 1008 hr (6 weeks)	Next Generation 1008 hr (6 weeks)
Color, ASTM D1500	3.5	3.0	6.5	4.5	8.5	7.5
Ruler, ASTM D6971 % Aminic:	6550.5	114.5	75.6	42.4	21.9	88.5
Ruler, ASTM D6971 % Phenolic:	447	52.2	24.7	43.1	0	77.2
RPVOT, ASTM D2272, minutes	421	820	831	969	1392	785
Membrane Patch Colorimetry, ΔE	70.248	67.563	63.36	35.369	101.57	3.4
Weight of residue, mg/L	714	90	134	52	156	20
MPC Patch Photo						
Test Vessel Photo						

Most of the Turbine Oils fails due to high varnish potential by week 3 to 4

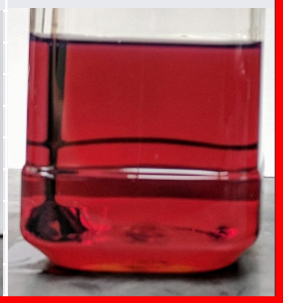
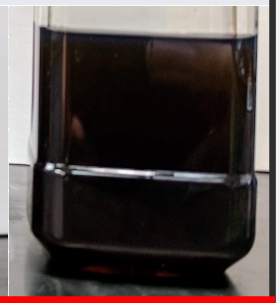
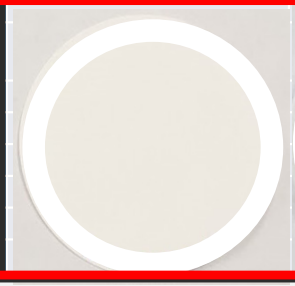
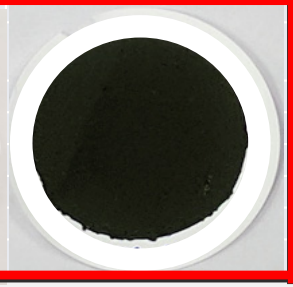
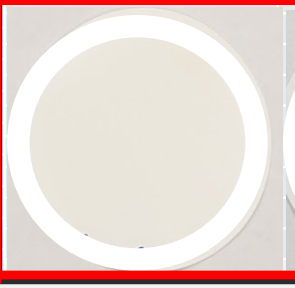
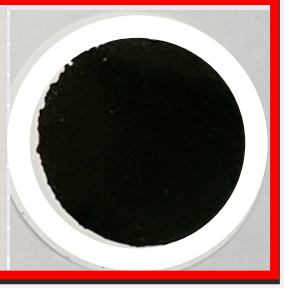
TOPP Data of Multiple Turbine Oils



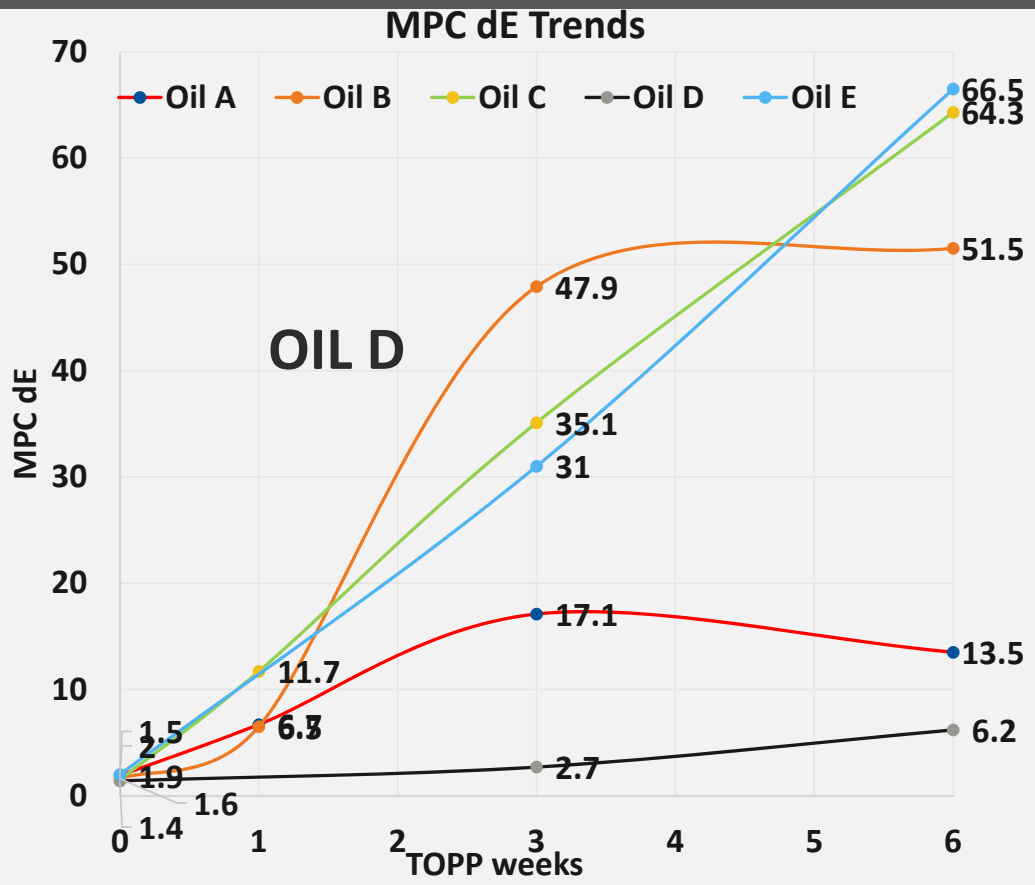
TOPP Data Of Multiple Turbine Oils

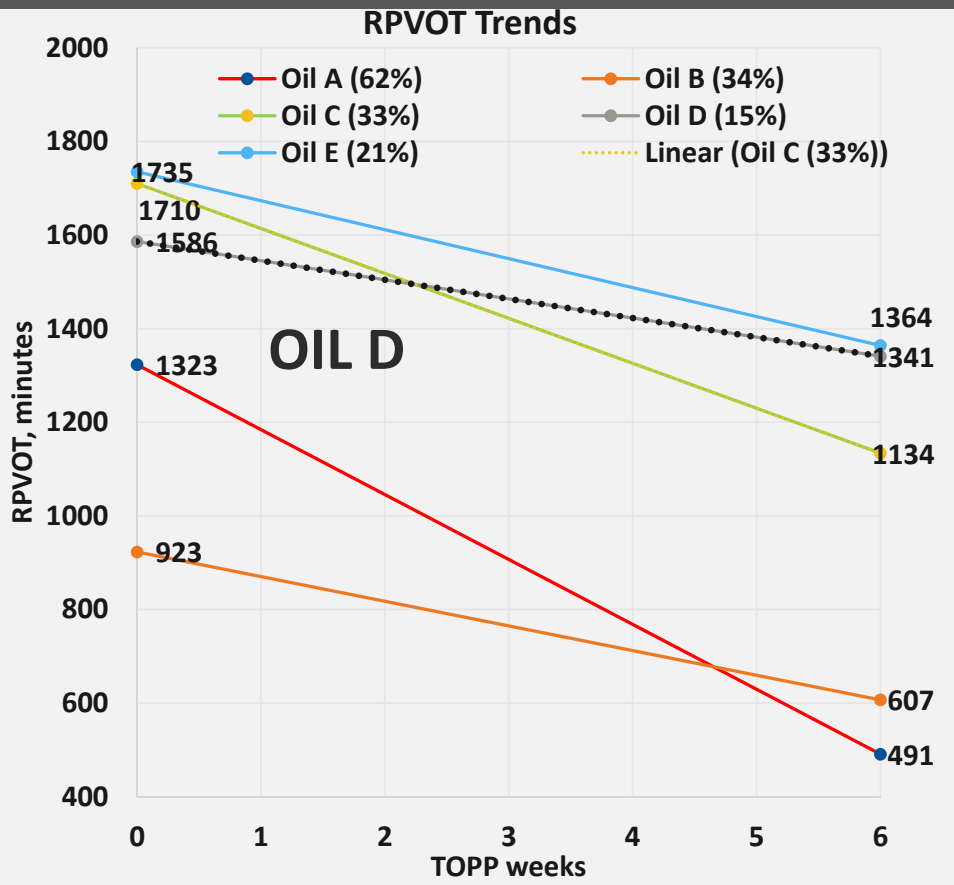


TOPP with Same AO in Different Base-stocks

Tests	Turbine Oil C (Baseline)	Turbine Oil C 6 Weeks	Turbine Oil D (Baseline)	Turbine Oil D 6 Weeks	Turbine Oil E (Baseline)	Turbine Oil E 6 Weeks
RULER, Area Aminic:	12109 (212%)	9600 (168.2%)	12463 (218%)	10070 (176.4%)	12669 (222%)	9539.5 (167.1%)
RULER, Area Phenolic	1499 (139%)	158 (14.7%)	1410 (131%)	635 (59%)	1350 (125.5%)	527 (49%)
Membrane Patch Colorimetry, ΔE	1.5	64.3	1.4	6.2	2	66.5
RPVOT, ASTM D2272, minutes	1710	1134	1586	1341	1735	1364
Photo of Turbine Oil						
Photo of MPC						

TOPP Observations





Turbine Oil Performance Prediction

- Steam turbine: 12 Years
- Gas turbine: 8 Years
- Hydro turbine: 20 years
- Compressor: 7 Years
- Evaluating different additive systems
- Evaluating various base-stocks
- Assessing fully formulated oil
- Estimate the long-term performance of the oil

Performance of the formulated oil may vary based on the severity of the operating conditions

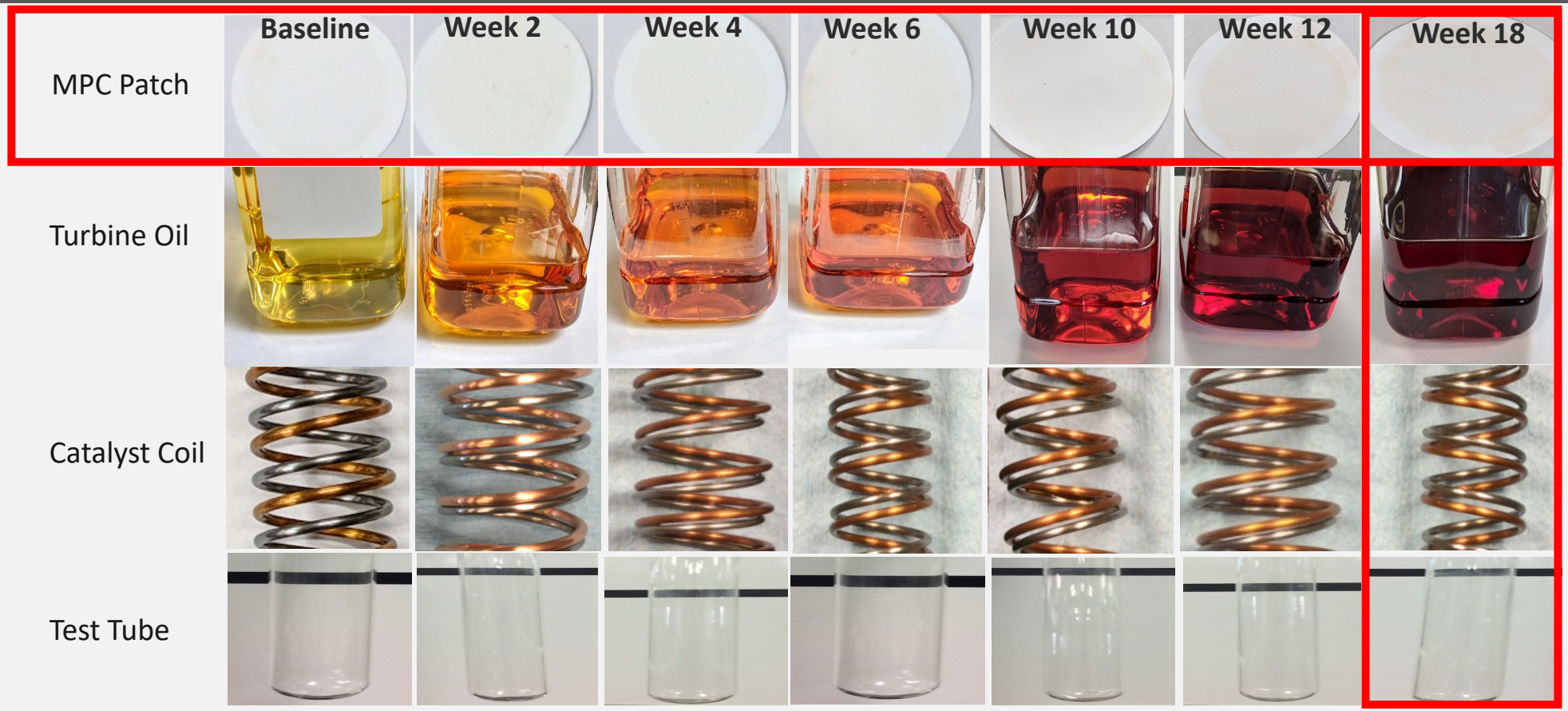
TOPP Findings

- Representative of real field scenario as compared to D943 and D7873
- Assess the physical as well as chemical properties of the turbine oil
- High RPVOT does not correspond to long term oxidation retention, monitor the depletion rate of antioxidants and RVOT
- Selection of appropriate antioxidants package is vital for long term RPVOT retention, lower deposit formation, and depletion rate
- Choice of proper base-stock/co-solubilizing agent is critical for long-term deposit control and formulation stability
- Some turbine oil formulations may not show high deposit forming tendencies initially but may form high deposits after being in-service for a couple of years
- Fill for life turbine oil provides long-lasting performance
- Turbine oil formulation developed on this foundation shown in the next slide

Next Generation Turbine Oil

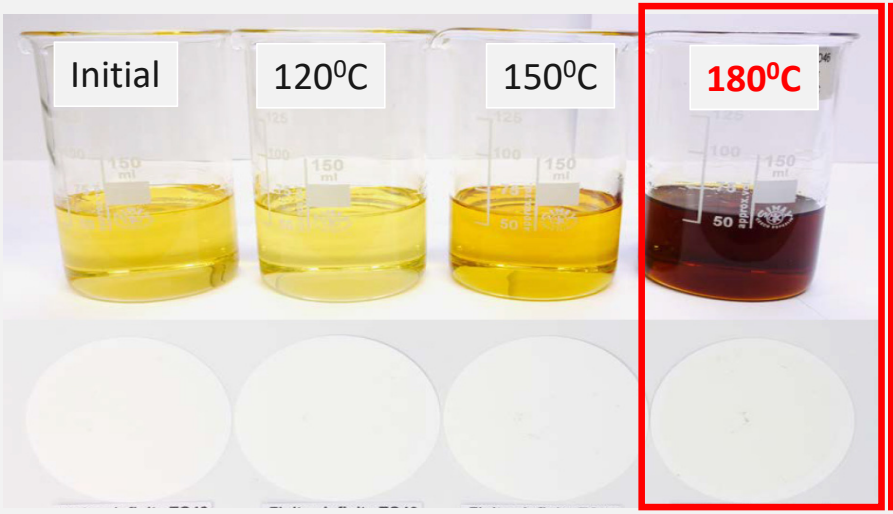
Test	Turbine Oil Baseline	Turbine Oil 336 hr (2 weeks)	Turbine Oil 672 hr (4 weeks)	Turbine Oil 1008 hr (6 weeks)	Turbine Oil 1680 hr (10 weeks)	Turbine Oil 2016 hr (12 weeks)	Turbine Oil 3024 hr (18 weeks)
Color, ASTM D1500	0.5	1	1.5	2.0	3.0	3.0	4.0
Ruler, ASTM D6971 % Amminic:	100	98.5	93.5	86	69.1	54.5	20.1
Ruler, ASTM D6971 % Phenolic:	100	91.7	86.8	63.1	46.1	32.4	13.3
RPVOT, ASTM D2272, minutes	1282	1189	1060	941	637	448	321
Membrane Patch Colorimetry ΔE	0.7	1.2	2.1	5.2	7.5	8.1	8.5
Weight of Residue, mg/L	8.2	10.0	21.0	35.4	43.0	41.0	39.3

Next Generation Turbine Oil



OEM Approval

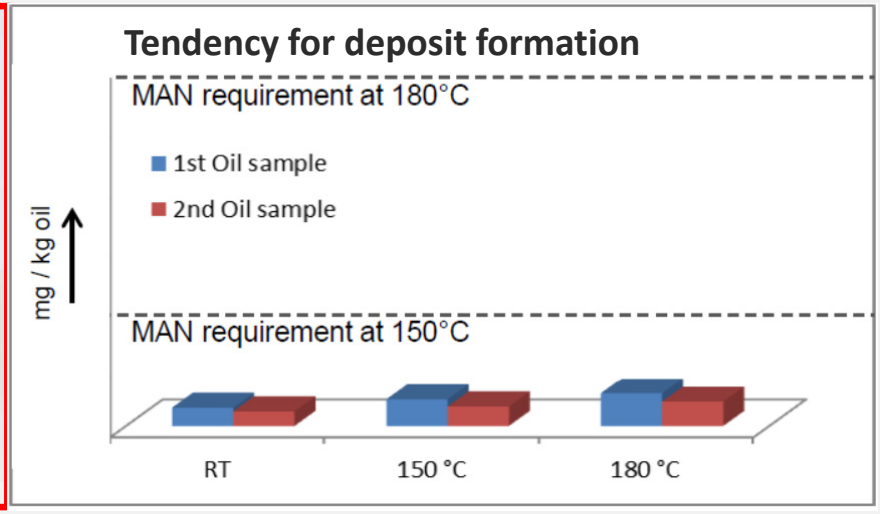
- Siemens TLV 901304 and TLV 901305
- Man Turbo (LTAT thermal stability test)



Good thermal resistance and low deposit forming tendencies

Meets or exceeds OEM specs for Solar and GE

No tendency for building deposits films



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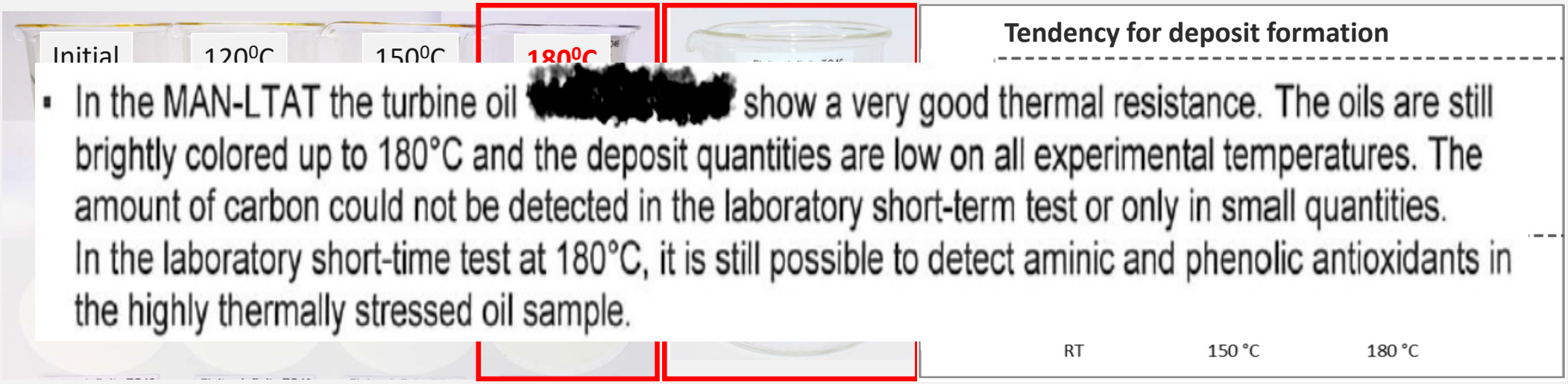

- In the MAN-LTAT the turbine oil [redacted] show a very good thermal resistance. The oils are still brightly colored up to 180°C and the deposit quantities are low on all experimental temperatures. The amount of carbon could not be detected in the laboratory short-term test or only in small quantities.
  In the laboratory short-time test at 180°C, it is still possible to detect aminic and phenolic antioxidants in the highly thermally stressed oil sample.

Good thermal resistance and low deposit forming tendencies

Meets or exceeds OEM specs for Solar and GE

No tendency for building deposits films

Thank You!!!

Acknowledgement:

Greg Livingstone, Fluitec International

Jo Ameye, Fluitec International

Nathan Walker, Lubrication Engineer

Wade Fleming, Lubrication Engineer

stle*Nashville*