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The Impact of Lubricating Oil Formulations on Filter Element Charging Behavior

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May 20-24, 2018

stle Minneapolis

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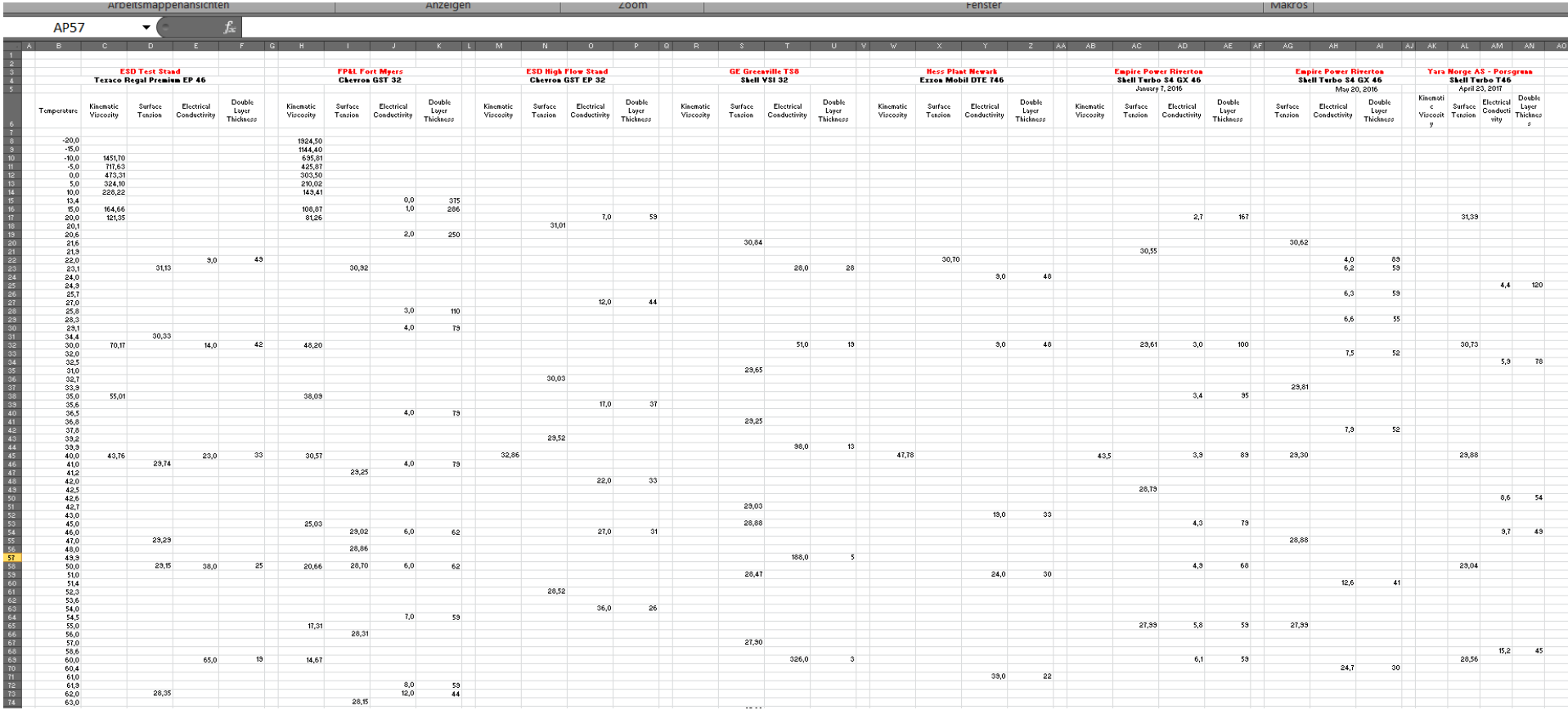
Variety of Oil Types

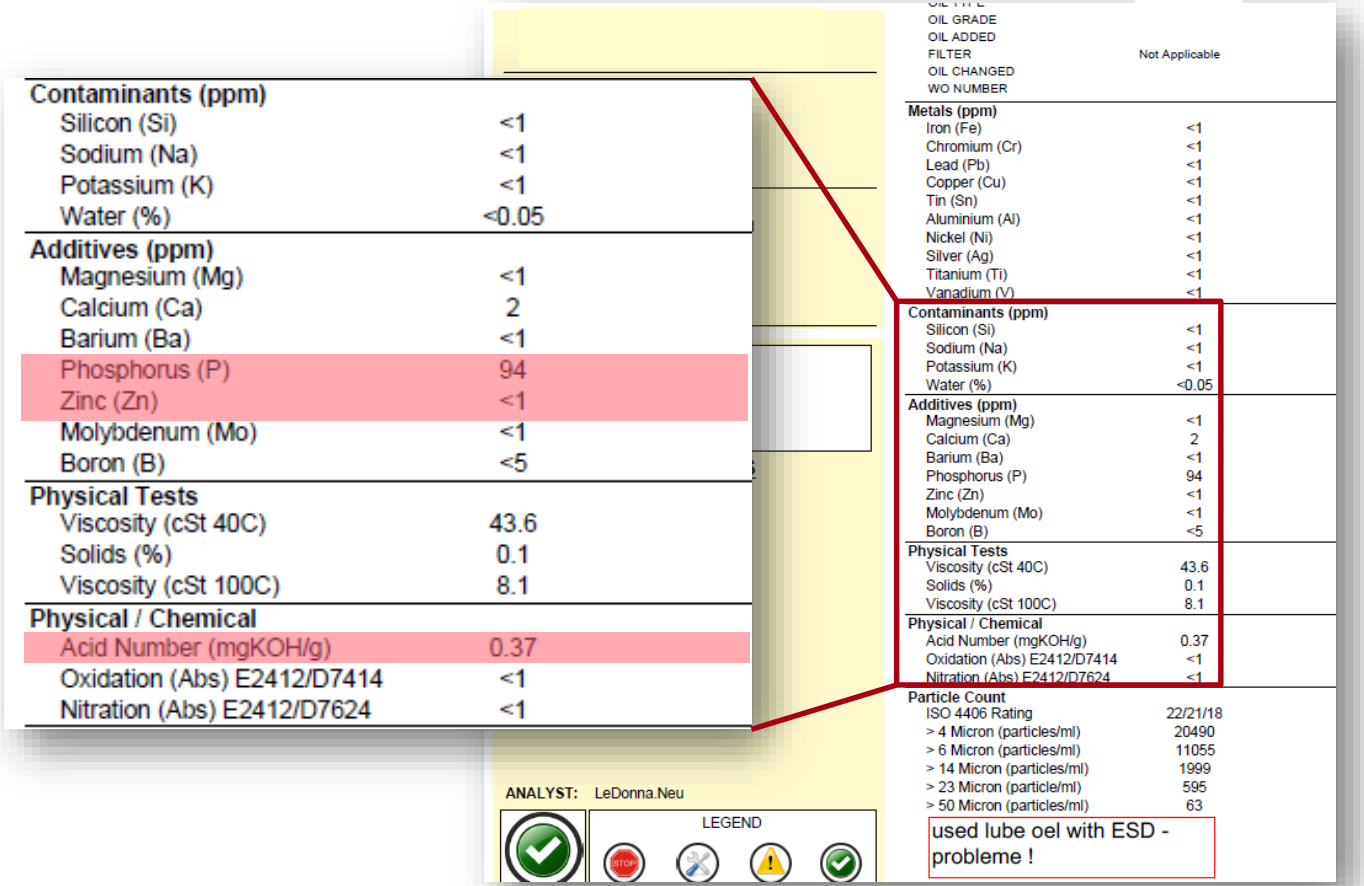
Predict and Understand How Oils Behave



	ESD Test Stand					FP&L Fort Myers				ESD High Flow Stand				GE Greenville TS8				Hess Plant Newark				Empire Power Riverton				Empire Power Riverton				Yara Norge AS - Porsgrunn			
	Texaco Regal Premium EP 46					Chevron GST 32				Chevron GST EP 32				Shell VSI 32				Exxon Mobil DTE T46				Shell Turbo S4 GX 46				Shell Turbo S4 GX 46				Shell Turbo T46			
																						January 7, 2016				May 20, 2016				April 23, 2017			
	Temperature	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness	Surface Tension	Electrical Conductivity	Double Layer Thickness	Kinematic Viscosity	Surface Tension	Electrical Conductivity	Double Layer Thickness
	-20,0					1924,50																											
	-15,0					1144,40																											
	-10,0	1451,70				695,81																											
	-5,0	717,63				425,87																											
	0,0	473,31				303,50																											
	5,0	324,10				210,02																											
	10,0	228,22				143,41																											
	13,4							0,0	375																								
	15,0	164,66				108,87		1,0	286																								
	20,0	121,35				81,26						7,0	59											2,7	167						31,39			
	20,1										31,01																						
	20,6							2,0	250																								
	21,6													30,84												30,62							
	21,9																																
	22,0			3,0	49																		30,55				4,0	69					
	23,1		31,13				30,92									28,0	28						30,70				6,2	59					
	24,0																							9,0	48								
	24,9																															4,4	120
	25,7																										6,3	59					
	27,0											12,0	44																				
	25,8							3,0	110																								
	28,3																										6,6	55					
	29,1							4,0	79																								
	34,4		30,33																														
	30,0	70,17		14,0	42	48,20										51,0	19						9,0	48		23,61	3,0	100				30,73		
	32,0																												7,5	52			
	32,5																															5,9	78
	31,0													29,65																			
	32,7										30,03																						
	33,3																									29,81							
	35,0	55,01				38,09																											
	35,6											17,0	37											3,4	95								
	36,5							4,0	79																								
	36,8													29,25																			
	37,8																												7,9	52			
	39,2										29,52																						
	38,9															38,0	13																
	40,0	43,76		23,0	33	30,57				32,86								47,78				43,5		3,9	89	29,30				29,88			
	41,0		29,74					4,0	79																								
	41,2						29,25																										
	42,0											22,0	33																				
	42,5																						28,79										
	42,6																															8,6	54
	42,7													29,03																			
	43,0																			19,0	33												
	45,0					25,03								28,88										4,3	79								
	46,0						29,02	6,0	62			27,0	31																			9,7	49
	47,0		29,29																							28,88							
	48,0						28,86																										
	43,9															188,0	5																
	50,0		29,15	38,0	25	20,66	28,70	6,0	62															4,9	68					29,04			
	51,0													28,47						24,0	30												
	51,4																										12,6	41					
	52,3										28,52																						
	53,6																																
	54,0											36,0	26																				
	54,5							7,0	59																								
	55,0					17,31																	27,99	5,8	59	27,99							
	56,0						28,31																										
	57,0													27,90																			
	58,6																															15,2	45
	60,0			65,0	19	14,67										326,0	3							6,1	59					28,56			
	60,4																										24,7	30					
	61,0																			39,0	22												
	61,9							8,0	59																								
	62,0		28,35					12,0	44																								
	63,0						28,15																										

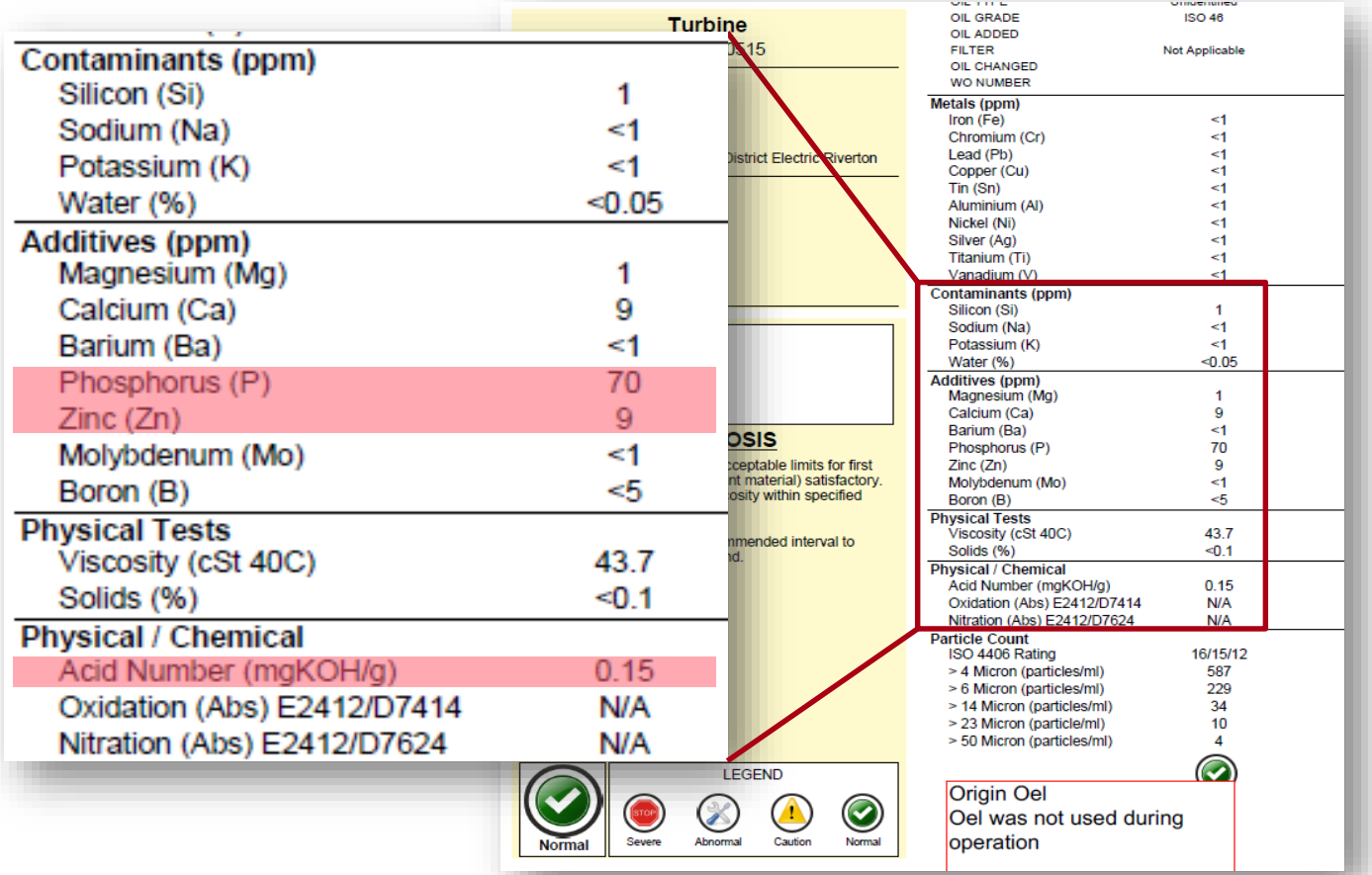
Oil Used for Flushing Leads to ESD Problems

- Zinc-free
- Very low conductivity!

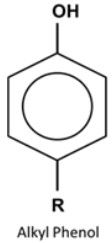


Contaminants (ppm)	
Silicon (Si)	<1
Sodium (Na)	<1
Potassium (K)	<1
Water (%)	<0.05
Additives (ppm)	
Magnesium (Mg)	<1
Calcium (Ca)	2
Barium (Ba)	<1
Phosphorus (P)	94
Zinc (Zn)	<1
Molybdenum (Mo)	<1
Boron (B)	<5
Physical Tests	
Viscosity (cSt 40C)	43.6
Solids (%)	0.1
Viscosity (cSt 100C)	8.1
Physical / Chemical	
Acid Number (mgKOH/g)	0.37
Oxidation (Abs) E2412/D7414	<1
Nitration (Abs) E2412/D7624	<1

Oil thought to be originally employed

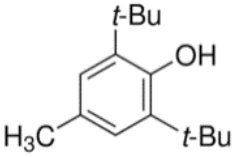


IR Results



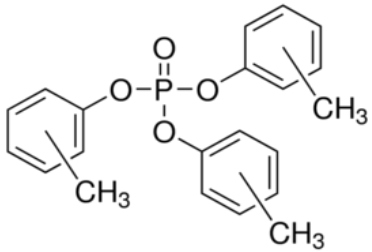
Hydraulic Oil GREEN

Alky Phenol

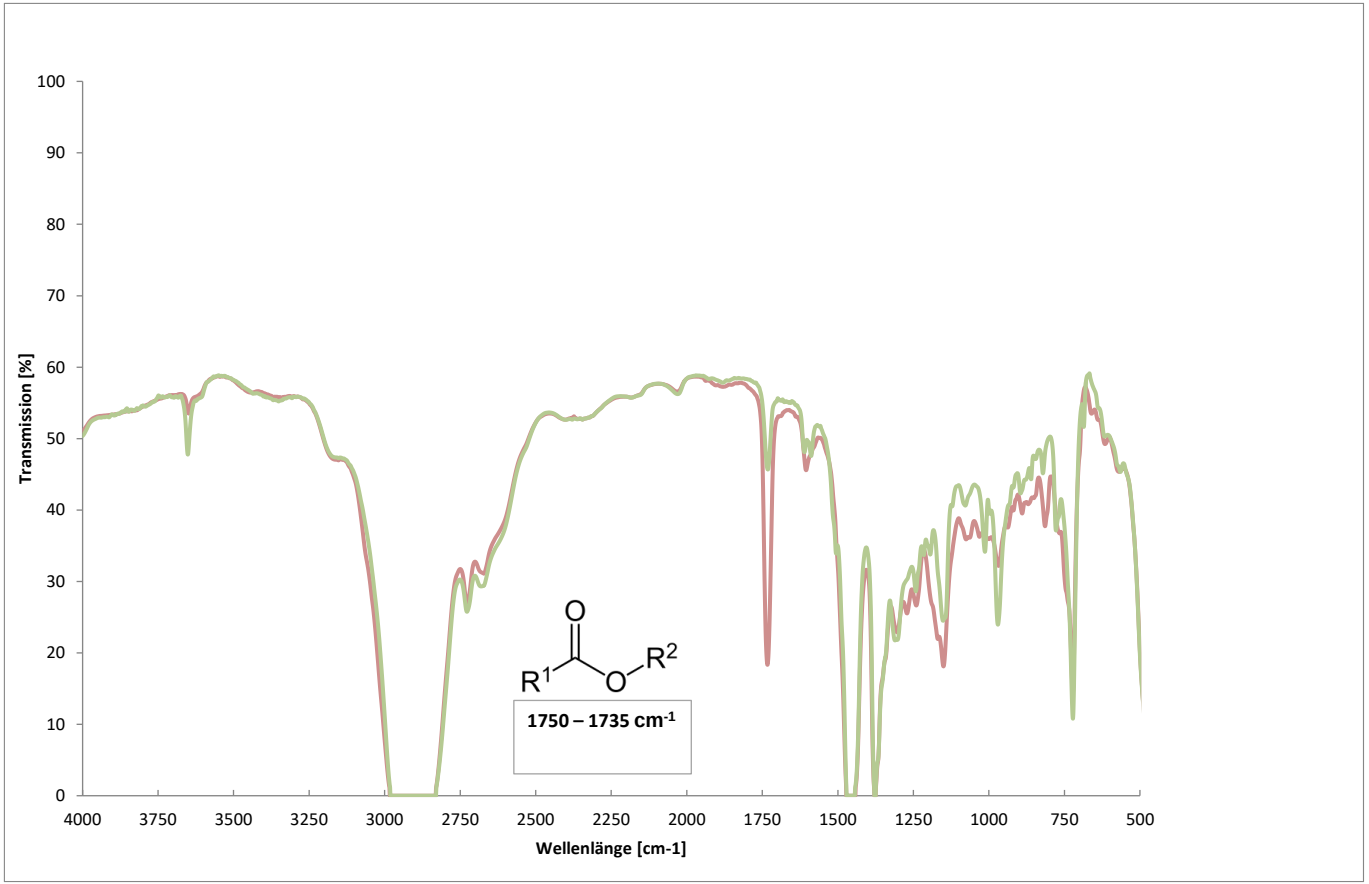


Hydraulic Oil RED

2,6-Di-Tertiär -Butyl-4-cresol



Tritolyl phosphate



Examples of Oil Additive Chemistries

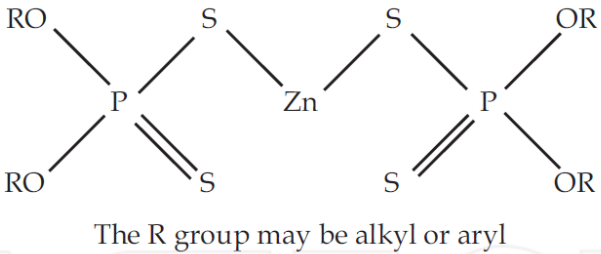


Fig. 1.3 Zinc dithiophosphate as antiwear additives / extreme pressure

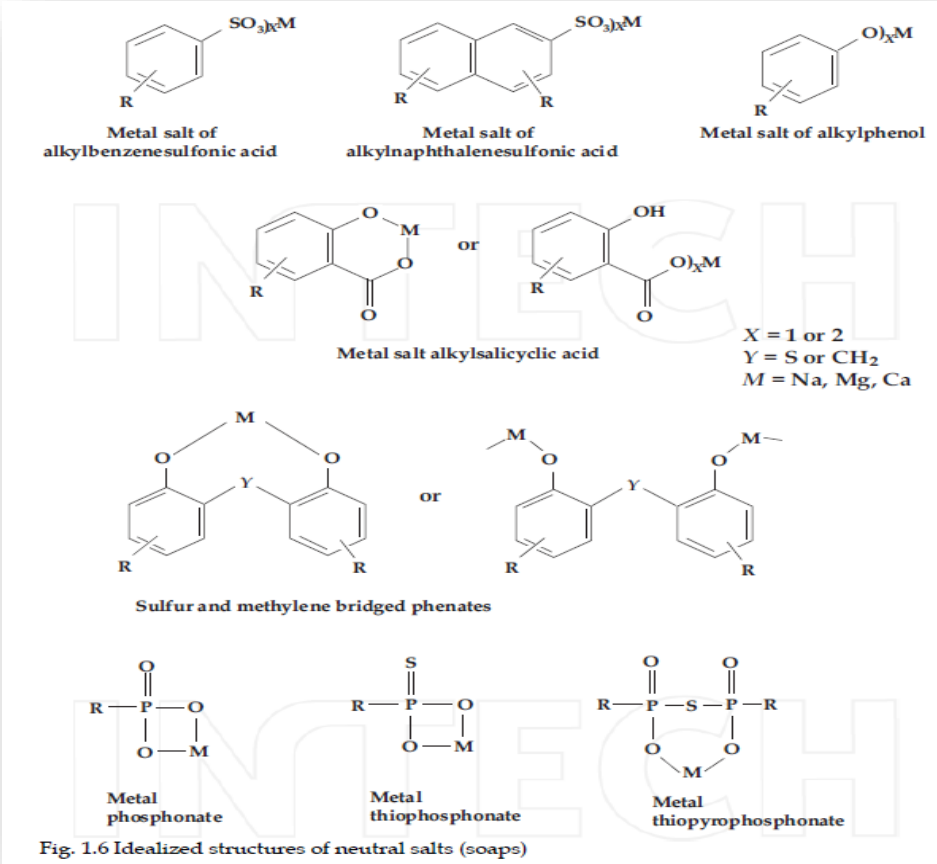
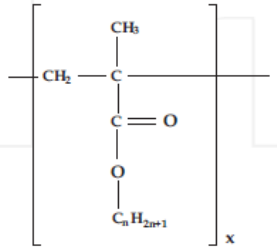


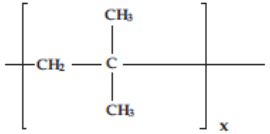
Fig. 1.6 Idealized structures of neutral salts (soaps)

Examples of Oil Additive Chemistries

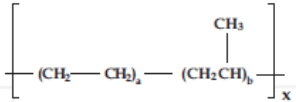
(a) Polymethacrylates (PMA)



(b) Polyisobutenes (PIB)



(c) Olefin co-polymers (OCP)



(d) Styrene/diene co-polymers

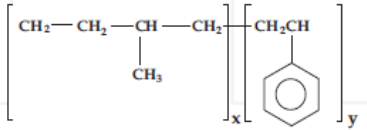


Fig. 1.10 Viscosity index improvers

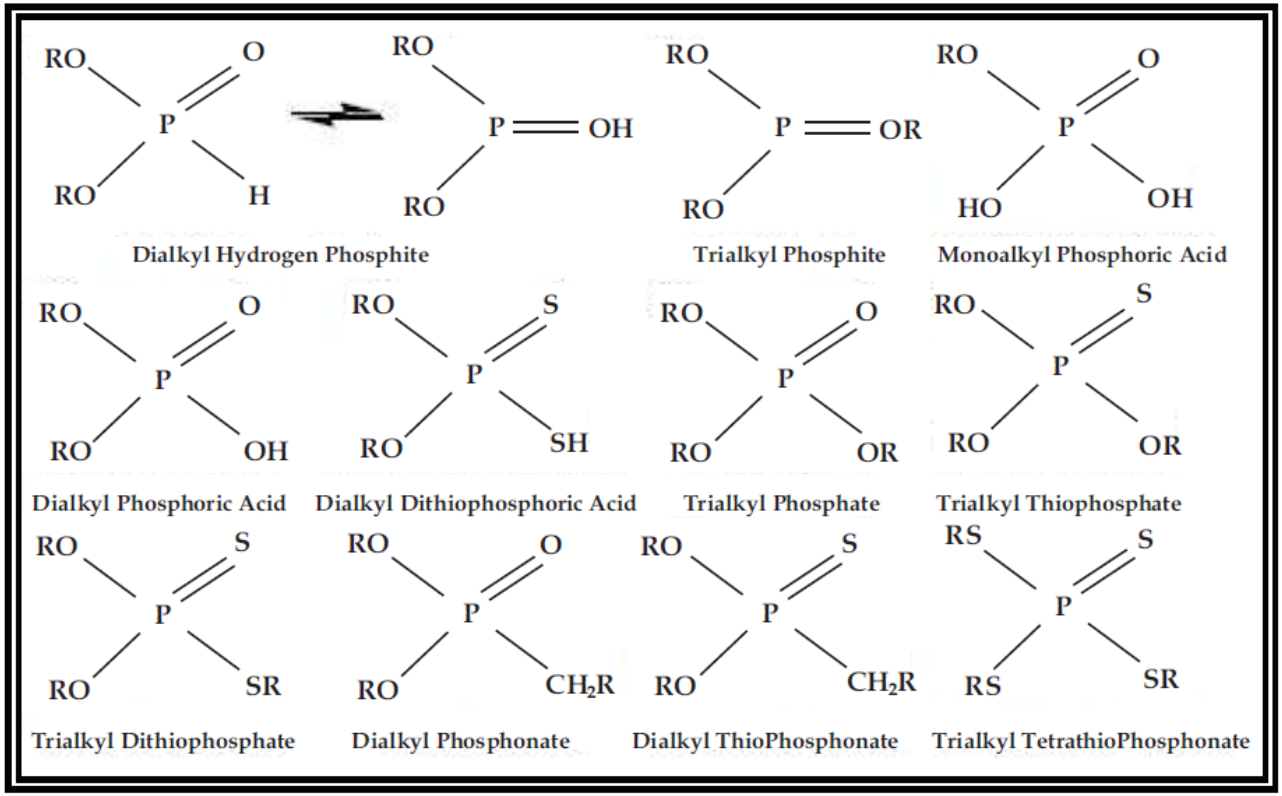


Fig. 1.2 Common phosphorus derivatives used as antiwear agents / extreme-pressure

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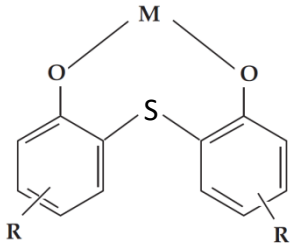
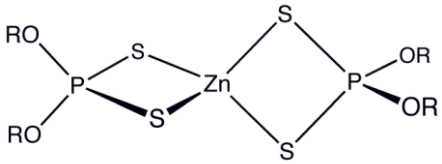
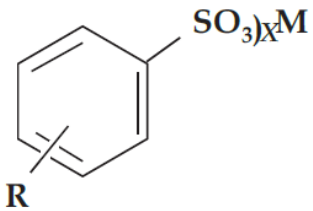
Electrostatic Test Rig
Physics of ESD in Liquids





(R = alkyl)



Presence of Ions Required to Carry Charge

- Typical Hydrocarbon Conductivities up to ~100 $pS \cdot m^{-1}$

Possible Charge Carriers

- Metal-containing Additives (ZnDTP, Ca/Mg sulfonates)
- Decomposition due to Oxidative or Chemical Attack
- Various Impurities (metal chips, water)
- Charge Formation Due to Helmholtz Double Layer

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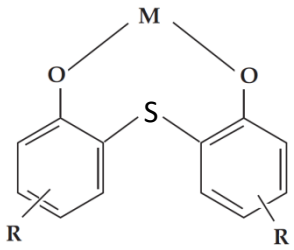
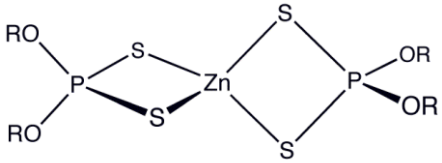
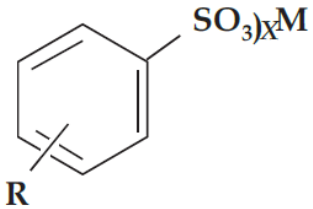
Electrostatic Test Rig
Oil Conductivity





(R = alkyl)



Classification of lube and hydraulic fluids acc. to API1509, APPENDIX E, E.1.3, REV:01-SEP-2011

Group	VI	Saturated hydrocarbon (%)	Sulfur – content (%)	Description	Electrical Conductivity @RT
I	95-105	< 90	> 0,03	Conventional	High
II	105-120	≥ 90	≤ 0,03	Hydrogenation	Low
III	> 120	≥ 90	≤ 0,03	Strong Hydrogenation	Low
IV	> 130	100	0,00	PolyAlphaOlefines (PAO)	Low
V	-	-	-	All other base oils	Different

Electrical Conductivity and Permittivity of Water

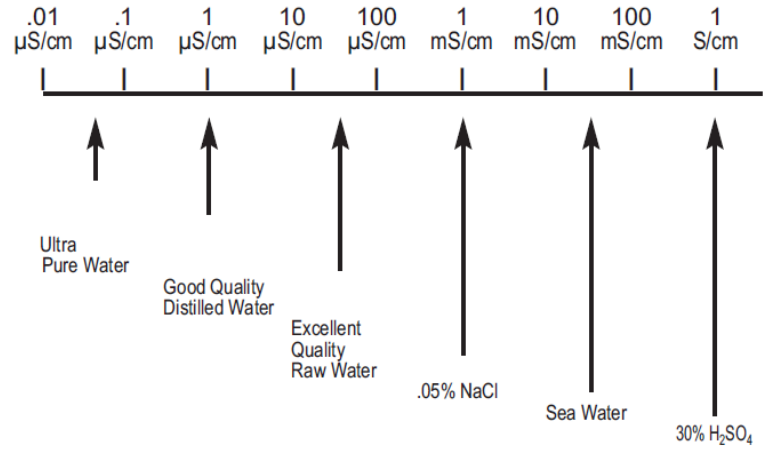


FIGURE 2. The graph shows the conductivity of pure water, distilled water, and typical electrolytes at 25°C. Distilled water has greater conductivity than pure water, because it is always contaminated with atmospheric carbon dioxide, which dissolves in water to form the weak electrolyte, carbonic acid.

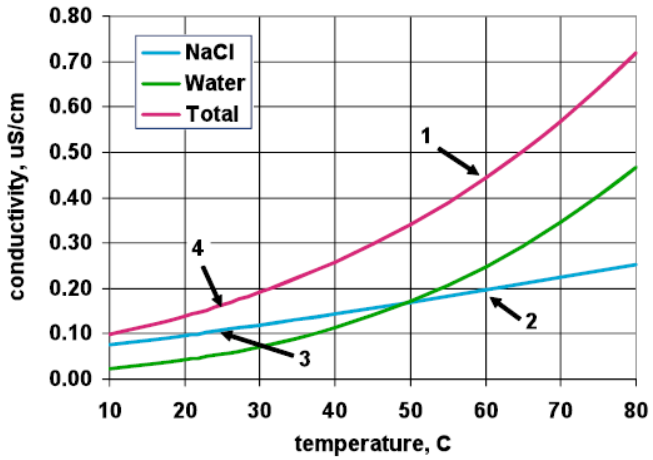
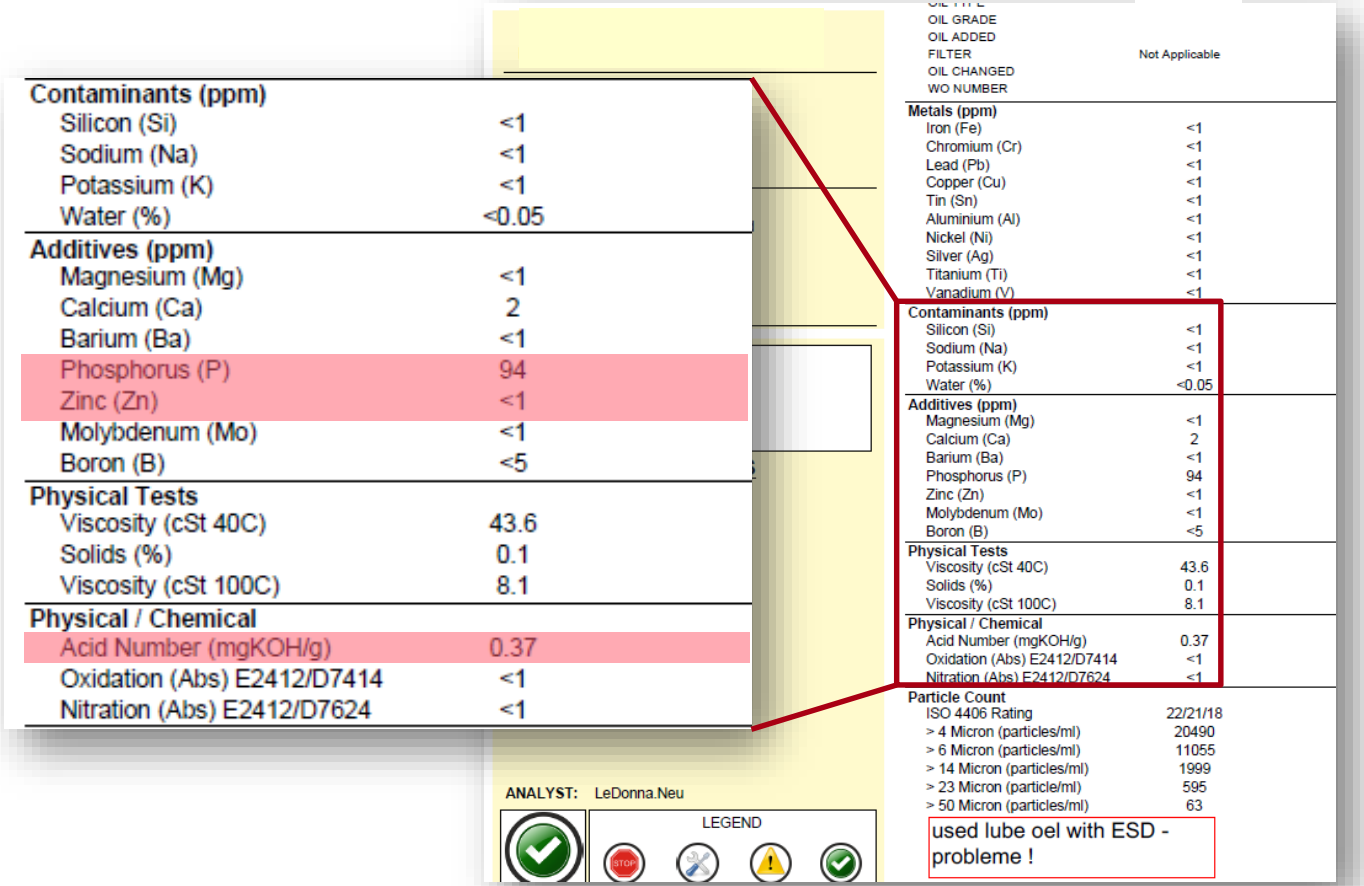


FIGURE 7. The total conductivity is the sum of the conductivity from water and sodium chloride ions. The large increase in the conductivity of water as temperature increases is caused primarily by the increased ionization of water at high temperature.

Oil Used for Flushing Leads to ESD Problems

- Zinc-free
- Very low conductivity!



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Boron (B)	<5
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Solids (%)	0.1
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Physical / Chemical	
Acid Number (mgKOH/g)	0.37
Oxidation (Abs) E2412/D7414	<1
Nitration (Abs) E2412/D7624	<1

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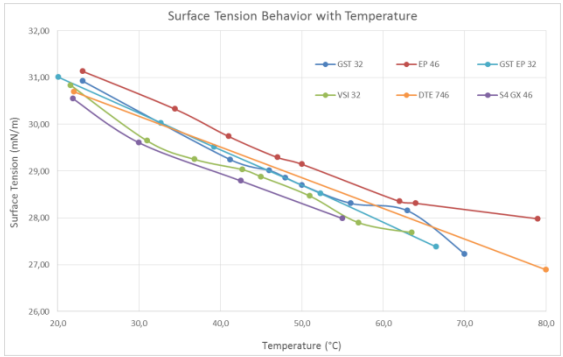
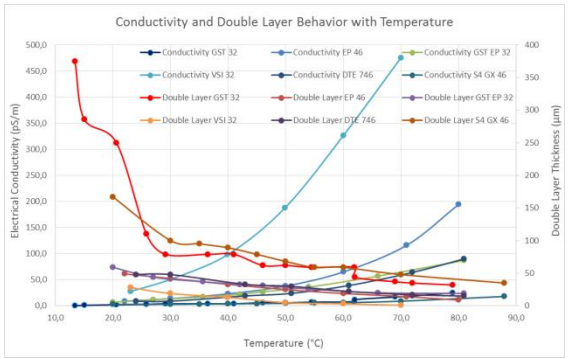
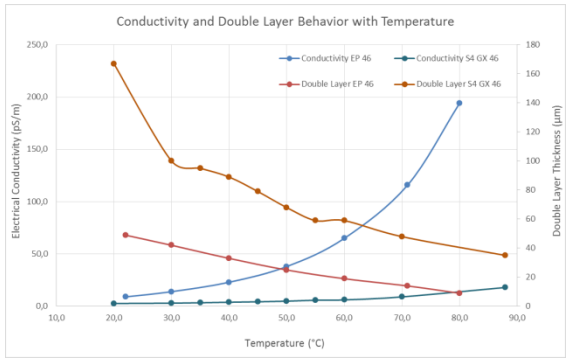
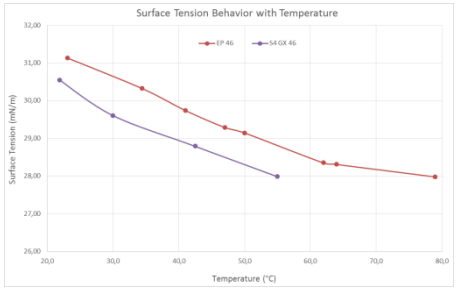
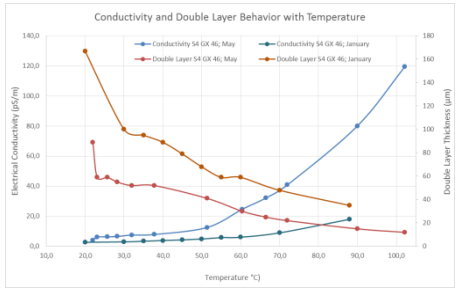
Predict and Understand How Oils Behave

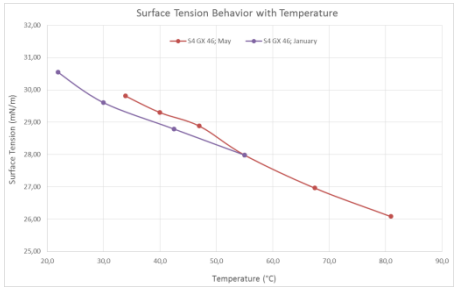


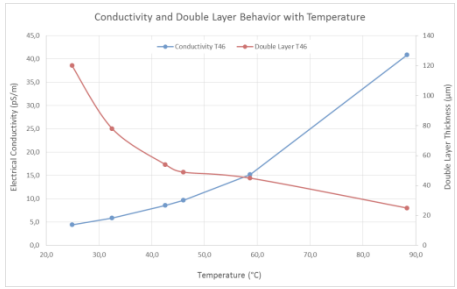




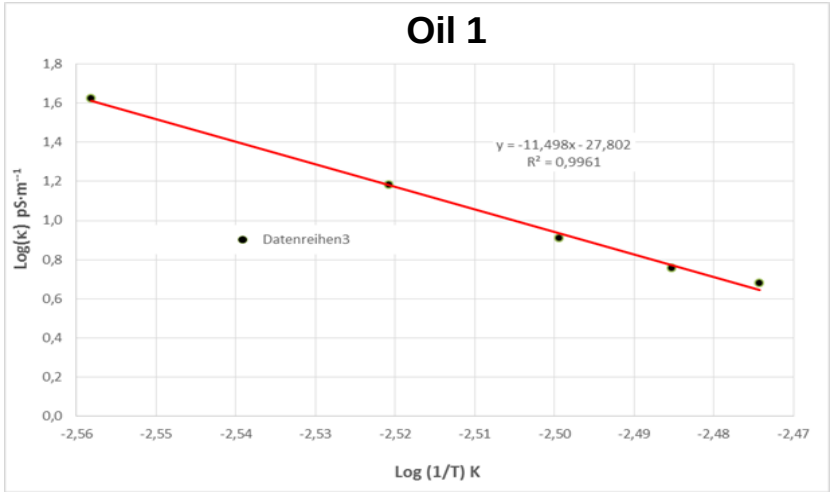


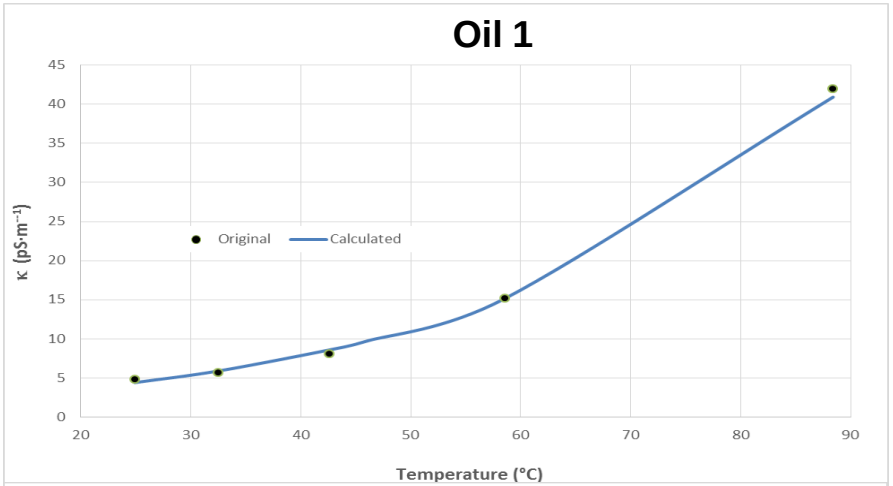


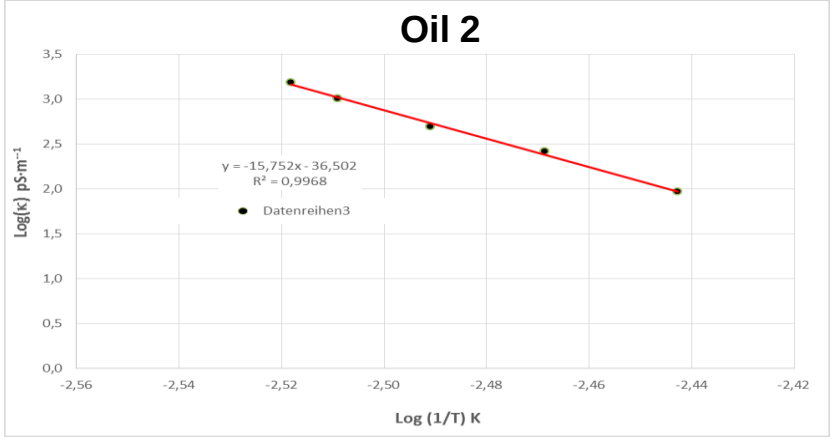


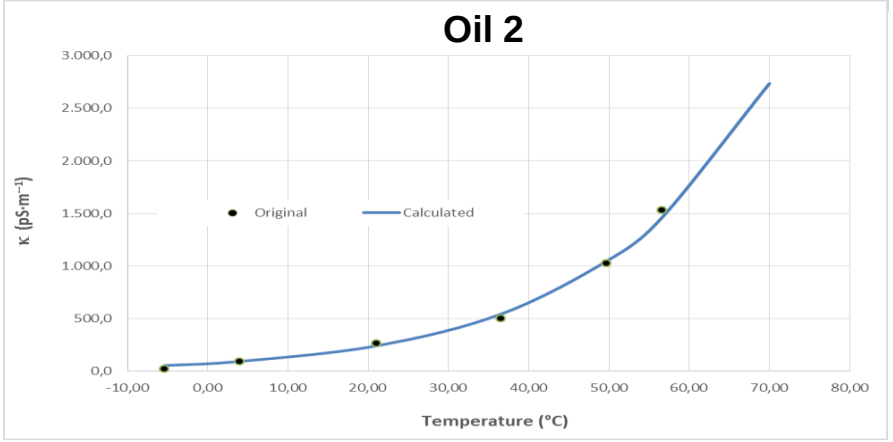


Predict and Understand How Oils Behave









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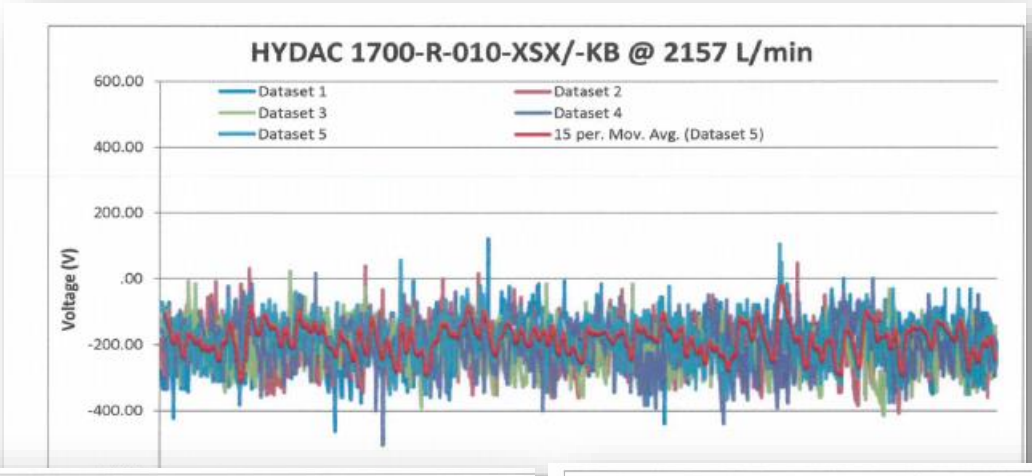
Field Test, Jan. 2016
Set I and Set II of Stat-X® Elements

Element Set I:
shipped Dec. 2015
Heavy arcing!

Element Set II:
(optimized)
delivered Jan. 2016

Charging reduced,
not eliminated;
arcing still apparent;
however…
POLARITY REVERSED !



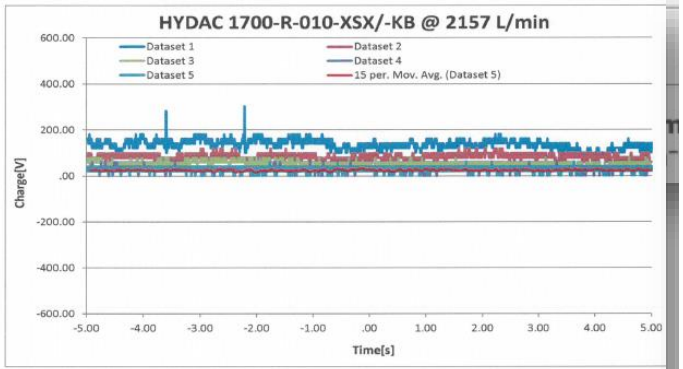


Figure 8: ESD Behavior of Filter Elements *in-situ*: Stat-X – Set II
Q 2157 L·min^{-1} (Φ 0.023 L·min^{-1}·cm^{-2}); κ 5 pS·m^{-1} @22°C.

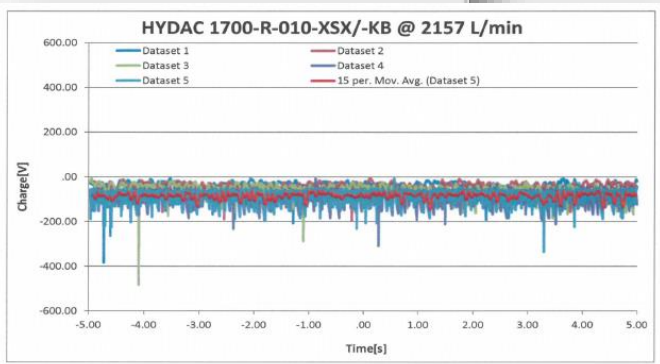


Figure 10: ESD Behavior of Filter Elements *in-situ*: Stat-X – Set II
Q 2157 L·min^{-1} (Φ 0.023 L·min^{-1}·cm^{-2}); κ 5 pS·m^{-1} @22°C.

Field Test, May 2016
Set III of Stat-X® Elements

Element Set III
(further optimized) shows great behavior under flushing and normal flow

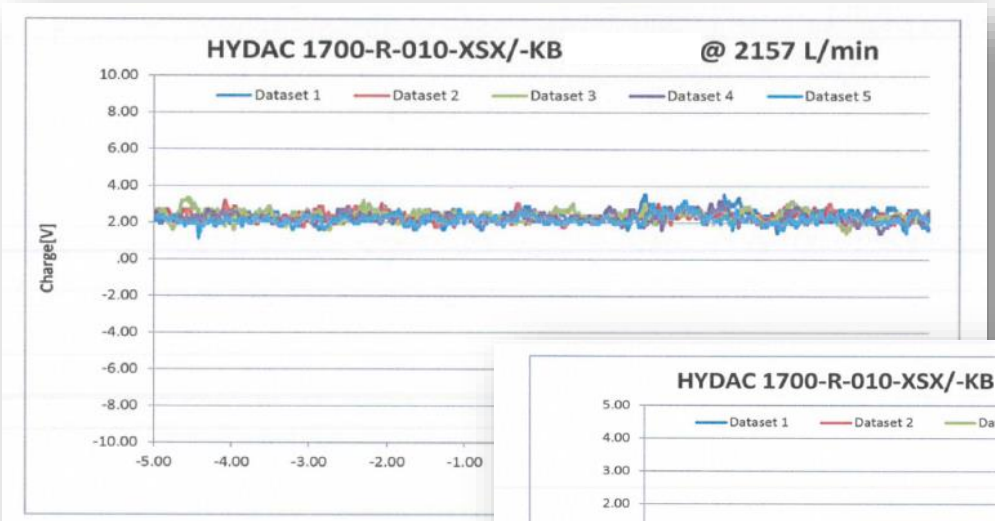


Figure 7: ESD Behavior of Filter Ele
May 2016. Q 2157 L·min⁻¹ (Φ 0.023

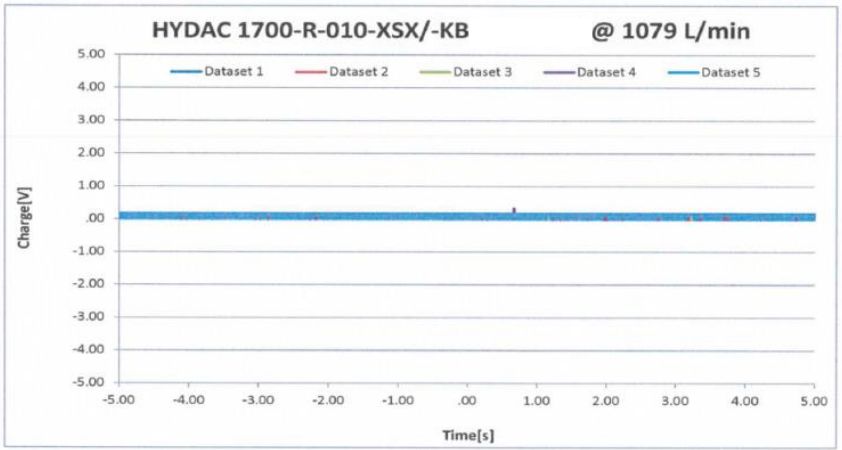


Figure 8: ESD Behavior of Filter Elements *in-situ*: Stat-X
May 2016. Q 1079 L·min⁻¹ (Φ 0.012 L·min⁻¹·cm⁻²); κ 6 pS·m⁻¹ @47°C.

OEM C - Field Test for Forklift

Properties	Test Method	Oil 1	Oil 2
Viscosity, cSt			
@ 40°C	ASTM D 445	31	44
@ 100°C	ASTM D 445	10.4	14.1
Viscosity, SUS @ -35°C	ASTM D 445	870	1,421
Viscosity Index	ASTM D 2270	353	348
Pour Point, °C	ASTM D 97	-60	-59
Flash Point, COC, °C	ASTM D 92	113	112
Specific Gravity, 25°C (60°F)	ASTM D 1298	0.882	0.885
Ferrous corrosion	ASTM D 665 A	Pass	Pass
Operating Range, °C*	---	-38 to 75	-45 to 75

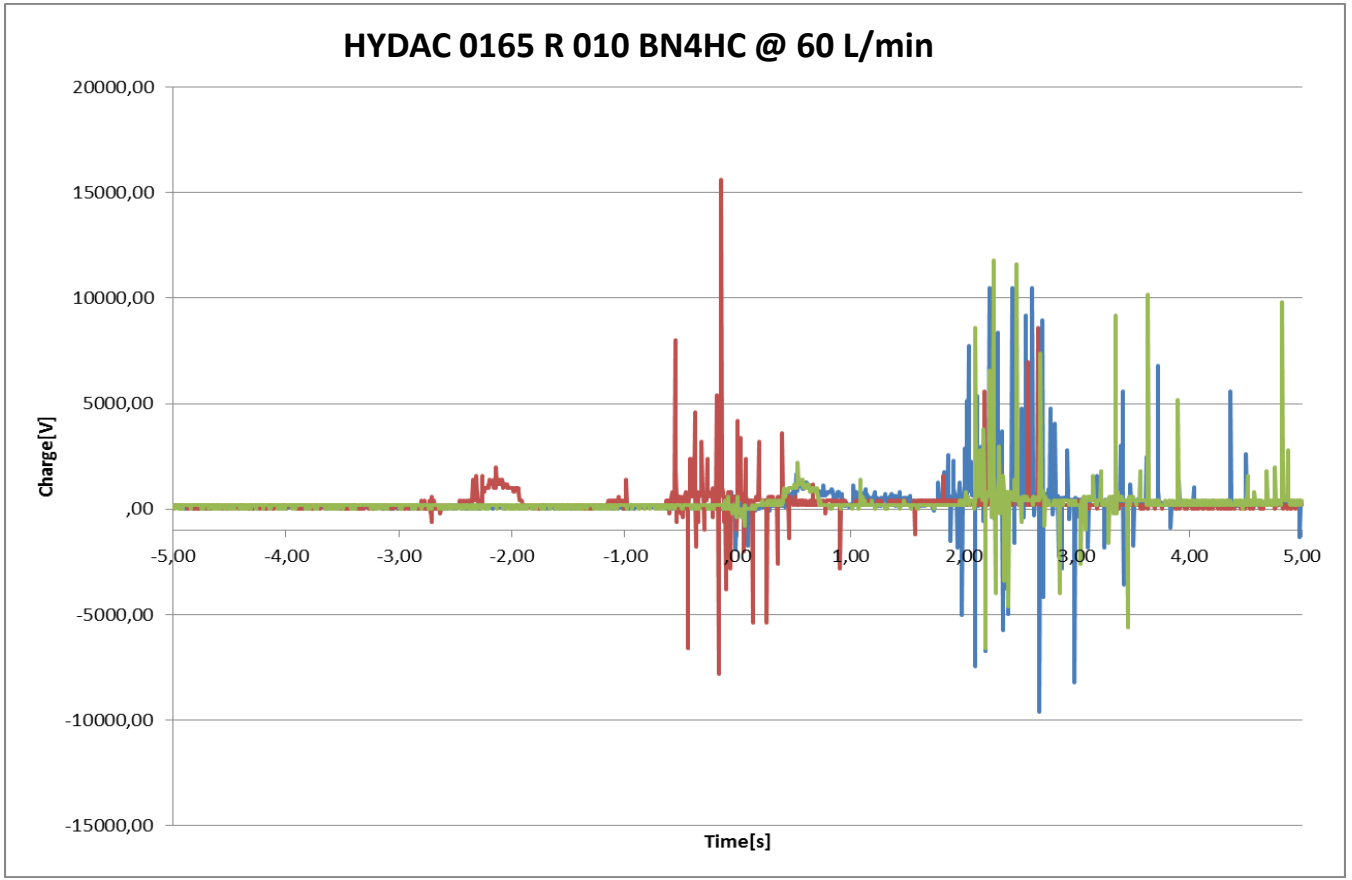
*Fluid Temperature. Start-ups at ambient temperatures below this are possible provided that the bulk fluid is allowed to warm up prior to being put under working load.

COMPOSITION/INFORMATION ON INGREDIENTS
Hazardous components Oil 1

Chemical Name	CAS-No.	Concentration (%)
Distillates (petroleum), hydrotreated light naphthenic	64742-53-6	>= 50 - < 70 %
Distillates (petroleum), hydrotreated light	64742-47-8	>= 10 - < 20 %
Phenol, isobutylenated, phosphate (3:1)	68937-40-6	>= 0.1 - < 1 %
2,6-di-tert-butyl-p-cresol	128-37-0	>= 0.1 - < 1 %

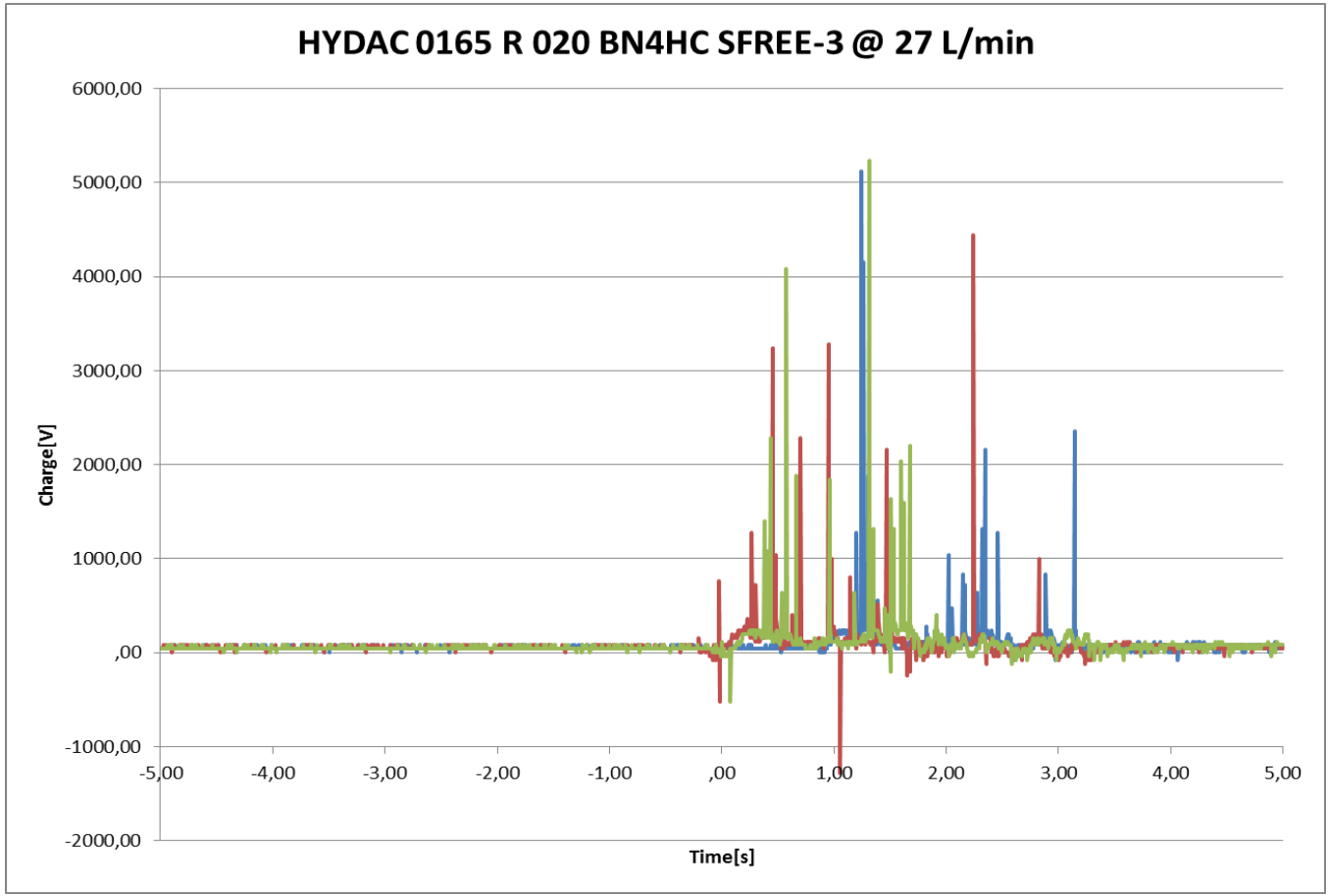
OEM C - Field Test for Forklift

Filter:	HYDAC RFM 165 with plastic pipe
Element:	HYDAC 0165 R 010 BN4HC
Flow:	60 L/min
Oil Temperature:	25 °C
Oil Conductivity:	12 pS/m



OEM C - Lab Test for Forklift

Filter:	HYDAC RFM 165 with plastic pipe
Element:	HYDAC 0165 R 020 BN4HC SFREE-3
Flow:	27 L/min
Oil Temperature:	25 °C
Oil Conductivity:	12 pS/m



Summary and Conclusion

- ESD Evaluations Require Sophisticated Equipment
- Current Models Provide Reasonably Good Interpretation of ESD Phenomena
- High Degree of Predictability of ESD Occurrence Achieved
- Ability to Solve Even Complex Cases within Reach

- Nevertheless: ESD issue NOT Completely Solved

- New Oil and Additive Formulations, New System Component Materials and Unusual Operating Conditions Create Environments Requiring Further Investigation