The Hidden World of Fluid Management

A Deeper View Into Engine Health Interpretation

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THE HIDDEN WORLD
OF FLUID MANAGEMEENT

AGENDA

- Modern engines complexity
- Fluids change over the years
- The importance of standard deviations by type of engine and application
- Key observations in oil, coolant and fuel results
- The complexity of comprehensive fluid interpretation

OBJECTIVES

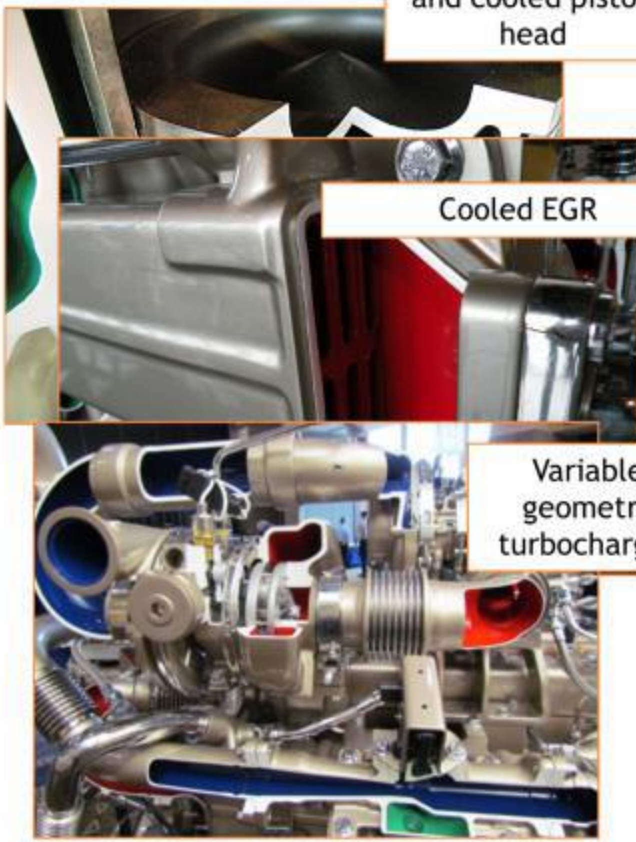
- Understand how engines and fluids have changed over the years
- Grasp the importance of standard deviation tables
- Learn the need for deeper fluid interpretation
- Take some of the challenges home and implement them

MODERN ENGINES
T3, IT4, FT4

Top ring location and cooled piston head

Cooled EGR

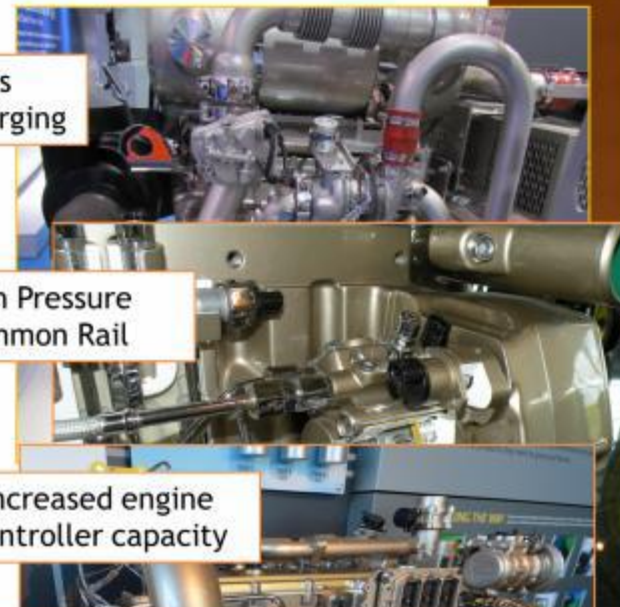
Variable geometry turbocharger



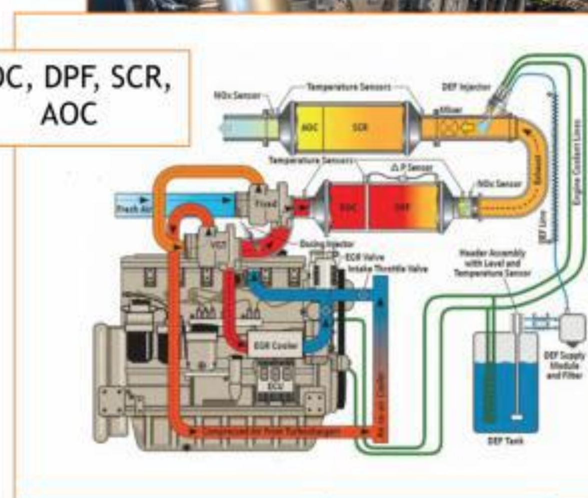
Series turbocharging

High Pressure Common Rail

Increased engine controller capacity



DOC, DPF, SCR, AOC



ENGINES CHANGES
OVER THE YEARS

Cooled Turbocharger

- Pilot injection and ramp-up injection are feasible thanks to electronics, in pursuit of stoichiometric combustion
- For this reason, engines run hotter
- Room for mistakes in maintenance has narrowed, especially on engine overheating tolerance, TBN/TAN ratio and fuel cleanliness

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- Engines breathe better through additional valving and more advanced turbocharging
- Engines need to comply with emissions restrictions

FLUIDS CHANGES
OVER THE YEARS

- Oils contain less TBN and still need to cope with increased acid neutralization and oxidation resistance requirements
- Oil flow has increased so it can be used to complement cooling
- Coolants- Because of added heat, coolants require a much more oxidation stable additive package
- Fuel is injected at pressures that are 12 times higher than 20 years ago (Injectors don't last as in the past)
- Fuel needs to be much cleaner than hydraulic fluid, and needs help from diverse fuel additives

The rules of the game in maintenance have changed!

APPLICATION IMPACT

- Engines still need to cope with light loads and long idling periods
- Engines still need to perform in high altitudes
- Application could involve an intermittent or stable continuous load
- Engines may experience fuel dilution as part of application and/or design

NEW CHALLENGES

- A deeper knowledge on machine health interpretation is needed
- We cannot continue doing what we have been accustomed to doing
- There are new rules in the game that you are expected to play by

A better fluid analysis interpretation from labs and users is a must!

WEAR TABLES

- Only Identical engines driving identical vehicles in similar applications could use a single wear table, because:
  - Oil sump capacity could be different
  - Power settings might be different
  - Injection mapping could be different
  - Liner wear and piston erosion signature will be different
  - Oil consumption is going to be different
  - Oil dilution could be different… so,

You need dedicated wear tables to really squeeze the power of oil analysis!

WEAR TABLES
WHAT VALUES ARE CONSIDERED NORMAL?

- What are normal readings for iron in 500 hours?
- And like this, there are many more questions…
- Lab precision has no meaning if you don't have a table developed for your engine

The Questions?

How much metal is too much wear?

THE ANSWER…
THE USE OF STANDARD DEVIATION TABLES

- Standard deviations tables allow us to measure engine behavior against its model/application data…

Standard Deviation is a measure of how spread out the numbers are from normalized interval samples

Formula: It is the **square root** of the **Variance**

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2}$$

Variance: Is the average of the **squared** differences from the Mean

STANDARD DEVIATIONS

Median Value

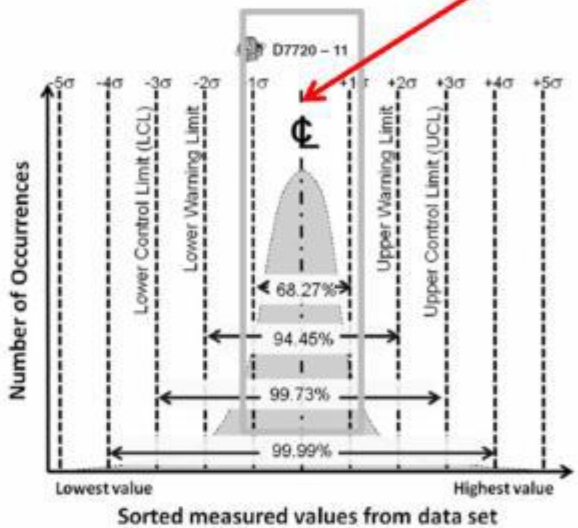


FIG. 1 SPC Parametric, Normal Distribution

- The ideal distribution of wear values follows the bell shape curve as in the graphic
- In the example, 68.27% of the population falls within 1 StdDev+ and 1 StdDv-
- These values are considered normal
- The critical values start beyond +/- 2 StdDev

The Standard Deviation is a measure of **how spread out numbers are**

Wear Sample Data Distribution

STANDARD DEVIATION TABLES
EXAMPLE OF DIFFERENT MODELS

- Every type of engine is like a different child

Isuzu Engine			
850D Excavators			
per 500 hrs after break-in			
* Limit if Hours are unknown is same as Critical			
Filtered System	Normal	Abnormal	Critical
*Fe	<58	58	>89
Pb	<15	15	>25
Cu	<17	17	>30
Cr	<5	5	>10
Al	<50	50	>65
Ni (Report Only)	<5	5	>10
Ag (Report Only)	<2	2	>3
Sn (Report Only)	<5	5	>10
Na	<31	31	>50
K	<30	30	>50
Ti (Report Only) - Do Not Flag if Oil Additive	<5	5	>10
Si	<14	14	>21

Mercedes Engine			
ADTs models 350D and 400D			
per 500 hrs after break-in			
Filtered System	Normal	Abnormal	Critical
*Fe (Limit If Hrs are unknown is same as critical level)	<45	45	>70
Pb	<15	15	>25
Cu	<29	29	>60
Cr	<5	5	>10
*Al (Limit If Hrs are unknown is same as critical level)	<25	25	>35
Ni (Report Only)	<10	10	>17
Ag (Report Only)	<2	2	>3
Sn (Report Only)	<5	5	>10
Na	<70	70	>134
K	<30	30	>50
Ti (Report Only)	<5	5	>10
*Si (Limit If Hrs are unknown is same as critical level)	<15	15	>25

Isuzu Engine

Mercedes Engine

MEASUREMENTS HANDLED
WITHOUT STANDARD DEVIATION CALCULATIONS

These contamination and physical properties values do not produce a bell shaped curve. The labs provide the maximum/minimum values and trigger points

- Sulfation
- Nitration
- Water
- Glycol
- Fuel
- PQ Index

Contaminants

- Oxidation
- Viscosity
- Viscosity shear
- TAN
- TBN

Physical Properties

KEY OBSERVATIONS
WEAR METALS

- Critical and non-critical metals

	Iron	Copper	Chrome	Aluminum	Tin	Lead	Nickel
Critical			X		X	X	X*
Non-Critical	X	X		X*			X*

Remember, your mission is not to react to wear metals only, but to understand why these are being produced and then addressing the root cause!

KEY OBSERVATIONS
WEAR METALS – IRON (TIME DEPENDANT)

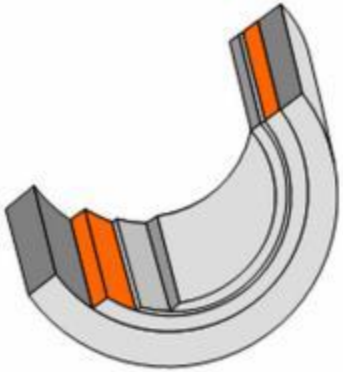
- Non-Critical Metals
  - Main source for iron readings is <u>liners</u>

Iron	Reasons for its presence
1	Hours of use (Time dependency)
2	Dirt contamination
3	Coolant leak
4	Low TBN high TAN
5	Severe fuel contamination
6	Valve guide and/or oil pump wear

Changing oil only addresses number 1 and 4, but does not fix root cause of the others, if any

KEY OBSERVATIONS
WEAR METALS - COPPER

- Non-Critical Metals
  - Copper passivation from oil cooler overrides the readings from bearings and other components containing bronze alloys
  - It is no longer a good measure of engine health



KEY OBSERVATIONS
WEAR METALS – LEAD AND TIN

- Critical Metals
  - Lead alone is not serious if within limits. Lead and tin together is bad news

Lead and Tin	Reasons for its presence
1	Acidic oil/Low TBN high TAN
2	Glycol contamination
3	Severe fuel contamination
4	Gross dirt contamination

KEY OBSERVATIONS
WEAR METALS – CHROMIUM

- Critical Metals
  - Chromium comes from piston rings and typically goes hand in hand with iron.

Chromium	Reasons for its presence
1	Dirt contamination
2	Glycol contamination
3	Low TBN high TAN
4	Severe fuel contamination

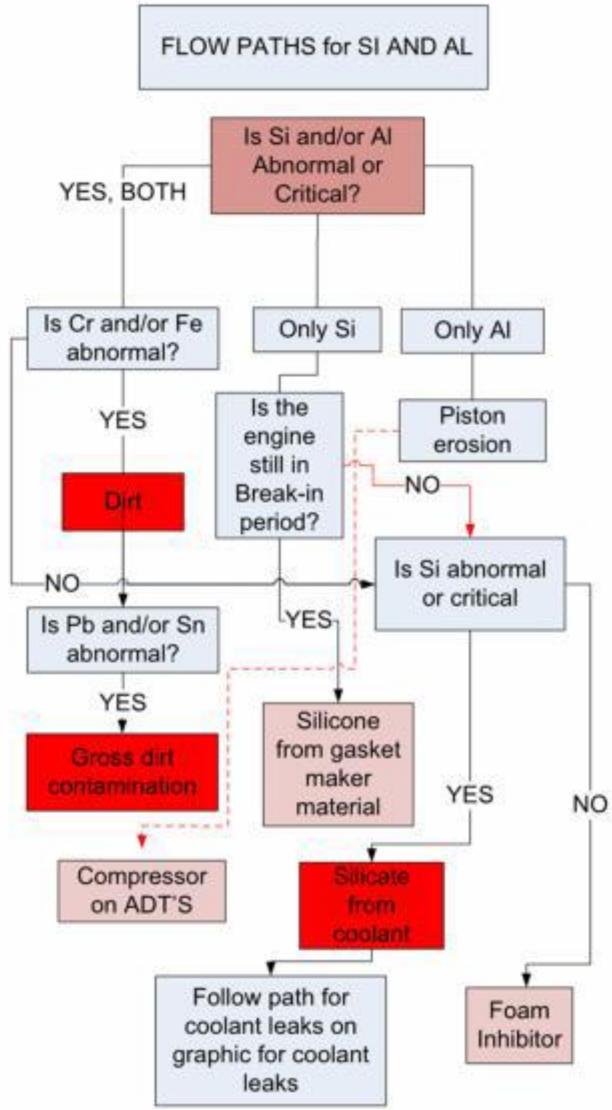
KEY OBSERVATIONS
CONTAMINANTS

	Si	Al	Na	K	Fuel	Soot	Water
Critical	X	X	X		X	X	X
Non-Critical	w/o Al	w/o Si	w/o K,Na,Si	If alone	If less than 6%	If less than 2%	If less than 2000 PPM

DIRT OR NOT DIRT
THAT IS THE QUESTION

Si can be several things:
- Dirt
- Silicone gasket maker
- Anti foaming additive
- Coolant silicates

Al could be:
- Piston material
- Dirt



KEY OBSERVATIONS
CONTAMINANTS - COOLANT

- How to recognize it?
- How do you determine if the leak is through liners?
- Reduced copper readings

	diagnosis	diagnosis	diagnosis	diagnosis	dia[illegible]
	34	15	24	20	[illegible]
xCr	2	<1	1	1	[illegible]
xPb	29	1	1	3	<1
xCu	15	8	2	1	1
xSn	5	<1	<1	<1	<1
xAl	7	4	5	6	3
xNi	<1	<1	<1	<1	<1
xAg	<1	<1	<1	<1	<1
xTi	<1	<1	<1	<1	<1
xV	<1	<1	<1	<1	<1
xSi	39	5	7	10	3
xNa	1114	49	<1	<1	1
xK	785	22	5	<5	6
xCOOLANT	Yes	No	No	No	No
xWater	<0.05	<0.05	<0.05	<0.05	<0.05
xSoot	0.5	0.2	0.6	0.4	0.6
xFUEL	<1	<1	<1	<1	<1
xMg	911	719	20	20	11
xCa	2268	1583	3655	3365	3424
xP	1036	1108	1472	1167	1055
xZn	1248	1101	1781	1507	1460
xMo	352	247	118	93	67
xB	206	192	106	99	64
xBa	<1	<1	<1	<1	<1
S100	15.1	15.0	15.4	14.8	15[illegible]
	9.4	7.2	10.5	9.3	[illegible]

Coolant leaks by liner cavitation

KEY OBSERVATIONS

CONTAMINATION - COOLANT

- ❑ How do you determine the coolant leak is through oil cooler
- ❑ By the high readings of copper in both, coolant and oil analysis

Coolant Report

Metals (ppm)				
Lead (Pb)	ppm	13	1	<1
Iron (Fe)	ppm	4	1	<1
Aluminium (Al)	ppm	<1	<1	<1
Copper (Cu)	ppm	137	155	6
Visual Appearance				
Clarity		Clear	Clear	
Petroleum Layer		None	None	
Sediment		None	None	
Color		Green	Green	
Physical / Chemical				
Glycol Content(D3321)	%	60	64	50
Reserve Alkalinity (ml HCl/10ml)		5.2	4.6	3.0
Additional				
Freeze Point (D3321 Refractometer)	°F	-60	-72	-34
pH (D1287/Meter)		7.6	7.4	7.7
Nitrites (Titrimetric/ IC D5827)	ppm	389	319	971
		524	142	
			119	

test info	diagnosis	diagnosis	diagnosis
xFe	38	29	26
xCr	1	<1	1
xPb	18	2	2
xCu	88	6	2
xSn	<1	<1	<1
xAl	4	3	3
xNi	3	<1	<1
xAg	<1	<1	<1
xTi	<1	<1	<1
xV	1	<1	<1
xSi	17	8	4
xNa	807	81	156
xK	457	136	71
xCOOLANT	Yes	Yes	Yes
xWater	<0.05	<0.05	<0.05
xSoot	0.4	0.91	1.50
xFUEL	<1	<1	<1
xMg	18	18	11
xCa	4182	3659	2907
xP	1536	1385	1199
xZn	1593	1668	1220
xMo	119	98	7
xB	44	51	19
xBa	<1	<1	<1
xVIS100	17.1	16.8	15.6
xTBN	9.6	9.7	6.7

Coolant Leaks Through Oil Cooler

Matching Reports

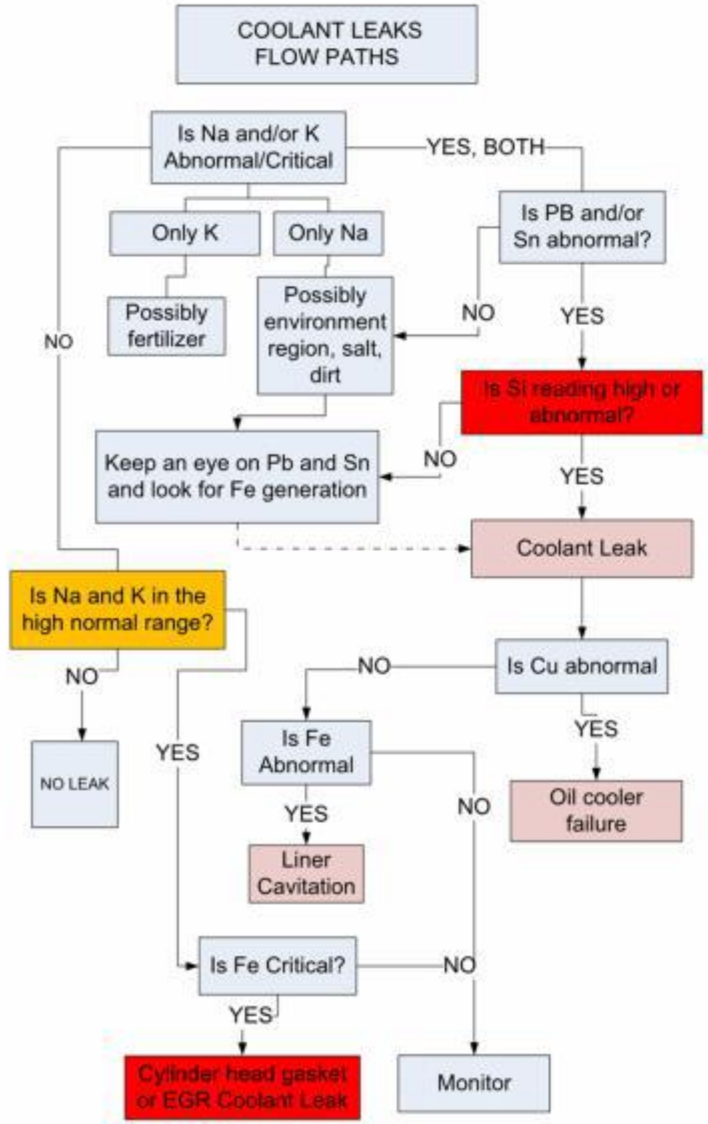
GLYCOL
OR NO GLYCOL
THAT IS THE QUESTION

<u>Na</u> could be many things:

- ☐ Coolant
- ☐ Dirt
- ☐ Salt

K could be:

- ☐ Coolant
- ☐ Fertilizer
- ☐ Soap



FUEL CONTAMINATION

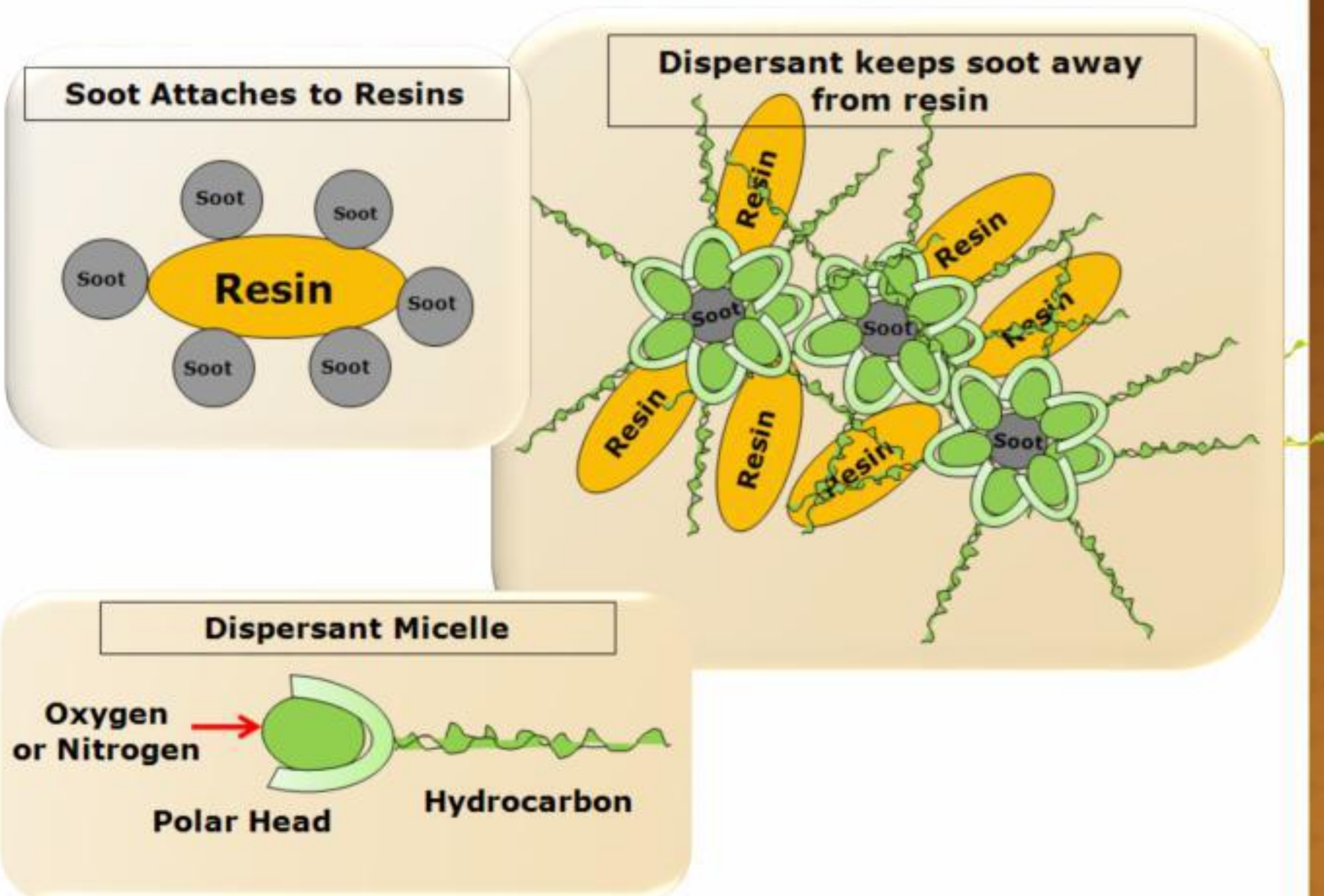
Viscosity Changes

APPROXIMATE ENGINE OIL VISCOSTY CHANGE (IN ENGINE USE) cSt @ 100 Degrees C							
Oils	**NEW**	**50**	**125H**	**250H**	**350H**	**500 H**	**550 H**
5W-30 Other	10.8 -10.4	10.3 - 9.4	9.3 - 8.4	9.3 -10.4	10.3 -11.4	11.3 - 12.4	12.3 - 13.4
10W-30	11.0 - 10.7	10.5 - 9.5	9.5 - **8.5**	9.50 -10.5	10.5 - 11.5	11.5 - 12.5	12.5 -13.5
10W-40 Other	14.6 -14.0	14.1 - 13.1	13.1 -12.1	13.1 - 14.1	14.1 - 15.1	15.1 - 16.1	16.1 - 17.1
15W-40	16.0 - 15.1	14.7 - 13.2	13.7 - **12.5**	13.5 - 14.7	14.5 - 15.7	15.5 -16.7	16.5 - 17.5
0W- 40	15.8 - 15.2	14.2 - 13.5	13.2 - 12.2	13.0 - 14.2	13.5 - 14.5	14.2 - 15.2	15.2 - 16.2
15W-40 Other	14.8 -15-5	14 - 13	12.0 -13.0	12.8 - 13.8	13.8 -14.8	14.8 -15.8	15.8 -16.8
Magic Numbers*. At 125 hours the oil reaches the lowest viscosity point							

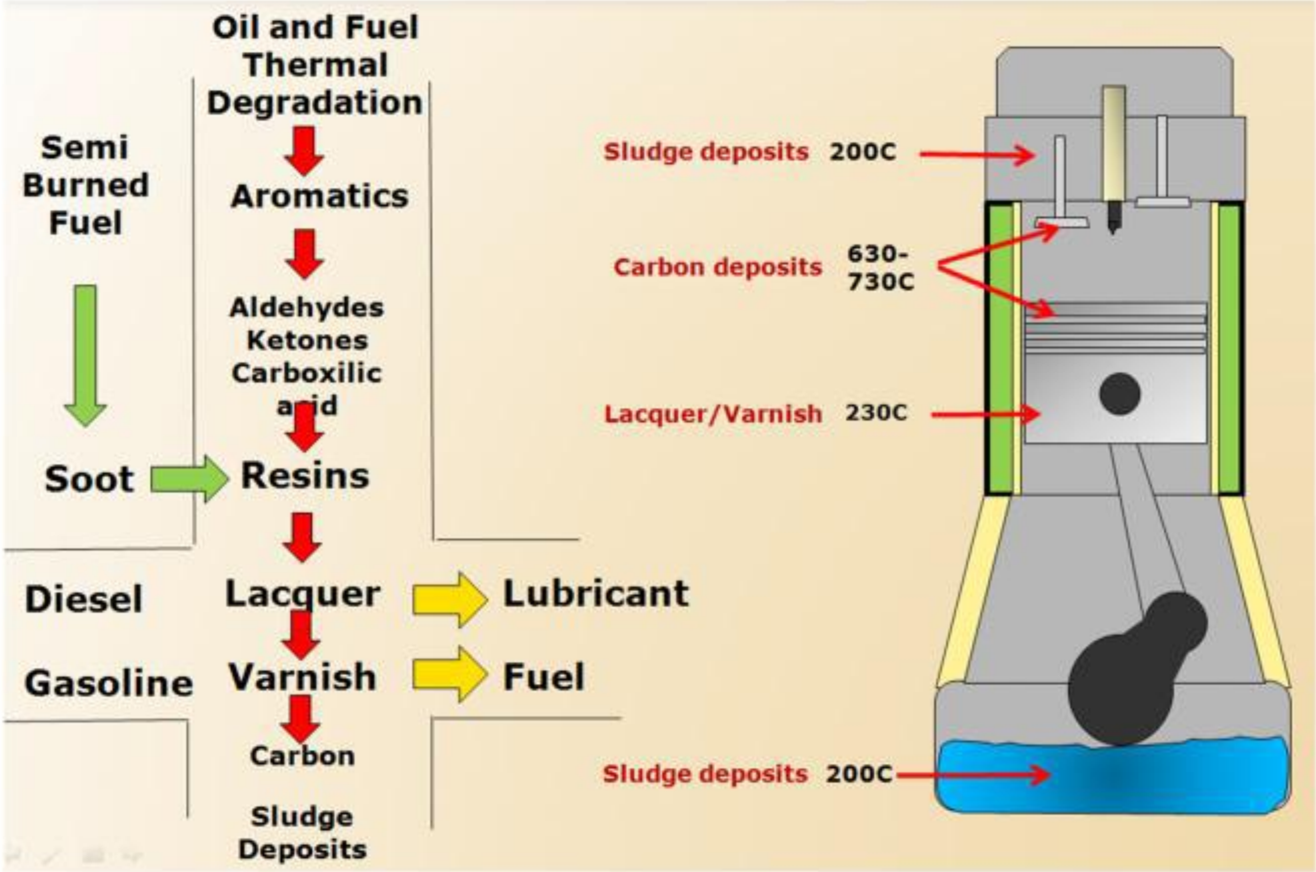
New Limits for Fuel Dilution Tier 3, iT4, fT4

Normal	Abnormal	Critical
4-5%	5 - 7%	>7%

SOOT CONTAMINATION
FORMATION AND CONTROL

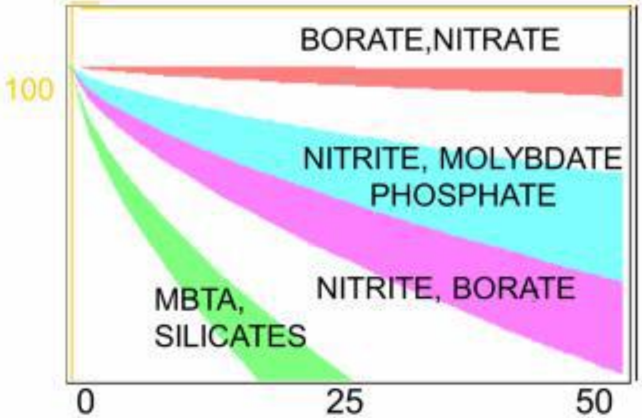


CARBON/LACKER/VARNISH
SLUDGE BUILD UP MECHANISM



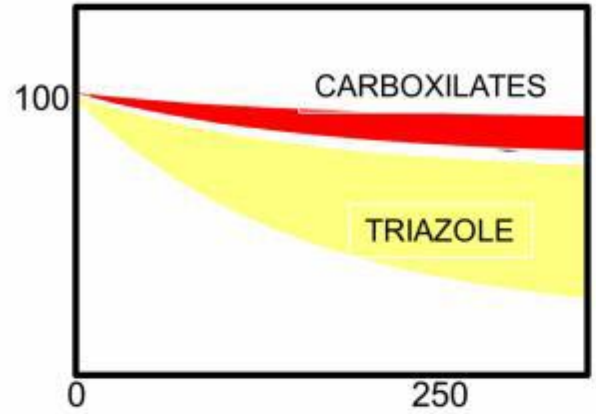
COOLANTS
NEED FOR IMPROVED PERFORMANCE
ADDITIVE EXHAUSTION COMPARISON

Traditional Coolant



50,000 Miles

ELC Coolant

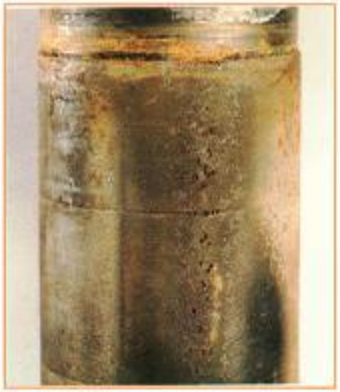


500,000 Miles

LINER CAVITATION & AL CORROSION
BY NITRITE EXHAUSTION - CONVENTIONAL COOLANT

Common causes for the depletion of Nitrite:

- Stray current, the Nitrite changes into Ammonia NH_3
- Ammonia then converts in the coolant to Ammonium hydroxide NH_4OH which is a highly alkaline substance
- Ammonia increases the pH (of the coolant) causing corrosion of nonferrous substances such as Aluminum
- Lack of Nitrite ends up in liner pitting (Cavitation)



FIELD TESTS FOR OA ELC
PH, ORGANIC ACID AND GLYCOL CONCENTRATION

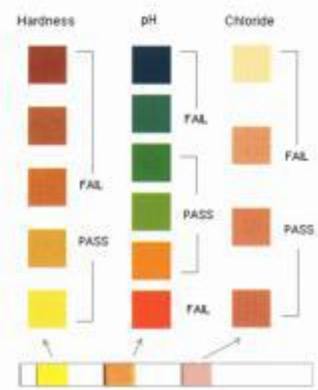
Still, you need to check for mixing and for the presence of metals using a formal lab test

ELC Coolant

Three ways sticks

DON'T FORGET ABOUT THE WATER
SPECIFICATIONS FOR OEM'S MG/L

	Caterpillar	Cummins	Detroit	John Deere	ASTM
Chlorates	50	100	40	5	40
Sulfates	50	100	100	5	100
Total dissolved solids TDS	250	500	340	10	340
Total Hardness	100	300	170	5	40



CTS-5 Make-up Water

FUEL ANALYSIS REPORT

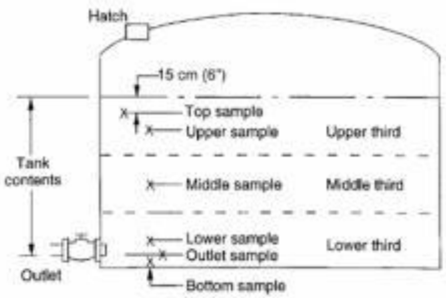
Water, particulate, bacteria, sulfur, distillation, cetane index, bio diesel

Appearance-Distillate Fuel (ASTM D4176)		
Clear and Bright	**Hazy**	
Free Water	**Excessive**	
Particulate	**Excessive**	
Distillation (ASTM D86)		
Initial Boiling Point	365	°F
10% Recovered	403	°F
50% Recovered	500	°F
90% Recovered	620	°F
End Point	665	°F
% Recovered	97.1	Volume %
Physical / Chemical		
API Gravity @ 60F (ASTM D287)	35.9	° API
Calculated Cetane Index (ASTM D4737)	46.2	CCI
Cold Filter Plugging Point (IP309/D6371)	12	°F
Water by Karl Fischer (ASTM E203/D6304)	**1695**	ppm
Sulfur (ASTM D4294/D5453/D7039)	18	ppm
Water by Distillation (ASTM D95)	0.3	Volume %
Biodiesel Blend Content (ALS 2001)	1.6	Volume %
Acid Number (mgKOH/g)	0.07	mgKOH/g
Cloud Point (ASTM D2500)	N/A	°F
Additional		
Total Particulate (ASTM D5452/D6217)	**32.0**	mg/L

WHERE AND WHEN TO TAKE FUEL SAMPLES?
CATCHING THE GHOSTS CAN BE VERY ELUSIVE

Bulk Thanks ASTM D4057-06

- After refueling is best
  - Do it at the middle of the tank
  - Indicate that in the sample information form (SIF)
- If done it before refueling...
  - Do it in lower third
  - Not in outlet level
  - Indicate that in the sample information form (SIF)



Machines

- Fuel gets cleaner during engine operation
  - Timing is of importance to catch contamination
    - Collect sample during first hour after refueling
    - Indicate time of sample collection on sample information form

FUEL TANKS

Fuel tanks are generally exposed and stationary

They can accumulate big quantities of water, rust and bacteria

FUEL ADDITIVES DEPENDENCY

Protect Fuel - Diesel Fuel Conditioners, features:

- **Detergent**
- **Dispersant**
- **Stability Improver**
- **Oxidation Inhibitor**
- **Cetane Improver**
- **Lubrication Improver**
- **Water Control**
- **Cold Flow Improver**
- **Anti-Settling Agent Wax**

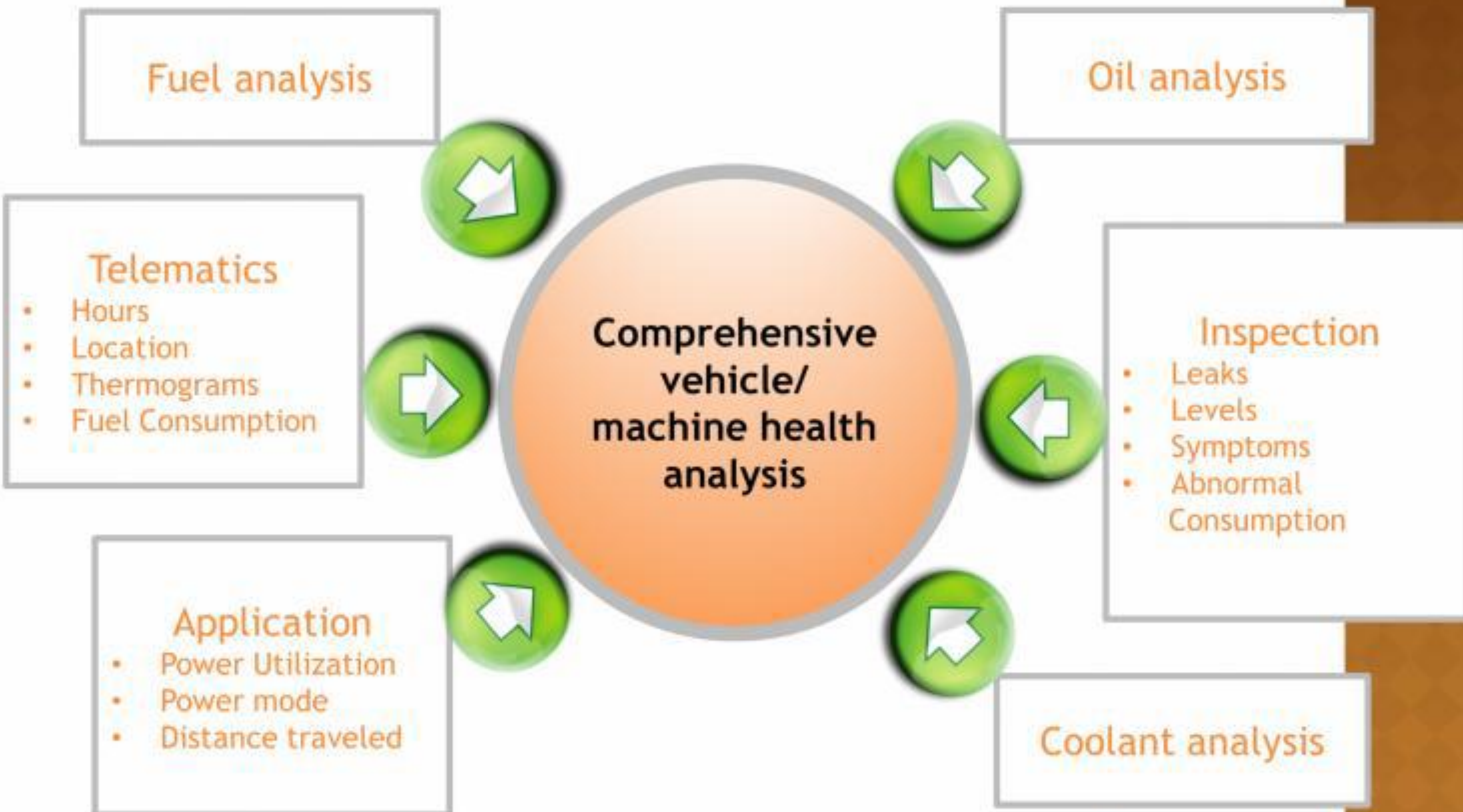
Normal Use

Protect Fuel - Keep Clean features:

- **Detergent**
- **Dispersant**
- **Stability Improver**
- **Oxidation Inhibitor**

Strong Cleaner

THE COMPLEXITY OF COMPREHENSIVE FLUID INTERPRETATION



Questions?