The Hidden World of Fluid Management

A Deeper View Into Engine Health Interpretation

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Condition Based Management Consultant
THE HIDDEN WORLD OF FLUID MANAGEMENT

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
- Series turbocharging
- High Pressure Common Rail
- Increased engine controller capacity
- Cooled EGR
- Variable geometry turbocharger
- 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
- 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

\[ \sigma = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \bar{x})^2} \]

Variance: Is the average of the **squared** differences from the Mean
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 StdDev-
- These values are considered normal
- The critical values start beyond +/- 2 StdDev

The Standard Deviation is a measure of how spread out numbers are.
STANDARD DEVIATION TABLES

EXAMPLE OF DIFFERENT MODELS

- Every type of engine is like a different child

### Isuzu Engine

**850D Excavators**

<table>
<thead>
<tr>
<th>Filtered System</th>
<th>Normal</th>
<th>Abnormal</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>&lt;58</td>
<td>58</td>
<td>&gt;89</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;15</td>
<td>15</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;17</td>
<td>17</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Al</td>
<td>&lt;50</td>
<td>50</td>
<td>&gt;65</td>
</tr>
<tr>
<td>Ni (Report Only)</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Ag (Report Only)</td>
<td>&lt;2</td>
<td>2</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Sn (Report Only)</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Na</td>
<td>&lt;31</td>
<td>31</td>
<td>&gt;50</td>
</tr>
<tr>
<td>K</td>
<td>&lt;30</td>
<td>30</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Ti (Report Only) - Do Not Flag if Oil Additive</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Si</td>
<td>&lt;14</td>
<td>14</td>
<td>&gt;21</td>
</tr>
</tbody>
</table>

*Limit if Hours are unknown is same as Critical*

### Mercedes Engine

**ADTs models 350D and 400D**

<table>
<thead>
<tr>
<th>Filtered System</th>
<th>Normal</th>
<th>Abnormal</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>&lt;45</td>
<td>45</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Pb</td>
<td>&lt;15</td>
<td>15</td>
<td>&gt;25</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;29</td>
<td>29</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Al</td>
<td>&lt;25</td>
<td>25</td>
<td>&gt;35</td>
</tr>
<tr>
<td>Ni (Report Only)</td>
<td>&lt;10</td>
<td>10</td>
<td>&gt;17</td>
</tr>
<tr>
<td>Ag (Report Only)</td>
<td>&lt;2</td>
<td>2</td>
<td>&gt;3</td>
</tr>
<tr>
<td>Sn (Report Only)</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Na</td>
<td>&lt;70</td>
<td>70</td>
<td>&gt;134</td>
</tr>
<tr>
<td>K</td>
<td>&lt;30</td>
<td>30</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Ti (Report Only)</td>
<td>&lt;5</td>
<td>5</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Si</td>
<td>&lt;15</td>
<td>15</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

*Limit if Hrs are unknown is same as critical level*
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

- Oxidation
- Viscosity
- Viscosity shear
- TAN
- TBN

Contaminants  Physical Properties
KEY OBSERVATIONS
WEAR METALS

- Critical and non-critical metals

<table>
<thead>
<tr>
<th></th>
<th>Iron</th>
<th>Copper</th>
<th>Chrome</th>
<th>Aluminum</th>
<th>Tin</th>
<th>Lead</th>
<th>Nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X*</td>
</tr>
<tr>
<td>Non-Critical</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X*</td>
<td></td>
<td></td>
<td>X*</td>
</tr>
</tbody>
</table>

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 **liners**

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

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

<table>
<thead>
<tr>
<th>Lead and Tin</th>
<th>Reasons for its presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acidic oil/Low TBN high TAN</td>
</tr>
<tr>
<td>2</td>
<td>Glycol contamination</td>
</tr>
<tr>
<td>3</td>
<td>Severe fuel contamination</td>
</tr>
<tr>
<td>4</td>
<td>Gross dirt contamination</td>
</tr>
</tbody>
</table>
KEY OBSERVATIONS
WEAR METALS - CHROMIUM

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

<table>
<thead>
<tr>
<th>Chromium</th>
<th>Reasons for its presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dirt contamination</td>
</tr>
<tr>
<td>2</td>
<td>Glycol contamination</td>
</tr>
<tr>
<td>3</td>
<td>Low TBN high TAN</td>
</tr>
<tr>
<td>4</td>
<td>Severe fuel contamination</td>
</tr>
</tbody>
</table>
## Key Observations

### Contaminants

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Al</th>
<th>Na</th>
<th>K</th>
<th>Fuel</th>
<th>Soot</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Non-Critical</td>
<td>w/o</td>
<td>w/o</td>
<td>w/o</td>
<td>If</td>
<td>If less than 6%</td>
<td>If less than 2%</td>
<td>If less than 2000 PPM</td>
</tr>
</tbody>
</table>
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

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 Leaks Through Oil Cooler
Matching Reports
GLYCOL
OR NO GLYCOL
THAT IS THE QUESTION

**Na** could be many things:
- Coolant
- Dirt
- Salt

**K** could be:
- Coolant
- Fertilizer
- Soap
# FUEL CONTAMINATION

## Viscosity Changes

<table>
<thead>
<tr>
<th>Oils</th>
<th>NEW</th>
<th>50</th>
<th>125H</th>
<th>250H</th>
<th>350H</th>
<th>500 H</th>
<th>550 H</th>
</tr>
</thead>
<tbody>
<tr>
<td>5W-30 Other</td>
<td>10.8-10.4</td>
<td>10.3 - 9.4</td>
<td>9.3 - 8.4</td>
<td>9.3 - 10.4</td>
<td>10.3 - 11.4</td>
<td>11.3 - 12.4</td>
<td>12.3 - 13.4</td>
</tr>
<tr>
<td>10W-30</td>
<td>11.0 - 10.7</td>
<td>10.5 - 9.5</td>
<td>9.5 - <strong>8.5</strong></td>
<td>9.50 - 10.5</td>
<td>10.5 - 11.5</td>
<td>11.5 - 12.5</td>
<td>12.5 - 13.5</td>
</tr>
<tr>
<td>15W-40</td>
<td>16.0 - 15.1</td>
<td>14.7 - 13.2</td>
<td>13.7 - <strong>12.5</strong></td>
<td>13.5 - 14.7</td>
<td>14.5 - 15.7</td>
<td>15.5 - 16.7</td>
<td>16.5 - 17.5</td>
</tr>
<tr>
<td>0W-40</td>
<td>15.8 - 15.2</td>
<td>14.2 - 13.5</td>
<td>13.2 - 12.2</td>
<td>13.0 - 14.2</td>
<td>13.5 - 14.5</td>
<td>14.2 - 15.2</td>
<td>15.2 - 16.2</td>
</tr>
<tr>
<td>15W-40 Other</td>
<td>14.8 - 15.5</td>
<td>14 - 13</td>
<td>12.0 - 13.0</td>
<td>12.8 - 13.8</td>
<td>13.8 - 14.8</td>
<td>14.8 - 15.8</td>
<td>15.8 - 16.8</td>
</tr>
</tbody>
</table>

*Magic Numbers*. At 125 hours the oil reaches the lowest viscosity point.

## New Limits for Fuel Dilution Tier 3, iT4, fT4

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Abnormal</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4 - 5%</td>
<td>5 - 7%</td>
<td>&gt;7%</td>
</tr>
</tbody>
</table>
SOOT CONTAMINATION
FORMATION AND CONTROL

Soot Attaches to Resins

Dispersant keeps soot away from resin

Dispersant Micelle

Oxygen or Nitrogen

Polar Head

Hydrocarbon
CARBON/LACKER/VARNISH
SLUDGE BUILD UP MECHANISM

- Semi Burned Fuel
  - Oil and Fuel Thermal Degradation
    - Aromatics
      - Aldehydes Ketones Carboxilic acid
    - Resins
  - Soot
  - Diesel
    - Lacquer
  - Gasoline
    - Varnish
    - Carbon
    - Sludge Deposits

- Sludge deposits 200°C
- Carbon deposits 630-730°C
- Lacquer/Varnish 230°C
- Fuel
  - Lubricant
  - Sludge deposits 200°C
COOLANTS
NEED FOR IMPROVED PERFORMANCE
ADDITIVE EXHAUSTION COMPARISON

Traditional Coolant

BORATE, NITRATE
NITRITE, MOLYBDATE PHOSPHATE
MBTA, SILICATES
NITRITE, BORATE

ELC Coolant

CARBOXILATES
TRIAZOLE

50,000 Miles

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$_4$OH** 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

<table>
<thead>
<tr>
<th></th>
<th>Caterpillar</th>
<th>Cummins</th>
<th>Detroit</th>
<th>John Deere</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorates</td>
<td>50</td>
<td>100</td>
<td>40</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Sulfates</td>
<td>50</td>
<td>100</td>
<td>100</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Total dissolved</td>
<td>250</td>
<td>500</td>
<td>340</td>
<td>10</td>
<td>340</td>
</tr>
<tr>
<td>solids TDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Hardness</td>
<td>100</td>
<td>300</td>
<td>170</td>
<td>5</td>
<td>40</td>
</tr>
</tbody>
</table>
# Fuel Analysis Report

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

<table>
<thead>
<tr>
<th>Appearance-Distillate Fuel (ASTM D4176)</th>
<th>Hazy</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear and Bright</td>
<td>365</td>
<td>°F</td>
</tr>
<tr>
<td>Free Water</td>
<td>403</td>
<td>°F</td>
</tr>
<tr>
<td>Particulate</td>
<td>500</td>
<td>°F</td>
</tr>
<tr>
<td>Distillation (ASTM D86)</td>
<td>620</td>
<td>°F</td>
</tr>
<tr>
<td>Initial Boiling Point</td>
<td>665</td>
<td>°F</td>
</tr>
<tr>
<td>10% Recovered</td>
<td>97.1</td>
<td>%</td>
</tr>
<tr>
<td>50% Recovered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90% Recovered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>End Point</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Recovered</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Physical / Chemical                     |      |    |
| API Gravity @ 60°F (ASTM D287)          | 35.9 | °API|
| Calculated Cetane Index (ASTM D4737)    | 46.2 | CCl|
| Cold Filter Plugging Point (IP309/D6371)| 12   | °F |
| Water by Karl Fischer (ASTM E203/D6304) |      | ppm|
| Sulfur (ASTM D4294/D5453/D7039)         | 16   | 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

<table>
<thead>
<tr>
<th>Bulk Thanks ASTM D4057-06</th>
<th>Machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>- After refueling is best</td>
<td>- Fuel gets cleaner during engine operation</td>
</tr>
<tr>
<td>- Do it at the middle of the tank</td>
<td>- Timing is of importance to catch contamination</td>
</tr>
<tr>
<td>- Indicate that in the sample information form (SIF)</td>
<td>- Collect sample during first hour after refueling</td>
</tr>
<tr>
<td>- If done it before refueling...</td>
<td>- Indicate time of sample collection on sample information form</td>
</tr>
<tr>
<td>- Do it in lower third</td>
<td></td>
</tr>
<tr>
<td>- Not in outlet level</td>
<td></td>
</tr>
<tr>
<td>- Indicate that in the sample information form (SIF)</td>
<td></td>
</tr>
</tbody>
</table>

![Diagram of fuel tank contents and sampling points]
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

Protect Fuel - Keep Clean features:
- Detergent
- Dispersant
- Stability Improver
- Oxidation Inhibitor

Normal Use

Strong Cleaner
THE COMPLEXITY OF COMPREHENSIVE FLUID INTERPRETATION

Fuel analysis

Telematics
- Hours
- Location
- Thermograms
- Fuel Consumption

Comprehensive vehicle/machine health analysis

Oil analysis

Inspection
- Leaks
- Levels
- Symptoms
- Abnormal Consumption

Application
- Power Utilization
- Power mode
- Distance traveled

Coolant analysis
Questions?